7

M74-37
III

E7.4-10.47.5.
CR-136876

INVESTIGATION OF ENVIRONMENTAL INDICES FROM THE EARTH RESOURCES TECHNOLOGY SATELLITE

E. A. WARD, J. C. ELLIOTT, F. J. FRIEDMAN,
E. L. RILEY, S. STRYKER
The MITRE Corporation
1820 Dolley Madison Blvd.
McLean, Virginia 22101

FEBRUARY 1974

TYPE III FINAL REPORT
AUGUST 1972 – FEBRUARY 1974

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER

Greenbelt Road
Greenbelt, Maryland 20771

12000
5/2/74

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
PR 568/MMC 200		

4. Title and Subtitle
INVESTIGATION OF ENVIRONMENTAL INDICES FROM THE EARTH RESOURCES TECHNOLOGY SATELLITE

5. Report Date
February 1974

6. Performing Organization Code

7. Author(s) E.A. Ward, J.C. Elliot, E.J. Friedman, E.L. Riley, S. Stryker

8. Performing Organization Report No.

9. Performing Organization Name and Address
The MITRE Corporation
Westgate Research Park
McLean, Virginia 22101

10. Work Unit No.

11. Contract or Grant No.
NAS 5-21842

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

13. Type of Report and Period Covered
Type III Final Report
Aug 72 - Feb 74

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Land use change, water quality, and air quality indices have been calculated from analysis of ERTS multispectral scanning imagery and computer compatible tapes. Specifications have been developed and discussed for an ERTS environmental monitoring system which help to serve the information needs of environmental managers at the Federal, state, regional, and local level. General conclusions of the investigation are that ERTS data is very useful in land use mapping and updating to 10-15 categories, and can provide an overall measure of air and water turbidity; however more and better ground truth and possibly additional spacecraft sensors will be required if specific air and water pollutants are to be quantified from satellite data.

17. Key Words (Selected by Author(s))
Environment
Land Use
Water Quality
Air Quality

18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified		

PREFACE

1. Objectives

The objectives of the MITRE investigation of environmental indices, as set forth in MITRE's proposal and as further defined in the Data Analysis Plan[1], were the following:

- Analyze ERTS MSS data to determine environmental trends (indices) in land use, water quality, and air quality for two test sites in Pennsylvania.
- Based on the investigation experience, develop specifications for a system to use ERTS data for monitoring environmental trends.

2. Scope of Work

In order to achieve the overall investigation objectives, the following were established during Phase I (Data Analysis Preparation) and Phase II (Preliminary Data Analysis) as the specific sub-objectives of the investigation, and they comprise the scope of work performed:

Land Use

- Classify land use to at least seven categories from the ERTS data (agriculture, woodlands, waterways, urban/suburban, erosion, transportation, and man-made earth-moving) for at least three coverage dates for each test site.

---

[1] Riley, E., et al. Data Analysis Plan PR-568/MMC#200 Environmental Indices from ERTS-1. WP-10209, The MITRE Corporation, February 1973.

- Test the classification results against available ground truth.
- Analyze the several ERTS land use classifications and define trends over time.
- Investigate signature algorithm development to allow use of one set of signatures for different coverage dates.

Water Quality

- Analyze water quality at several points along the Susquehanna River for one ERTS coverage.
- Test results against ground truth and/or DCP data.
- Define water quality signatures and indices for the ERTS coverage date.

Air Quality

- Investigate the correlation of ERTS reflectance data with mesoscale air quality for as many coverages as become available.
- Analyze the ERTS coverages to define trends over time.
- Identify microscale air quality targets and trends.
- Investigate signature algorithm development.

With two exceptions-developing signature algorithms for transfer of signature information over time and comparing ERTS data to DCP water quality data - all the above sub-objectives were accomplished in the course of the investigation. Additionally a number of new tasks not envisioned at the start of the investigation, but related to the accomplishment of the overall objectives, were undertaken and accomplished during Phase III (Continuing Data Analysis). These tasks were the following:

Land Use

- Comparison of ERTS land use classification with a recent planning commission land use study in Test Site 1.
- Classification of two additional ERTS coverages beyond the three initally called for in Test Site 1.
- Successful transfer of signatures between test sites.
- Special strip mine and reclamation classification in Test Site 2.

Water Quality

- Investigation of the every-sixth-line striping problem in ERTS data.
- Study of water quality DCP requirements.
- Study of microscale water quality targets.

Air Quality

- Test of mesoscale air quality analysis outside the test sites.
- Study of requirements for mesoscale air quality analysis.

3. Summary of Conclusions

The first objective of determining environmental trends for air quality, water quality, and land use has been achieved. The second, complementary objective - developing specifications for an ERTS environmental monitoring system based on the results of the first objective - has been successfully approached in the final stage of Phase III.

4. Recommendations

Recommendations for improving the application of ERTS data to earth resources management comprise the final section of this report. Highlights of the items discussed in more detail in that section are the following:

- Establishment (preferably by NASA) of a library of state-of-the-art analysis techniques and software open to all legitimate investigators.
- Development (by NASA or contractors) of hybrid computer systems which will allow more rapid reduction of masses of spacecraft generated data than is now possible using digital methods.
- Publication of guidelines (by NASA, EPA, others) which indicate the minimum environmental ground truth requirements to be used for calibration of ERTS data, and to justify allocation of a Data Collection Package (DCP).
- Design (preferably by NASA) of standardized training and test procedures for ERTS data analysis systems in controlled training areas.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONT)

LIST OF ILLUSTRATIONS (CONT)

LIST OF ILLUSTRATIONS (CONT)

LIST OF ILLUSTRATIONS (CONT)

LIST OF ILLUSTRATIONS (CONT)

LIST OF TABLES

LIST OF TABLES (CONT)

LIST OF TABLES (CONT)

1.0 INTRODUCTION

1.1 Scope and Purpose of Report

This Type III Report is the final report on the results accomplished by The MITRE Corporation under Contract NAS 5-21482, Investigation of Environmental Indices from the Earth Resources Technology Satellite. The period of performance was August 1972 to February 1974.

1.2 Objectives of the Investigation

The overall objectives to be achieved during this period were the following.

- Analyze ERTS MSS data to determine environmental trends (indices) in land use, water quality, and air quality for two test sites in Pennsylvania.
- Based on the investigation experience, develop specifications for a system to use ERTS data for monitoring environmental trends.

1.3 Schedule

The schedule for achieving these objectives was divided into three main phases. These were Data Analysis Preparation (Phase I), Preliminary Data Analysis (Phase II), and Continuing Data Analysis (Phase III). For the most part this report is organized chronologically to describe work performed in each phase. Figure 1-1 outlines the schedule of work actually performed during the period of investigation.

Phase I was the initial resource review, experiment planning, and procedures testing stage of the investigation. In this period test sites, specific test areas, and environmental parameters of

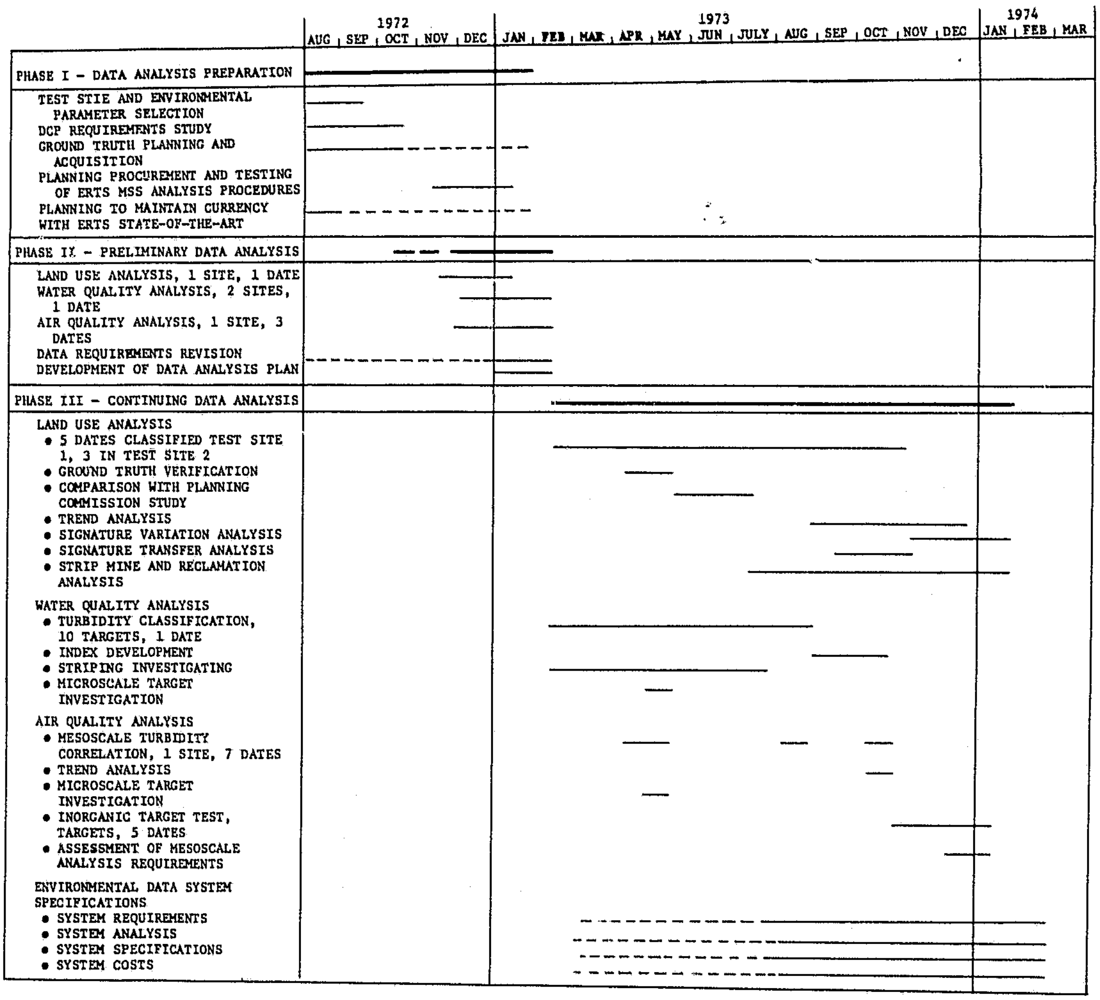


FIGURE 1-1
SCHEDULE FOR THE MITRE INVESTIGATION OF ENVIRONMENTAL INDICES FROM ERTS

interest were selected. The DCP's were delivered and a study was conducted of the requirements for using water quality and air quality stations with the DCP's. Ground truth data requirements and resources were reviewed, and acquisition of the ground truth began. State-of-the-art MSS analysis procedures and software were examined, an analysis software package was procured, and analysis procedures were tested. Finally, preparations were made to maintain currency with the latest ERTS developments throughout the course of the investigation.

Phase II, Preliminary Data Analysis, began with the first operational analysis of ERTS MSS data for land use, water quality, and air quality information in Test Site 1. As a result of the preliminary analysis, several revisions to data analysis requirements were identified. The final task of Phase II was development of the formal Data Analysis Plan, which established the analysis guidelines, procedures, and schedule for the remainder of the investigation.

Phase III, Continuing Data Analysis, comprised the main effort of the investigation. The work performed in this phase culminated in the achievement of the investigation objectives: analysis of environmental trends, and specifications for an ERTS system to monitor environmental trends. In the land use area, classification, comparison with ground truth, trends, and signature analysis were conducted for five ERTS overflight dates in Test Site 1 and three in Test Site 2. Additionally, a special analysis was made in an area of Test Site 2 to demonstrate the value of ERTS in strip mining and reclamation monitoring.

For water quality, signature information was developed for several turbidity levels on the Susquehanna River for one coverage date and a water quality index was developed. A number of microscale water quality targets were detected, and information was provided to EPA on a special flood assessment request.

In the air quality analysis, a gross correlation in the empirical data has been shown between ERTS measured reflectance and ground turbidity measurements for the Harrisburg test area for seven coverage dates. More refined analysis with inorganic targets over turbidity measurement sites and an atmospheric model demonstrated that more research in this area should result in better quantification of the indicated relationship between ERTS reflectivity and mesoscale air quality. Additionally, microscale target analysis resulted in detection of three point sources of air pollution in Test Site 1.

Finally, by incorporating the experience and knowledge gained throughout the land use, water, and air analysis, specifications were developed for an ERTS environmental data system. This effort resulted in a definition of system requirements, system analysis, system specifications, and system costs.

The full report which follows generally adheres to the outline and chronology as shown in the investigation schedule, Figure 1-1.

1.4 ERTS Data Analyzed

Table 1-1 is a log of all the ERTS overflights with MSS image and CCT covering all or a portion of either Test Site during the course of the MITRE investigation. Because of the requirements for less than 20 percent cloud cover, all four channels good, and most of a Test Site

TABLE 1-1
OVERFLIGHT LOGS

SAT. NO.	I.D. NUMBER				CLOUD COVER (%) CC	ORBIT NO.	RBV			MSS				DATE	SITE NO.		REMARKS	DATE RECEIVED		
	DAYS SINCE LAUNCH	HOUR	MIN.	TNTH. OF MIN.			1	2	3	4	5	6	7		1	2		TAPE	B/W IMAGES	COLOR IMAGES
1	007	15	12	4	100	96	G	G	G	G	G	G	G	Jul. 30		x				
1	007	15	13	1	100	96	F	F	F	G	G	G	G	Jul. 30	x					
1	008	15	18	0	100	111	G	G	G	G	F	G	G	Jul. 31		x				
1	008	15	18	3	100	111	P	P	P	G	F	G	G	Jul. 31	x	x				
1	008	15	18	5	100	111	G	G	G	G	G	G	G	Jul. 31	x					
1	009	15	24	1	40	124	G	G	G	G	G	G	P	Aug. 01	x		Special ordered 9/28/72	11/6/72	11/25/72	12/19/72
1	009	15	24	4	20	124	G	G	G	G	G	G	P	Aug. 01	x		Special ordered 9/28/72	11/6/72	12/29/72	12/19/72
1	025	15	12	4	100	347				F	G	G	G	Aug. 17		x				
1	025	15	13	0	100	347				G	G	G	G	Aug. 17	x					
1	026	15	18	0	90	361				G	G	G	G	Aug. 18		x				
1	026	15	18	2	80	361				G	G	G	G	Aug. 18	x	x				
1	026	15	18	5	80	361				G	G	G	G	Aug. 18	x					
1	027	15	24	2	60	375				G	G	G	G	Aug. 19	x		Reviewed at GSFC-No good			
1	027	15	24	5	60	375				G	G	G	G	Aug. 19	x		Reviewed at GSFC-No good			
1	043	15	13	0	70	598				G	G	P	G	Sep. 04	x	x	Reviewed at GSFC-No good			
1	044	15	18	2	50	612				G	G	P	G	Sep. 05	x	x				
1	044	15	18	5	90	612				F	F	P	G	Sep. 05	x					
1	045	15	24	3	10	626				G	G	P	G	Sep. 06	x		Tape Ordered 10/27/72		10/26/72	5/18/73
1	061	15	12	5	30	849				G	G	G	G	Sep. 22		x				
1	062	15	18	1	20	863				G	G	P	G	Sep. 23		x	CC 100% over site 2		10/30/72	
1	062	15	18	4	40	863				G	G	P	G	Sep. 23	x	x	CC 100% over site 1			
1	062	15	19	0	10	863				G	G	P	G	Sep. 23			Special Order D.C. scene	2/15/73	1/29/73	5/18/73
1	063	15	24	2	90	877				G	G	G	G	Sep. 24	x					
1	079	15	13	1	0	1100				G	G	G	G	Oct. 10		x		12/6/72	11/14/72	3/3/73
1	079	15	13	3	10	1100				G	G	G	G	Oct. 10	x			12/6/72	11/14/72	3/3/73
1	080	15	18	3	0	1114				G	G	G	G	Oct. 11		x		12/5/72	11/17/72	5/18/73
1	080	15	18	5	0	1114				G	G	G	G	Oct. 11	x	x		12/5/72	11/17/72	5/17/73
1	080	15	19	2	0	1114				G	G	G	G	Oct. 11	x			12/5/72	11/17/72	3/3/73
1	081	15	24	4	100	1128				G	G	G	G	Oct. 12	x					
1	081	15	25	0	80	1128				G	G	G	G	Oct. 12	x					

TABLE 1-1 (CONTINUED)
OVERFLIGHT LOGS

SAT. NO.	I.D. NUMBER: DAYS SINCE LAUNCH	I.D. NUMBER: HOUR	I.D. NUMBER: MIN.	I.D. NUMBER: TNTH. OF MIN.	CLOUD COVER (%) CC	ORBIT NO.	RBV 1	RBV 2	RBV 3	MSS 4	MSS 5	MSS 6	MSS 7	DATE	SITE NO. 1	SITE NO. 2	REMARKS	DATE RECEIVED: TAPE	DATE RECEIVED: B/W IMAGES	DATE RECEIVED: COLOR IMAGES
1	097	15	13	3	100	1351				G	G	G	G	Oct. 28	x					
1	098	15	18	5	100	1365				G	G	G	G	Oct. 29	x	x				
1	098	15	19	1	100	1365				G	G	G	G	Oct. 29	x					
1	099	15	24	3	90	1379				P	G	G	G	Oct. 30	x					
1	099	15	25	0	70	1379				G	G	G	G	Oct. 30	x					
1	115	15	13	4	100	1602				P	G	G	G	Nov. 15	x	x				
1	116	15	19	0	50	1616				G	G	G	G	Nov. 16		x				
1	116	15	19	2	10	1616				G	G	G	G	Nov. 16	x	x			1/9/73	
1	117	15	25	1	70	1630				G	G	G	G	Nov. 16	x					
1	133	15	13	5	10	1853					P	P	G	Dec. 03	x	x			1/17/73	
1	134	15	19	0	100	1867					P	P	G	Dec. 04		x				
1	134	15	19	3	100	1867					P	P	G	Dec. 04	x	x				
1	135	15	25	1	90	1881					G	G	G	Dec. 05	x					
1	151	15	13	4	100	2104				G	G	G	G	Dec. 21	x	x				
1	152	15	19	0	90	2118				G	G	G	P	Dec. 22		x				
1	152	15	19	2	90	2118				G	P	P	G	Dec. 22	x	x				
1	153	15	25	1	90	2132				G	G	G	G	Dec. 23	x					
1	169	15	13	2	80	2355				G	G	G	G	Jan. 08		x				
1	170	15	18	4	0	2369				G	G	G	G	Jan. 09		x			3/19/73	
1	170	15	19	1	0	2369				G	G	G	G	Jan. 09	x			7/15/73	2/15/73	
1	171	15	24	3	30	2383				G	G	G	G	Jan. 10	x					
1	171	15	24	5	10	2383				G	G	G	G	Jan. 10	x				2/13/73	
1	187	15	13	3	0	2606				G	G	G	G	Jan. 10		x			3/3/73	
1	187	15	14	0	0	2606				G	G	G	G	Jan. 26	x				3/3/73	
1	188	15	18	5	70	2620				G	G	G	G	Jan. 27		x				
1	188	15	19	2	90	2620				G	G	G	G	Jan. 27	x	x				
1	188	15	19	4	90	2620				G	G	G	G	Jan. 27	x					
1	189	15	25	0	90	2634				G	G	G	G	Jan. 28	x					
1	189	15	25	3	90	2634				G	G	G	G	Jan. 28	x					
1	205	15	13	2	0	2857				G	G	G	G	Feb. 13		x			3/29/73	
1	205	15	13	5	0	2857				G	G	P	G	Feb. 13	x	x			3/29/73	
1	205	15	14	1	0	2857				G	G	P	G	Feb. 13	x				3/27/73	

TABLE 1-1 (CONTINUED)
OVERFLIGHT LOGS

SAT. NO.	I.D. NUMBER: DAYS SINCE LAUNCH	HOUR	MIN.	TNTH. OF MIN.	CLOUD COVER (%) CC	ORBIT NO.	RBV 1	RBV 2	RBV 3	MSS 4	MSS 5	MSS 6	MSS 7	DATE	SITE NO. 1	SITE NO. 2	REMARKS	DATE RECEIVED: TAPE	B/W IMAGES	COLOR IMAGES
1	206	15	19	1	10	2871				G	G	G	G	Feb. 14		x			3/15/73	
1	206	15	19	3	20	2871				G	G	G	G	Feb. 14	x	x			3/15/73	
1	206	15	20	0	90	2871				G	G	G	G	Feb. 14	x					
1	207	15	25	2	80	2885				G	G	G	G	Feb. 15	x					
1	207	15	25	4	60	2885				G	G	G	G	Feb. 15	x					
1	223	15	13	4	90	3108				P		G		Mar. 03		x				
1	223	15	14	0	100	3108				G		G		Mar. 03	x	x				
1	223	15	14	3	100	3108				G		G	P	Mar. 03	x					
1	224	15	19	2	100	3122				G	G	G	G	Mar. 04		x				
1	224	15	19	5	100	3122				G	G	G	P	Mar. 04	x	x				
1	224	15	20	1	90	3122				G	G	G	G	Mar. 04	x					
1	225	15	25	3	100	3136				G	G	G	G	Mar. 05	x					
1	225	15	25	5	100	3136				G	P	G	G	Mar. 05	x					
1	241	15	13	4	30	3359				G	G	G	G	Mar. 21		x				
1	241	15	14	1	40	3359				G	G	P	G	Mar. 21	x	x				
1	241	15	14	3	90	3359				G	G	P	G	Mar. 21	x					
1	242	15	19	3	70	3373				G	G	G	G	Mar. 22		x				
1	242	15	19	5	50	3373				G	G	G	G	Mar. 22	x	x				
1	242	15	20	2	30	3373				G	G	G	G	Mar. 22	x					
1	243	15	25	3	0	3387				G	G	G	G	Mar. 23	x			5/9/73	5/4/73	
1	243	15	26	0	0	3387				G	G	G	G	Mar. 23	x			5/9/73	5/4/73	
1	259	15	13	4	100	3610				G	G	G	G	Apr. 08		x				
1	259	15	14	1	100	3610				G	G	G	G	Apr. 08	x	x				
1	259	15	14	3	100	3610				G	G	G	G	Apr. 08	x					
1	260	15	19	2	10	3624				G	G	G	G	Apr. 09		x		5/24/73	5/25/73	
1	260	15	19	5	10	3624				G	G	G	G	Apr. 09	x	x		5/24/73	5/25/73	
1	260	15	20	1	10	3624				G	G	G	G	Apr. 09	x			5/21/73	5/25/73	
1	261	15	25	3	80	3638				G	G	G	G	Apr. 10	x					
1	261	15	26	0	70	3638				G	G	G	G	Apr. 10	x					
1	277	15	13	3	100	3861				G	P	G	G	Apr. 21		x				
1	277	15	14	0	100	3861				G	P	G	G	Apr. 26	x	x				
1	277	15	14	2	100	3861				G	P	G	G	Apr. 26	x					
1	278	15	19	2	100	3875				P	P	G	P	Apr. 27		x				

TABLE 1-1 (CONCLUDED) OVERFLIGHT LOGS

SAT. NO.	I.D. NUMBER: DAYS SINCE LAUNCH	I.D. NUMBER: HOUR	I.D. NUMBER: MIN.	I.D. NUMBER: TNTH. OF MIN.	CLOUD COVER (%) CC	ORBIT NO.	RBV 1	RBV 2	RBV 3	MSS 4	MSS 5	MSS 6	MSS 7	DATE	SITE NO. 1	SITE NO. 2	REMARKS	DATE RECEIVED: TAPE	DATE RECEIVED: B/W IMAGES	DATE RECEIVED: COLOR IMAGES
1	278	15	19	4	100	3875				P	P	G	P	Apr. 27	x	x				
1	278	15	20	1	100	3875				P	P	G	P	Apr. 27	x					
1	279	15	25	3	100	3889				G	G	G	G	Apr. 28	x					
1	279	15	25	5	90	3889				G	G	G	G	Apr. 28	x					
1	295	15	13	3	40	4112				G	G	G	G	May 14		x				
1	295	15	13	5	40	4112				G	G	G	G	May 14	x	x				
1	295	15	14	2	30	4112				G	G	G	G	May 14	x					
1	296	15	19	1	90	4126				P	P	G	G	May 14		x				
1	296	15	19	3	80	4126				P	P	G	G	May 15	x	x				
1	296	15	20	0	80	4126				P	G	G	G	May 15	x					
1	297	15	25	2	0	4140				G	G	G	G	May 16	x			6/23/73	6/17/73	
1	297	15	25	4	0	4140				G	G	G	G	May 16	x			6/23/73	6/17/73	
1	313	15	13	2	30	4363				G	G	G	G	Jun. 01		x				
1	313	15	13	4	10	4363				G	G	G	G	Jun. 01	x	x			6/10/73	
1	313	15	14	1	10	4363				G	G	G	G	Jun. 01	x			6/13/73	6/10/73	
1	314	15	19	5	10	4377				G	G	G	G	Jun. 02	x			8/30/73	7/25/73	
1	315	15	25	1	70	4391				G	G	P	G	Jun. 03	x					
1	315	15	25	3	60	4391				G	G	P	G	Jun. 03	x					
1	331	15	13	0	90	4614				G	G	G	G	Jun. 19		x				
1	331	15	13	3	100	4614				G	G	G	G	Jun. 19	x	x				
1	331	15	13	5	100	4614				G	G	G	G	Jun. 19	x					
1	349	15	12	5	10	4865				G	G	P	G	July 07		x		8/2/73	9/24/73	
1	349	15	13	2	10	4865				G	G	P	G	July 07	x			8/6/73	9/24/73	
1	350	15	18	3	10	4879				G	G	G	G	July 08		x		8/8/73	9/5/73	
1	350	15	19	0	10	4879				G	G	G	G	July 08	x			8/8/73	9/5/73	
1	350	15	19	2	10	4879				G	G	G	G	July 08	x			8/16/73	9/5/73	
1	369	15	24	5	20	5144				P	G	G	G	July 27	x			8/22/73	8/24/73	
1	386	15	18	3	20	5381				G	G	G	G	Aug. 13	x			10/26/73	11/23/73	
1	403	15	12	0	10	5618				G	G	G	G	Aug. 30		x		9/25/73	10/3/73	
1	403	15	12	3	0	5618				G	G	G	G	Aug. 30	x			9/25/73	10/3/73	
1	403	15	12	5	0	5618				G	G	G	G	Aug. 30	x			9/25/73	10/3/73	
1	404	15	18	1	10	5632				G	G	G	G	Aug. 31	x			10/30/73	10/30/73	
1	404	15	18	4	10	5632				G	G	G	G	Aug. 31	x			10/30/73	10/30/73	

included in the CCT's, only about 30 percent of the total overflights were acceptable. These overflights are shown in Table 1-2. As the "Remarks" column indicates, not all of the acceptable dates were actually useful for the land use, water quality, and air quality analyses. Table 1-3 summarizes the log. Only 5.8 percent of all overflights of the two Test Sites have been useful for the analysis of the training areas of interest, (See section 2.1 for definition of training areas.) This was a sufficient number of useful coverages, however, to accomplish the stated objectives of the investigation.

TABLE 1-2
ACCEPTABLE OVERFLIGHT DATES FOR SITES 1 AND 2*

SITE #1

SAT. NO.	I.D. NUMBER				CLOUD		RBV			MSS						DATE RECEIVED		
	DAYS SINCE LAUNCH	HOUR	MIN.	TNTH. OF MIN.	COVER (%) CC	ORBIT NO.	1	2	3	4	5	6	7	DATE	REMARKS	TAPE	B/W IMAGES	COLOR IMAGES
1	079	15	13	3	10	1100				G	G	G	G	Oct. 10	Covers only mouth of Susquehanna	12/6/72	11/14/72	3/3/73
1	080	15	18	5	0	1114				G	G	G	G	Oct. 11	1st Harrisburg date	12/5/72	11/17/72	5/18/73
1	080	15	19	2	0	1114				G	G	G	G	Oct. 11	too far south of Harrisburg	12/5/72	11/17/72	3/3/73
1	116	15	19	2	10	1616				G	G	G	G	Nov. 16	High Cirrus throughout image		1/9/72	
1	170	15	19	1	0	2369				G	G	G	G	Jan. 09	2nd Harrisburg date	7/15/73	2/15/73	
1	171	15	24	5	10	2383				G	G	G	G	Jan. 10	Site 1 inadequately covered		2/13/73	
1	187	15	14	0	0	2606				G	G	G	G	Jan. 26	Mouth of Susquehanna only		3/3/73	
1	206	15	19	3	20	2871				G	G	G	G	Feb. 14	cloud cover 100% over Harrisburg		3/15/73	
1	243	15	25	3	0	3387				G	G	G	G	Mar. 23	too far west of Harrisburg	5/9/73	5/4/73	
1	243	15	26	0	0	3387				G	G	G	G	Mar. 23	too far south of Harrisburg	5/9/73	5/4/73	
1	260	15	19	5	10	3624				G	G	G	G	Apr. 09	3rd H-burg date-Cirrus confusion	5/24/73	5/25/73	
1	260	15	20	1	10	3624				G	G	G	G	Apr. 09	Susquehanna Mouth only	5/21/73	5/25/73	
1	297	15	25	2	0	4140				G	G	G	G	May 16	too far west of Harrisburg	6/23/73	6/17/73	
1	297	15	25	4	0	4140				G	G	G	G	May 16	too far south west of Harrisburg	6/23/73	6/17/73	
1	313	15	13	4	10	4363				G	G	G	G	Jun. 01	too far east of Harrisburg		6/10/73	
1	313	15	14	1	10	4363				G	G	G	G	Jun. 01	Susque. Mouth - no Harrisburg	6/13/73	6/10/73	
1	314	15	19	5	10	4377				G	G	G	G	Jun. 02	Mouth of Susquehanna Only	8/30/73	7/25/73	
1	350	15	19	0	10	4879				G	G	G	G	July 08	4th Harrisburg date	8/08/73	9/5/73	
1	350	15	19	2	10	4879				G	G	G	G	July 08	Mouth of Susquehanna Only	8/16/73	9/5/73	
1	386	15	18	3	20	5381				G	G	G	G	Aug. 13	Cloud Cover Directly over Harrisburg	10/26/73	11/23/73	
1	403	15	12	3	0	5618				G	G	G	G	Aug. 30	Too far east of Harrisburg	9/25/73	10/3/73	
1	403	15	12	5	0	5618				G	G	G	G	Aug. 30	Mouth of Susquehanna Only	9/25/73	10/3/73	
1	404	15	18	1	10	5632				G	G	G	G	Aug. 31	Good Harrisburg Date	10/30/73	10/30/73	
1	405	15	18	4	10	5632				G	G	G	G	Sep. 01	Mouth of Susquehanna Only	10/30/73	10/30/73	

SITE #2

1	079	15	13	1	0	1100				G	G	G	G	Oct. 10	too far east of Wilkes-Barre	12/6/72	11/14/72	3/5/73
1	080	15	18	3	0	1114				G	G	G	G	Oct. 11	1st Scranton/W B date	12/5/72	11/17/72	5/18/73
1	080	15	18	5	0	1114				G	G	G	G	Oct. 11	too far south of Scranton/W B	12/5/72	11/17/72	5/18/73
1	116	15	19	2	10	1616				G	G	G	G	Nov. 16	High Cirrus throughout		1/9/72	
1	170	15	18	4	0	2369				G	G	G	G	Jan. 09	2nd Scranton/W B date		3/19/73	
1	187	15	13	3	0	2606				G	G	G	G	Jan. 26	too far So. of Scranton/W B		3/3/73	
1	205	15	13	2	0	2857				G	G	G	G	Feb. 13	does not show W B or Susque.		3/29/73	
1	206	15	19	1	10	2871				G	G	G	G	Feb. 14	CC approx. 80% over test site		3/15/73	
1	206	15	19	3	20	2871				G	G	G	G	Feb. 14	CC actually 60-70%		3/15/73	
1	260	15	19	2	10	3624				G	G	G	G	Apr. 09	3rd Scranton/WB date	5/24/73	5/25/73	
1	260	15	19	5	10	3624				G	G	G	G	Apr. 09	too far south-west of site	5/24/73	5/25/73	
1	313	15	13	4	10	4363				G	G	G	G	Jun. 01	too far east of Scranton/W B		6/10/73	
1	350	15	18	3	10	4879				G	G	G	G	July 08	4th Scranton /W.B Date	8/8/73	9/5/73	
1	403	15	12	0	10	5618				G	G	G	G	Aug. 30	Does not include WB Nanticoke	9/25/73	10/3/73	

*ALL TAPES AND IMAGES WITH A QUALITY RATING, ON ALL 4 MSS BANDS, OF AT LEAST 'G', AND WITH A CLOUD COVER OF 20% OR LESS

TABLE 1-3

OVERFLIGHT DATA USEFUL FOR ANALYSIS

	TEST SITE 1	TEST SITE 2	TOTAL
OVERFLIGHT OPPORTUNITIES	95	60	155
OVERFLIGHT ACCEPTABLE	24	14	38
OVERFLIGHT USEFUL FOR ANALYSIS	5	4	9
PERCENT OF USEFUL OVERFLIGHTS	5.3	6.7	5.8

2.0 INVESTIGATIVE ACTIVITIES - PHASES I, II, & III

2.1 Phase I - Data Analysis Preparation

Phase I was the initial period of the investigation during which resource review, experiment planning, and testing out of analytical procedures were carried out in preparation for the analysis phases which were to follow. The investigation preparation phase was comprised of the following specific tasks:

- Test site and test area selection*
- Environmental parameter selection
- Assessment of DCP requirements
- Planning for ground truth data acquisition
- Planning and testing of MSS data analysis procedures
- Planning for maintaining currency with related ERTS investigations

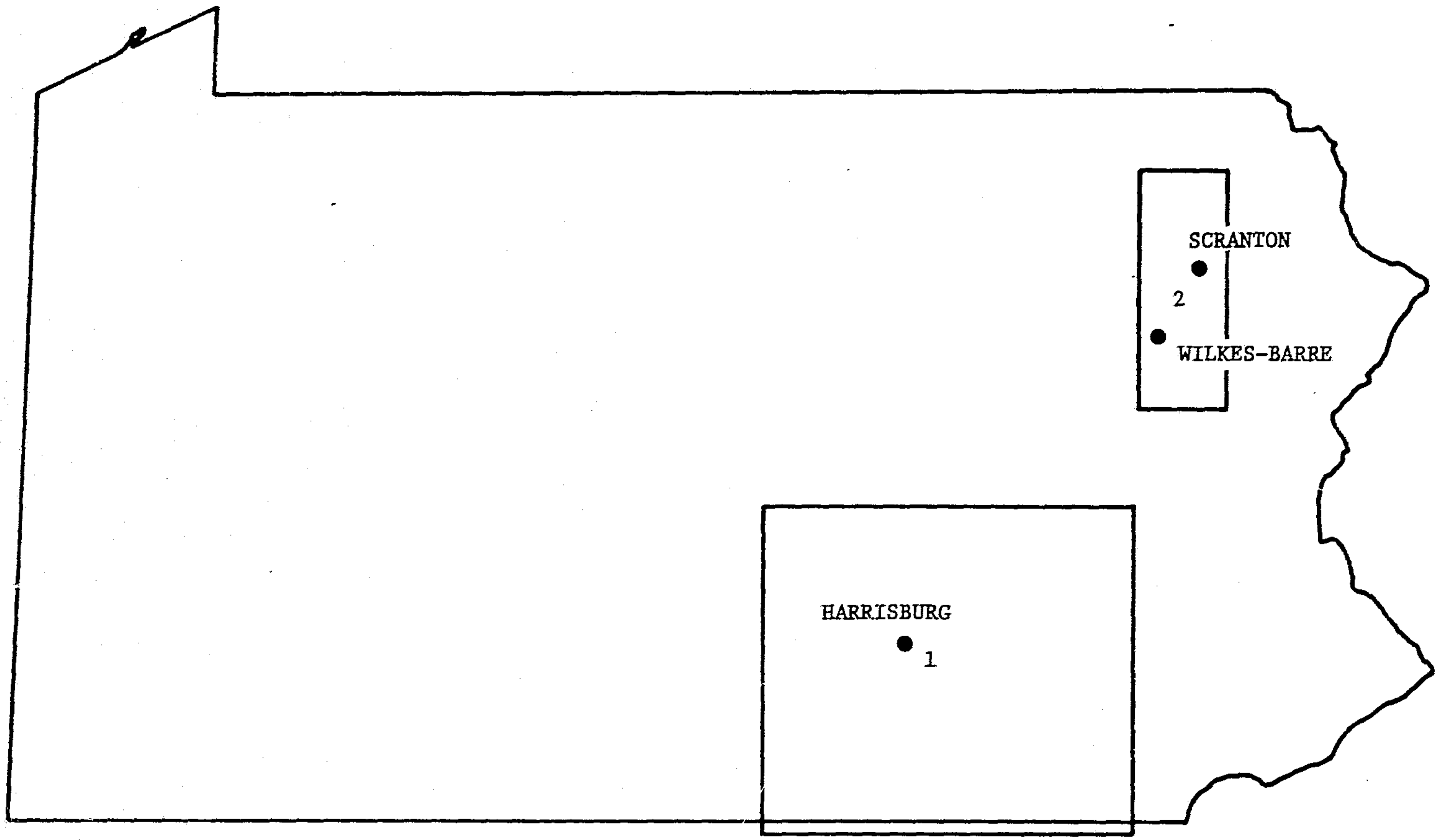
While the work completed in each of these areas has been reported in detail in the MITRE Type I and Type II Reports, it will be useful here to review the results of Phase I.

2.1.1 Test Site and Parameter Selection

First, the two Test Sites for the MITRE investigation, as determined in conference with Commonwealth of Pennsylvania and NASA officials for the amended proposal, are shown in Figure 2-1. Test Site 1 is the

---

*As used throughout this report, Test Site shall refer to one of the two large sites identified in the amended proposal as the geographical area for which MITRE will receive ERTS MSS data; test area refers to more specific targets of interest within each Test Site for investigating the environmental parameters of interest; and training area refers to small portions of a test area which, because of a readily identifiable feature or intensity and uniformity characteristics, are most useful for developing MSS signatures that are then used to classify the test area.



PENNSYLVANIA

FIGURE 2-1
MITRE ERTS-1 TEST SITES

larger of the two sites centered on metropolitan Harrisburg. Land use, water quality along the Susquehanna River, and air quality analysis were planned for the MSS data from this site. Test Site 2 is the smaller site centered on Wilkes-Barre/Scranton. Land use, water quality and air quality analysis were planned for Test Site 2, with a later emphasis on monitoring surface mining activity prevalent in the area.

Among the main reasons for the selection of these two sites in Pennsylvania were the following:

- Availability of an extensive in-house environmental data base on the areas from MITRE's work for the U.S. Bureau of Mines in the northeastern Pennsylvania region.
- Availability of environmental data from EPA and the Commonwealth which could be used for correlation with ERTS-1 overflights.
- Availability of MSS data analysis software from the Pennsylvania State University.
- Availability of recent aircraft overflight data covering the Susquehanna River in the Harrisburg vicinity for comparison with ERTS-1 MSS data.
- Engineering and scientific personnel available for consultation from the Commonwealth of Pennsylvania.
- The suitability of the areas for the analysis of the potential of remote sensing of environmental parameters, because of the broad range of land use, water, and air pollution targets.

Once the two overall investigation sites had been decided upon, MITRE, with the concurrence of the NASA Chief Scientific Monitor, held discussions with officials of the Commonwealth of Pennsylvania Department of Environmental Resources, Pennsylvania State University's Office of Remote Sensing of Earth Resources, the U.S. Geological Survey's Harrisburg office, the U.S. Environmental Protection Agency's Region III office, and others to determine test areas within the two test sites which were of highest priority for environmental analysis. The chart shown as Table 2-1 summarizes those areas that were chosen as targets in the planning phase of the investigation.

Once the test sites and test areas were defined, the environmental parameters to be investigated were determined. Although the land, water, and air parameters were generally discussed in the amended proposal, Phase I allowed a more specific determination of parameters which could potentially be observed in the ERTS data. First a review was made of pre-ERTS state-of-the-art developments in MSS analysis of land use, water quality and air quality. Charts summarizing reported results were prepared (for examples of the charts, see Table 2-2), and a planning list of environmental parameters was drafted. The list of environmental parameters that was settled upon during the investigation preparation phase is shown as Table 2-3. These were the initial parameters in each of the three areas that MITRE would attempt to identify in the ERTS MSS data, and then a system would be specified for operational monitoring of those parameters which proved amenable to ERTS detection.

TABLE 2-1

PRELIMINARY TARGETS

SITE	TARGET AREA	TARGET QUANTITIES	LAND AIR, OR WATER	SUGGESTED BY
1	HOLTWOOD DAM LAKE	ALGAE, THERMAL, SILT	W	EPA REGION III; PA. W.Q.
1	CONOWINGO DAM LAKE	" , " , "	W	" " " ; " " "
1	SAFE HARBOR LAKE	" , " , "	W	" " " ; " " "
1	CODORUS CREEK LAKE (INDIAN ROCK)	" , SILT	W	" " " .
1	BRUNNER ISLAND EFFLUENT	THERMAL, CHEMICALS, SILT	W	" " " .
1	CONEWAGO CREEK MOUTH	THERMAL, SILT	W	" " " .
1	LIME KILN AT ANNVILLE	PLUME DYNAMICS & LONG TERM EFFECT ON VEG.	A	" " " .
1	HARRISBURG	HAZE, ALL AIR & WATER QUALITY PARAMETERS	A,W	-
1	SUSQUEHANNA RIVER-SUNBURY TO MD.	WATER QUALITY	W	-
1	LANCASTER	HAZE, ALL AIR QUALITY PARAMETERS	A	STATE OF PA.
1	YORK	" , " " " "	A	" " "
1	SWATARA CREEK MOUTH	SILT	W	USGS/HARRISBURG
1	CONESTOGA CREEK MOUTH	SILT, OIL	W	" / "
1	JUNIATA RIVER MOUTH	SILT	W	" / "
1	THREE MILE ISLAND	ALL AIR & WATER QUALITY PARAMETERS	A,W	PSU
1	ALL OF SITE 1	LAND USE	W,L	-
1	ALL OF SITE 1	ANY DENUDED AREAS	L	STATE OF PA.
2	ALL OPEN PIT MINES	LINEAR DIM., AREA, & VOLUME; PH, THERMAL	L,W	EPA REG.III; PA. W.Q.O.
2	" REFUSE BANKS	" " , " , & " ; " "	L,W	" " " ; " "
2	SUSQUEHANNA RIVER	ALL WATER QUALITY PARAMETERS	W	-
2	" " AT DANVILLE	" " " "	W	-
2	" " AT HUNLOCK CREEK	" " " "	W	-
2	SCRANTON	HAZE, ALL AIR QUALITY PARAMETERS	A	STATE OF PA.
2	WILKES-BARRE	" , " " " "	A	" " "
2	ALL OF SITE 2	LAND USE	W,L	-
2	" " " 2	ANY DENUDED AREAS	L	STATE OF PA.

TABLE 2-2

PRE-ERTS REVIEW OF ENVIRONMENTAL & LAND.

USE SIGNATURE INFORMATION

MEDIUM LAND USE

ENVIRONMENTAL CATEGORY	MSS SIGNATURE INFORMATION	POTENTIAL USEFULNESS	OTHER COMMENTS	REFERENCE
L.0 (Land Use Generally)	All ERTS channels are complementary and useful in land characteristics identification.	Monitoring land use changes.		Short and MacLeod (Goddard). Fourth Annual Earth Resources Program Review, Vol. I, p. 7-7. (NASA, 1972)
L.1 Agriculture (Primarily Corn Blight)	Various bands from 0.47μ to 0.92μ have been useful in monitoring plant stress	May permit monitoring of pollution effects on vegetation.	Thermal, reflective IR and visible channels have all been used in conjunction. No single channel seems best.	T. Phillips (LARS, Purdue U.), ibid., Vol. V, p. 128-8.
I.1 Agriculture (Primarily Corn Blight)	The band from 1.0μ to 1.4μ seems best for crop discrimination.	May permit monitoring of pollution effects on specific plant types	Also useful in crop yield estimates.	Nalepka, et.al. (WRL Ann Arbor), ibid, p. 130-1.
L.2 Forest and Woodland	The band from 0.52μ to 0.58μ appears best for identifying forests and discriminating between hardwoods and softwoods.	(Same as above)	Also useful in forest inventory.	S. Whitley (Mississippi Test Facility), ibid., Vol. I, p. 15-1.
L.3 Waterways L.4 Erosion Areas (Also: W.2 Water-Silt)	NIMBUS 3 HRIR data shows progress of run-off down Niger and Indus observed in 0.7-1.3μ region	May be useful in silt and turbidity monitoring.	Also useful in overall hydrological studies of river basins.	Solomonson and MacLeod (Goddard) Fourth Annual Earth Resources Program Review, Vol. I, p. 5-1 (NASA, 1972).

TABLE 2-2 (Continued)

MEDIUM WATER

ENVIRONMENTAL CATEGORY	MSS SIGNATURE INFORMATION	POTENTIAL USEFULNESS	OTHER COMMENTS	REFERENCE
W.0 (Water Generally)	Generally present MSS data can identify suspended particles, but not discriminate such parameters as DO, BOD, nitrates, etc.	At a minimum, MSS can monitor gross pollution and thereby alert ground team to monitor for specific pollutants	Thermal and laser sensors may be better for water monitoring.	Keefer and Sherz (U. of Wisconsin) from ASCE Meeting in Phoenix, Jan. 1971. p. 9 of reprint.
W.1. Oil	Best detection appears to be in the 0.32μ to 0.38μ band.	Oil spills can be monitored during daylight.	Active sensors will permit day and night monitoring. U.V. and the 8μ to 14μ bands can determine thickness of spills. Fluorescence techniques are promising.	Wezernak and Polcyn (WRL Ann Arbor) Technological Assessment of Remote Sensing Systems for Water Pollution Control p. 4-36.
W.2 Silt (See Land Use, 1.8 Wetlands and Estuaries)	--	--	--	--
W.3 Industrial Chemicals	The 0.58μ to 0.62μ band appears best for detecting chemical effluents.	Daylight monitoring of industrial water pollution is possible.	I.R. Monitoring may be better in detecting discharges day or night by difference in water temperature.	Wezernak and Polcyn, ibid., p. 1-23.
W.4 Eutrophication	--	--	--	--
W.5 Turbidity	Measurement appears best in the 0.4μ to 0.65μ range.	Total suspended particles can be monitored for water pollution control.	Present passive sensing is not adequate for any great depth, but active systems are promising.	Wezernak and Polcyn, ibid., p. 1-23.

TABLE 2-2 (Continued)

MEDIUM WATER

ENVIRONMENTAL CATEGORY	MSS SIGNATURE INFORMATION	POTENTIAL USEFULNESS	OTHER COMMENTS	REFERENCE
W.6 Chlorophyll (Phytoplankton)	Detectable subsurface reflectance rise at 0.56μ, fixed at 0.53μ, diminish at 0.45μ. (At 0.56μ alone, cannot discriminate between chlorophyll and sediment. At 0.45μ alone, cannot discriminate between chlorophyll and other blue absorbing substances.	Indirect measure of pollution effect on aquatic life. Ground observation required.	Useful in understanding aquatic food change, migrations, and worldwide CO_2/O_2 exchange.	S. Duntley (Scripps) Fourth Annual Earth Resources Program Review, Vol. IV, p. 102-6, (NASA, 1972).
W.6 Chlorophyll	Subtracting sample reflectance intensity at 0.443μ from reference reflectence intensity at 0.525μ, corrected by gain control, yields a measure of chlorophyll content.	Indirect measure of pollutant effect on aquatic life. Ground observation required.	Useful also in understanding aquatic food chain, migrations, and world CO_2/O_2 exchange.	J. Averson (NASA Ames) Fourth Annual Earth Resources Program Review, Vol. IV, p. 104-1 (NASA, 1972).
W.7 Specific Characteristics				
W.7.2 B.O.D.	Waste treatment outfall is detectable at 0.72μ to 0.80μ.	Gross monitoring of sewage; ground observation required for B.O.D. analysis.	As with other water parameters, active sensing should enhance remote capabilities.	Wezernak and Polcyn, op.cit., p. 1-23.

TABLE 2-2 (Continued)

MEDIUM AIR

ENVIRONMENTAL CATEGORY	MSS SIGNATURE INFORMATION	POTENTIAL USEFULNESS	OTHER COMMENTS	REFERENCE
A.9.1 - SO_2 and A.10 Vegetation Damage	Visible and IR shows plant damage (pines) near coke ovens.	Source monitoring (reveals where and when to look).	At present, other than remote sensing is required to tell composition and concentration of air pollutants.	Harney, et.al., BuMines Fourth Annual Earth Resources Program Review, Vol. III, p. 65-1 (NASA, 1972).

TABLE 2-3

PARAMETERS OF INTEREST

L.0 LAND USE

- L.1 Agriculture
- L.2 Forest and Woodland
- L.3 Waterways
- L.4 Erosion Areas
- L.5 Urban/Suburban
- L.6 Transportation
- L.7 Areas Undergoing Earth Moving
- L.8 Wetlands/Estuaries

W.0 WATER

- W.1 Oil
- W.2 Silt
- W.3 Industrial Chemicals
- W.4 Eutrophication
- W.5 Turbidity
- W.6 Chlorophyll
- W.7 Specific Characteristics
  - W.7.1 pH
  - W.7.2 D.O.
  - W.7.3 B.O.D.
  - W.7.4 Temperature
  - W.7.5 Conductivity

A.0 AIR

- A.1 Clear Air
- A.2 Light Haze
- A.3 Medium Haze
- A.4 Heavy Turbidity
- A.5 Black (soot)
- A.6 Brown (NO_x)
- A.7 Blue (fine particulate)
- A.8 White (moisture)
- A.9 Specific Pollutants
  - A.9.1 SO_2
  - A.9.2 CO
  - A.9.3 O_3
- A.10 Vegetation Damage

2.1.2 DCP Requirements Assessment

Initially as outlined in the MITRE proposal, two Data Collection Packages (DCP's) were planned for the investigation: one dedicated to air quality, and one dedicated to water quality. During the planning and preparation and preliminary analysis phases, the decision to use NOAA's Turbidity Network data as ground truth for the air quality analysis and difficulties in obtaining a tie-in of existing monitoring stations to a DCP led eventually to the decision to dedicate both requested DCP's to acquisition of water quality ground truth data. Subsequently, after a thorough assessment of what water quality ground truth data were available in the test sites, and of what the requirements were for procuring adequate new water quality monitoring equipment tied into DCP's, it was determined that the most cost-effective and reasonable course for this investigation would be to make maximum use of the existing water quality stations maintained by the USGS for the Corps of Engineers (COE). Of the two COE water quality stations selected only one DCP has been operational during the investigation, and it has been limited to reporting water quantity, rather than any measure of quality. As a result ground truth data and the DCP have been of limited usefulness to the MITRE investigation. It is felt that it may be highly useful, however, to include here a detailed discussion of MITRE's DCP experience for the potential benefit to other investigators.

2.1.2.1 DCP Siting Efforts. MITRE's DCP siting efforts followed along three lines: (1) locating existing water and air quality stations in which the DCP would speed the reporting process, (2) identifying new sites of interest to Federal, state and/or local organizations, and (3) acquiring ground truth valuable to the MITRE experiments.

Many existing air and water sites were analyzed. For water, all Federal and state water quality stations in the Test Site were examined for possible utility to siting efforts. The Commonwealth of Pennsylvania has water quality data recorded from 192 sites; however, examination of these found many stations discontinued, or operating in a manual mode (grab sample, etc.) and many stations reported under a different name in the Federal water data bases.[1,2,3] In addition, daily average data of the more common water quality parameters useful to MITRE's effort (turbidity, pH, DO, conductivity, temperature) were rarely recorded on a continuous basis.

Similarly, for air quality, it was learned that the State of Pennsylvania was operating four surveillance systems. These systems are:

(1) The Philadelphia County Aerometric Monitoring System (PCAMS)

---

[1] "Catalog of Information on Water Data - Index to Surface Water Section," Office of Water Data Coordination, U.S. Department of Interior, Edition 1970.

[2] "Catalog of Information of Water Data - Index to Water Quality Section," Office of Water Data Coordination, U.S. Department of Interior, Edition 1970.

[3] EPA STORET Water Quality Information Systems.

(2) The Allegheny County Air Monitoring System (ACAMS)

(3) The Commonwealth of Pennsylvania Air Monitoring System (COPAMS)

(4) The Pennsylvania Air Quality Surveillance System (PAQSS)

The two (Philadelphia and Allegheny) county systems are comprised of primary real time stations and secondary sampling stations to monitor air quality in the respective counties. PCAMS, ACAMS, and COPAMS are real time systems theoretically capable of relating to a DCP. PAQSS is a comprehensive surveillance system designed primarily to document air quality in the air basin areas of the State.

Only COPAMS and PAQSS cover portions of the two MITRE test sites selected for study. Excerpted below are several paragraphs from the Commonwealth of Pennsylvania's Air Quality Implementation Plan[1] to emphasize the present status and near future plans for air quality monitoring.

> In general, the remaining surveillance systems are tailored to the growth and population density patterns of the State. Particular emphasis is placed upon the most heavily polluted areas. Outside of the heavily polluted and densely populated areas, monitoring will be done to examine transition and growth areas and to determine background levels. A few monitoring stations are used to maintain surveillance of specific major sources.
>
> The PAQSS system will be comprised of approximately 100 stations, 50 of which are currently in operation throughout the State. Each station is, or will be, sampling total suspended particulate on a uniform schedule of one sample every sixth day by means of a high volume sampler. All filters are analyzed in the State Laboratories for quantitative determinations of fluorides, sulfates, beryllium, cadmium, lead and iron. Randomly selected filters are analyzed for 14 other metals and benzene soluable organics. Settleable particulates

---

[1] "Commonwealth of Pennsylvania's Air Quality Implementation Plan." Pennsylvania Department of Environmental Resources, December 10, 1971.

and total sulfation are determined at each station on a monthly basis with dustfall jars and sulfation plates.

At approximately one-fourth of the PAQSS sites a sampling package continuously monitoring sulfur dioxide, carbon monoxide and soiling (COHS) will be installed. At a similar number of other sites a second package for sampling nitrogen oxides, oxidants and total hydrocarbons will be installed. These sampling packages will be moved to different PAQSS sites on a random schedule so that an annual cycle of data for each pollutant will be obtained at each site in a four-year period.

Monthly and quarterly mean values will be calculated for each site. Annual summaries will be prepared indicating the mean, standard deviation, minimum and maximum values. The number of times any air quality standard is exceeded at any site will also be determined.

COPAMS will be comprised of at least 17 continuously operating stations providing real time information by telemetry into a central control computer located in Harrisburg. Each station will be equipped to monitor sulfur dioxide, carbon monoxide, soiling, hydrogen sulfide, dioxide, methane and non-methane hydrocarbons, nitrogen oxides, wind speed, wind direction, temperature difference between 4 and 16 meters, ambient temperature and dew point temperature. All parameters will be monitored continuously with instantaneous values being recorded once per minute.

Only the COPAMS stations turned out to be sufficiently automated to consider the installation of a DCP. Several meetings on this with the State officials uncovered two interesting constraints: (1) the Commonwealth felt MITRE could obtain all the air quality data needed via COPAM without installing a DCP link on any of its stations, and (2) the State would not permit a DCP link to be installed as a back-up mode of communication for the State and the COPAM contractor felt nothing would be gained and that progress on COPAM would be reduced by such an effort.

With these constraints and a decision to use NOAA Turbidity Network data for air quality ground truth, it was therefore logical that MITRE look into the placement of two water quality DCP stations. Nevertheless, requirements for both air and water DCP's were assessed, and suggested sites were obtained from the Commonwealth of Pennslyvania, Office of Water Quality; Region III of EPA; Pennslyvania State University; and the USGS/Harrisburg Office.

EPA Region III was most interested in the water quality including siltation and eutrophication behind the three major dam systems on the Susquehanna River (Holtwood, Safe Harbor, Conowingo), the Codorus Creek Lake for siltation and eutrophication, the water effluents from an existing steam-elective power plant on Brunner Island, the water quality from Conewago Creek which drains a heavily industrialized area near Harrisburg, the air pollutants emitted by a lime kiln plant in Annville, and the drainage from all open pit mines and refuse banks in and around the Wilkes-Barre/Scranton area of Pennsylvania. No EPA order of priority was arrived at for these possible DCP sitings.

The State Water Quality Office personnel were more specific. They would prefer coverage of water quality in the three Dam areas, the acidity dynamics of the West Branch of the Susquehanna around Renovo, and the appearance of any denuded areas which may cause runoff siltation in either test site.

The Pennsylvania State University was interested in the air and water quality around a new nuclear power plant site at Three Mile Island just south of Harrisburg. Finally USGS/Harrisburg was interested in water quanity and quality at three of four tributaries to the Susquehanna (Swatara Creek, Conestoga Creek and Juniata River).

Table 2-1 shows this array of possible test areas in which DCP's might have been applied (p. 16).

The DCP station design and hardware procurement tasks (section 2.1.2.2 and 2.1.2.3) were then performed to aid in the selection of two final DCP sites.

2.1.2.2 DCP Station Configurations Analyzed. Of the many siting/experiment possibilities covered it appeared that the following nine had the most potential of being operative within 90 days of receipt of the DCP's as required by the terms of this contract.

(a) Refurbish and upgrade one of the two installed but unused Commonwealth water quality stations - Hunlock Creek and Danville.

(b) Use DCP as an alternate communication link on one of the seventeen COPAM air quality stations - Harrisburg being installed first.

(c) Install an automatic water quality station with DCP link at Harrisburg to replace present manual system.

(d) Install an automatic water quality station at Philadelphia Electric Company's new nuclear power plant at Peach Bottom in the Conowingo Dam Reservoir.

(e) Use DCP as an alternate communication link on the existing USGS/USA-COE water quality stations at Renovo or Beech Creek. (This was a high priority for the Commonwealth).

(f) Link the MITRE air quality station at McLean, Virginia, via DCP.

(g) Construct a mobile air and/or water quality station by using existing MITRE air quality sensors and new equipment as necessary for multiple site use.

(h) Use DCP as strap down data link for the EPA Region III mobile van. (EPA wanted to pursue this option independently).

(i) Water quality/quantity station operated by USGS in Susquehanna and its tributaries.

The attributes and constraints of these various configurations are summarized in Table 2-4. Capital, installation, and operating costs were obtained from various sources including hardware manufacturers, the USGS and MITRE instrumentation personnel.

2.1.2.3 DCP Hardware Procurement/Disposition. The two DCP's and the platform tester were received at MITRE (McLean, Virginia) on October 5, 1972. These items carried the following information.

Serial No. 0069	Data Collection Platform Assembly Model No. 63A 104 100G-3, Rev. B; DCP Electronics S/N EAB-OM-156; DCP Antenna S/N 154.
Serial No. 0145	Data Collection Platform Assembly Model No. 63A 104 100G-3, Rev. B; DCP Electronics S/N EAB-OM-175; DCP Antenna S/N 133.
Serial No. 022	Platform Tester, Model 47E225158G1 Rev. A.

After review of the value of data obtained from the possibilities discussed in section 2.1.2.2 versus the cost to the program, it was decided that the two DCP's would be dedicated to the water quality station at Renovo (option e), and to the water quantity station at Newport,

TABLE 2-4
SEVERAL POSSIBLE DCP STATION CONFIGURATIONS

	Site	Experiment	Existing Sensor Capability	Additional Capital Costs	Installation and Operation Costs (11 Months)	Housing Available?	Power Available?	Protection Available?
a)	Hunlock Creek	water quality	Proteck SM 625 water monitor -4 parameters.	$8,000[1]	$25,000	Yes	Yes	Yes
						(United Gas and Illuminating Co. owned)		
	Danville	water quality	Same as Hunlock Creek	$8,000[1]	$25,000	Yes	Yes	Yes
						(On private property, must subcontract for)		
b)	Harrisburg	air quality	COPAM Station - 10 parameters	(Must be installed by COPAM prime contractor - GE; State of Pennsylvania would not fund.)		Yes	Yes	Yes
	Harrisburg	air quality	COPAM Central Control for 17 stations	Same as above		Yes	Yes	Yes
c)	Harrisburg	water quality	None	$8,000	$25,000	Yes	Yes	Yes
d)	Peach Bottom	water quality	Six parameters - some are manual operations	$5,000[2]	$11,000[2]	Yes	Yes	Yes
e)	Beech Creek or Renovo	water quality	Three parameters - Data Master Controllers.	Initially quoted verbally at $10K per station, later reduced to zero if USGS installs DCP and uses also.		Yes	Yes	Yes

[1]Proteck station was inspected by EPA personnel and recommended that the station not be utilized and replaced by Schneider Robot Monitor RM 25 with robot backflush cleaner system.

[2]Philadelphia Electric Company would provide some help installation and maintenance but would rather take data we need at time of satellite passage and thus not install DCP.

TABLE 2-4 (CONTINUED)

	Site	Experiment	Existing Sensor Capability	Additional Capital Costs	Installation and Operation Costs (11 Months)	Housing Available?	Power Available?	Protection Available?
f)	McLean	air quality	Existing Station - 5 parameters	$9,760	$19,590	Yes	Yes	Yes
	McLean	air quality	Existing Station plus 2 parameters - 7 parameters	$12,275	$20,510	Yes	Yes	Yes
g)	Mobile	air and/or water	Seven air parameters plus six water parameters	$20,000	$25,000	Yes	Yes (Using Existing Surplus Van)	Yes
h)	Mobile	air and/or water	EPA Region III Van under construction ready in June 1973.	$0	$0	Yes	Yes	Yes
i)	Various Sites in Susquehanna Basin	water quantity and/or quality	varying from site to site through Data Master Controllers	$0	$0	Yes	Yes	Yes

Pennsylvania, on the Juniata River. Philadelphia Electric Company data at Peach Bottom would be accepted for the dam basins on the Susquehanna, and the COPAM data from the Commonwealth of Pennsylvania would be used for air quality over MITRE Test Sites 1 and 2.

Accordingly, after conversation with Dr. Richard W. Paulson of the USGS/Harrisburg and Mr. Arthur Fihelly of NASA/ERTS Project Office, MITRE shipped the three items listed above to Dr. Paulson on 20 November 1972. USGS acknowledged receipt of the DCP's, but the installation at one water quality and one water quantity station did not proceed as planned. Experience with the water quality station had convinced USGS that they did not have the resources to keep the station running continuously and reliably so as to justify the DCP data link. MITRE as a result was faced with the alternative of having two stations reporting water quantity only or installing a substitute quality station.

The requirements study was immediately resumed to determine if a substitute water quality station could be established within the constraints of time, resources, and unattended reliability. Commonwealth of Pennsylvania, EPA Region III officials, USGS officials, and individual vendors were contacted to discuss alternative sites and equipment which might meet specifications in the time frame required. The culmination of this effort was the finding that most instrument packages could not meet requirements, but, according to Mr. Anthony Mentink of EPA's water quality laboratory in Cincinnati, one state-of-the-art package that might meet specifications was that offered by the Schneider

Instrument Company, MITRE obtained a quotation from this company which did indicate their package could meet specifications. Additionally, it was learned that the nearby Montgomery County, Maryland, water pollution control agency was operating Schneider equipment, so that a real operational assessment was possible. The Principal Investigator accordingly met with Montgomery County officials and inspected the sampling station on Seneca Creek. This experience revealed that the equipment was indeed among the best available, but it still required attention, at least for backflushing, approximately once a week. When these findings were subsequently discussed with USGS officials in Pennsylvania, it was found that they would not be able to maintain a water quality station for the investigation on a once a week basis without reimbursement and that MITRE could not be allowed to attach to one of their existing sites, i.e. hands-off. In addition USGS had a high priority project of its own with the Susquehanna River Basin Commission to establish a streamflow warning and forecasting network with DCP's, and they requested that both MITRE DCP's be dedicated to stream gage measurement and included in their network. In view of the costs, time remaining to the investigation, and unreliability of water quality instruments not carefully maintained and attended, it was decided to use both DCP's for water quantity measurement and have them maintained by USGS.

As a result both DCP's were field installed as stream gage stations and put into operation - one on the West Branch of the Susquehanna at Lewisburg, Pennsylvania, and one on the East Branch at Towanda, Pennsylvania. MITRE has been receiving output continually from the

Lewisburg Station only. The data are actually collected several times within the three minute intervals per pass. Only one of these sets is recorded unless there is a significant change (± 0.01 feet in stage height) in the information. There are approximately five readings recorded for each day for this station. Since the information MITRE has received is only water quantity and not quality, this information is averaged further on a daily basis. The output from this DCP is included as Figure 2-2. These data have not proved to be particularly useful (1) because of the DCP location out of the direct water test area (i.e., Susquehanna River Mouth to Sunbury) and (2) the fact that the DCP is only recording water quantity.

MITRE's second DCP on the Susquehanna River at Towanda, Pennsylvania, has never operated properly and was returned to the USGS/Harrisburg office for a checkout and repairs. Unable to repair the DCP at Harrisburg, USGS shipped it to the NASA Mississippi Test Facility for overhaul. To MITRE's knowledge this DCP has been in Mississippi for the entire period of Phase III of the MITRE investigation.

MITRE's other source for water quality information, the Philadelphia Electric Company, has only partly followed through with the in-situ support promised initially. On February 6, 1973 data were sent by Fred N. Megahan, Assistant Chief Chemist, for 10 random dates from October 31, 1972 through December 24, 1972. MITRE's investigation of water quality (turbidity) centered on data obtained for the 11 October 1972 overflight date which was not covered by the company data. Data for January 1973 through March 1973 were recently received by MITRE.

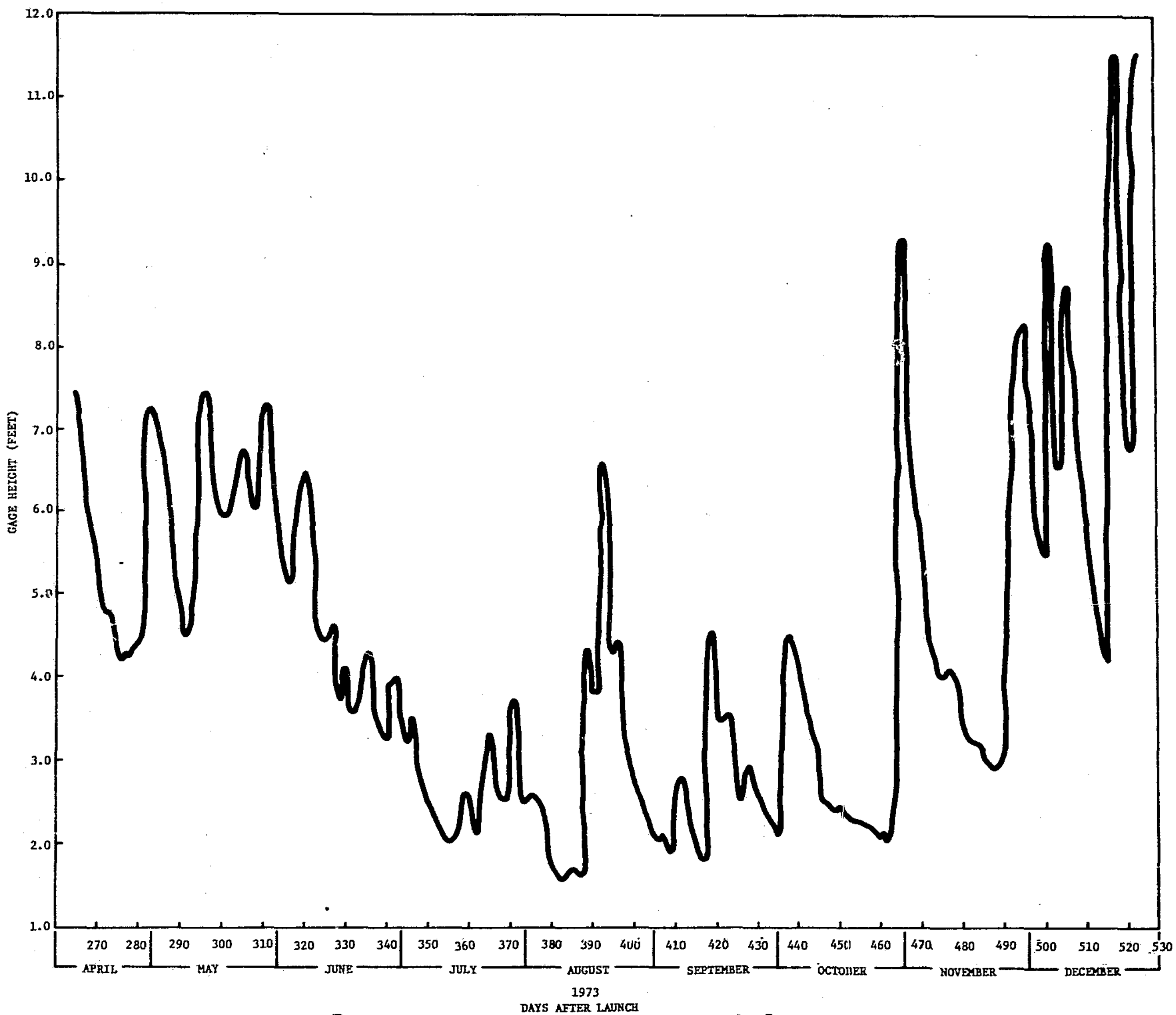


FIGURE 2-2
DATA FROM LEWISBURG DCP STATION

MITRE's attempt to get useful water quality calibration information using DCP's along the Susquehanna River has met with little success. The Federal and state data were not taken on ERTS overflight dates. Also a real difficulty is that the theoretical or claimed capabilities for present state-of-the-art water quality instruments, especially for unattended operation, can be very different from actual field performance. Mr. Gilmore Trafford from NASA-Wallops has experienced a similar dilemma on water quality instrumentation. Thus field performance required the attention of operating personnel at a schedule which USGS and MITRE were not prepared to meet. Nevertheless, the water quantity information has proved useful to the efforts of the USGS and the Susquehanna River Basin Commission.

2.1.3 Planning for Ground Truth Data Aquisition

Almost equal in importance to the receipt and analysis of the ERTS MSS data was the acquisition of reliable ground truth data to calibrate and verify the ERTS results. In the proposal phase and Data Analysis Preparation Phase (I) contacts were established with the cognizant Federal, state, regional and local officials for both test sites to make arrangements for acquiring all available ground truth data which would be useful to the MITRE investigation. As a result of initial arrangements, some ground truth data (e.g. USGS 7.5 minute quadrangle maps covering both test sites and data from MITRE's and other environmental studies) were on hand at the beginning of Phase I; and the bulk of the remaining documents, maps, photography, and personal consultations became available during Phase I. However, because several new sources were uncovered in the course of the investigation, there was no attempt made to limit ground truth data acquisition to Phase I. Some very important data, especially with regard to the current status of surface mining in Test Site 2, were acquired as late as Phase III of the investigation. For convenience, a review of the most useful ground truth data has been assembled and presented as a separate listing for land use, water quality, and air quality (Tables 2-5, 2-6, and 2-7, respectively.)

TABLE 2-5

PRIMARY GROUND TRUTH SOURCES: LAND USE

DOCUMENTS

- Arthur D. Little, Inc. (For U.S. Army Corps of Engineers) Environmental Study of Luzerne and Lackawanna Counties, Pennsylvania, 1968.
- Commonwealth of Pennsylvania. Department of Environmental Resources, Secretary's Report, 1971.
- Commonwealth of Pennsylvania. Quarterly Review. Various issues, 1971-1972.
- Lackawanna County Regional Planning Commission[1]. Comprehensive Plan Update: Economic and Population Study, 1973.
- Lackawanna County Regional Planning Commission[1]. Housing Report, 1973.
- Lackawanna County Regional Planning Commission[1]. Planning Objectives and Standards, 1964.
- Lackawanna County Regional Planning Commission[1]. Refuse Disposal Study and Plan, 1965.
- Lackawanna County Regional Planning Commission[1]. Sewerage Development Plan, 1966.
- Lackawanna County Regional Planning Commission[1]. Transportation Report, 1973.
- Luzerne County Planning Commission. Concept Development Plan, 1965.
- Luzerne County Planning Commission. Land Use Plan, 1963, with updating data received September 1973.
- Luzerne County Planning Commission. Suggested Land Use Regulations, 1966.
- Luzerne County Planning Commission. Zoning Ordinance, 1970.
- The MITRE Corporation. Comprehensive Analysis and Action Alternatives for Northeastern Pennsylvania. MTR 6165, 1970.

---

[1]Many of the Commission's reports were prepared with the assistance of Candeub, Cabot and Associates.

TABLE 2-5 (Continued)

DOCUMENTS

- The MITRE Corporation. Environmental Action Programs for Northeastern Pennsylvania: Refuse Bank Removal, Subsidence Monitoring. MTR 6165, 1972.
- The MITRE Corporation. Tropical Storm Agnes: Long Range Flood Recovery MTR 6429, 1973.
- NASA. Symposium on Significant Results Obtained from the ERTS-1 NASA SP 327, 1973.
- Peters, Spicer, and Lovell. Location, Magnitude, Characteristics and Potential Uses of Pennsylvania Refuse, 1968.
- Planning Commission of the Borough of Taylor. Comprehensive Plan, 1963.
- Scranton Industrial Development Authority. Feasibility Study of Proposed Keyser Valley Industrial Park, 1966.
- Susquehanna River Basin Study Cordinating Committee. Susquehanna River Basin Study: Main Report and Appendices, 1970.
- Tri-County Regional Planning Commission. Future Land Use Plans, Cumberland, Dauphin, and Perry Counties, 1971.
- Tri-County Regional Planning Commission. Harrisburg Area Transportation Study, 1971.
- Tri-County Regional Planning Commission. Population Study, 1972.
- Throop Borough Planning Commission. Comprehensive Plan, 1966.
- U.S. Department of the Interior. Acid Mine Drainage Abatement Measures for Selected Areas within the Susquehanna River Basin. WA66-21, 1968.
- Wilbur Smith and Associates. The Wyoming Valley: Planning and Development Considerations, 1973.

MAPS

- Blue Coal Company: USGS outline maps at 1" = 400' scale showing location of the company's surface mining permit areas and actual active strip mining sites in the Nanticoke, Pennsylvania, area.

TABLE 2-5 (Continued)

MAPS

- Commonwealth of Pennsylvania, Department of Environmental Resources: USGS outline maps at 1" = 400' scale from the state permit files showing strip mine permit areas in Test Site 2.

- Economic Development Council of Northeastern Pennsylvania: Regional, county, and local jurisdiction maps showing a color-coded display of land use in Test Site 2.

- Lackawanna County Planning Commission: Color-coded land use map of the Lackawanna County portion of Test Site 2.

- Luzerne County Planning Commission: Color-coded land use map of the Luzerne County portion of Test Site 2.

- Pennsylvania Power and Light Company: Planimetric prints at a 1" + 400' scale covering Test Site 2.

- Peters, Spicer, and Lovell: Small scale map showing the location of culm piles and silt banks in the anthracite region of Pennsylvania.

- Tri-County Regional Planning Commission: color-coded land use, transportation, and political subdivision maps covering Test Site 1.

- U.S. Geological Survey: All current 7.5 minute and 15 minute quadrangle maps for complete coverage of both Test Site 1 and Test Site 2.

PHOTOGRAPHY

- The MITRE Corporation: Hand-held ground photography of specific mining area targets in Test Site 2 illustrating active mining, unreclaimed old mining and refuse banks, revegetation in mining areas, and backfilled and graded areas.

- NASA/Pennsylvania State University: NASA U-2 photographic coverage of Test Site 1 and Test Site 2.

- Pennsylvania Power and Light Company: Aircraft black and white photography reproduced at a scale of 1" = 400', dated 1966, covering all of Test Site 2.

TABLE 2-5 (Continued)

AGENCIES CONSULTED

- Commonwealth of Pennsylvania, Department of Environmental Resources: Officials were closely consulted throughout the investigation for assistance and assessment of results of land use analysis in Test Site 1 and Test Site 2.

- Economic Development Council of Northeastern Pennsylvania: Officials were consulted for assistance in obtaining ground truth data from local jurisdictions in the Test Site 2 area, and for assessment of the land use analysis results.

- Environmental Protection Agency, Region III Office: Officials were consulted on land use generally for both test sites, and specifically for strip mining targets of interest in Test Site 2.

- Tri-County Regional Planning Commission: Officials were consulted to obtain land use information for Test Site 1 and for assessment of land use analysis results.

- U.S. Bureau of Mines, Wilkes-Barre Field Office: Officials were consulted for specific information on the status of strip mining and reclamation in Test Site 2.

- Special note: Mr. Charles Zink, Vice-President of the Blue Coal Company, and Mr. Dale Reynolds, his Chief Surveyor, provided outstanding advice and assistance to the MITRE investigation in the form of discussions, maps, documentation, and on-site inspection of Blue Coal's active mining areas in Test Site 2.

TABLE 2-6

PRIMARY GROUND TRUTH SOURCES: AIR QUALITY

TECHNICAL PAPERS

- Clodman and Taggart. "The Movement of Large-Scale Air Pollution Areas as Determined by Satellite Photography." Unpublished paper for the Director, Meteorological Services Research Branch, Atmospheric Environmental Service, Downsview, Ontario, Canada, October 1972.

- Commonwealth of Pennsylvania, Department of Environmental Resources. "Commonwealth of Pennsylvania's Air Quality Implementation Plan." December 1971.

- Flowers, McCormick, and Kurfis. "Atmospheric Turbidity over the United States, 1961-1966." Journal of Applied Meteorology, Vol. 8 No. 6 December 1969.

- Griggs. "A Method to Measure the Atmospheric Aerosol Content Using ERTS-1 Data." Unpublished paper for NASA's Symposium of Significant Results Obtained from the ERTS-1, December 1973.

- Larsen. "United States Air Quality." Archives of Environmental Health, Vol. 8 February 1964.

- McCormick. "Atmospheric Turbidity." Presented at 60th annual Meeting of the Air Pollution Control Association, Paper 67-32 June 1967.

- McCormick and Baulch. "The Variation with Height of the Dust Loading over a City as Determined from the Atmospheric Turbidity." Journal of the Air Pollution Control Association. Vol. 12, No. 10 October 1962.

- McCormick and Kurfis. "Vertical Diffusion of Aerosols over a City." Quarterly Journal of the Royal Meteorological Society Vol. 92, No. 393, July 1966.

- Rogers, Peacock and Shalor. "A Technique for Correcting ERTS Data for Solar and Atmospheric Effects." Unpublished paper for NASA's Symposium on Significant Results Obtained from the ERTS-1, December 1973.

- Yamamota and Tanaka. "Increase of Global Albedo Due to Air Pollution." Journal of the Atmospheric Sciences Vol 29 No. 8 November 1972.

- (ed.), "Little Solid Particle Air Pollution Found over Ocean, Clean Air and Water News, No. 16, 1972.

TABLE 2-6 (Continued)

AEROMETRIC DATA SOURCES

- Allegheny County Aerometric Monitoring System. Pittsburgh, Pennsylvania.
- Commonwealth of Pennsylvania Air Monitoring System. Harrisburg, Pennsylvania.
- National Aerometric Data Bank. Research Triangle Park, North Carolina.
- National Oceanographic and Atmospheric Administration Turbidity Network Data for the U.S. and the World.
- Daily Weather Maps for the period of the investigation.
- Pennsylvania Air Quality Surveillance System. Harrisburg, Pennsylvania.
- Philadelphia County Aerometric Monitoring System. Philadelphia, Pennsylvania.

TABLE 2-7

PRIMARY GROUND TRUTH SOURCES: WATER QUALITY

WATER QUALITY DATA SOURCES

- EPA STORET Water Quality Information Systems - computer outputs recording measurements of temperature, conductivity, pH, chlorides.
- EPA REGION III, Annapolis - contacted concerning water quality on 11 October 1972 in the Potomac River.
- Philadelphia Electric Company - data collected from the Peach Bottom Atomic Power Station.
- State of Pennsylvania, Department of Health - quarterly measurements of temperature, conductivity, pH, chlorides.
- USGS/Harrisburg - contacted concerning the water quality investigation on the Susquehanna River; monthly measurements of temperature, conductivity, pH, chlorides.

WATER QUALITY PUBLICATIONS

- Pennsylvania Department of Environmental Resources. Water Quality Management Information Systems (WAMIS). June 1970.
- Federal Water Quality Administration. Susquehanna River Basin Study. Washington, June 1970.
- Pennsylvania Department of Health, Bureau of Environmental Health, "Lackawanna Valley Mine Drainage Pollution Abatement Project." Harrisburg, May 17, 1967.
- U.S. Department of the Interior, Geological Survey. Water Resources Data for Pennsylvania. Washington, 1971.
- U.S. Department of the Interior, Geological Survey. Swatara Creek Basin of Southeastern Pennsylvania. Washington 1967.
- U.S. Department of the Interior, Office of Water Data Coordination. Index to Water Quality Section. Washington 1970.
- U.S. Department of the Interior, Office of Water Data Coordination, Index to Surface Water Section. Washington 1970.
- U.S. Geological Survey, Water Resource Division. Monthly Water Resources Summary for Pennsylvania. Philadelphia, August 1972.

TABLE 2-7 (Continued)

WATER QUALITY PUBLICATIONS

- Anderson, Peter W. "Variations in the Chemical Character of the Susquehanna River at Harrisburg, Pennsylvania." Washington 1963.

2.1.4 Planning and Testing ERTS MSS Data Analysis Procedures

From the inception of the proposal for this investigation, MITRE's approach to ERTS MSS data analysis had been to review available state-of-the-art analysis techniques and select one which had the potential for serving as the tool for achieving MITRE's investigation objectives. The Laboratory for the Application of Remote Sensing at Purdue, the Jet Propulsion Laboratory, the Environmental Research Institute of Michigan, and many others had developed computer and photo interpretive programs and procedures for analysis of MSS data. Thus a review and selection approach seemed more logical than the duplicative effort of developing original analysis tools at MITRE. The MSS analysis program package being developed at Pennsylvania State University's (PSU's) Office of Remote Sensing of Earth Resources at the time of contract award had been suggested to MITRE by NASA as a good new system, and one which would have synergistic effects as far as common test sites were concerned. The system, described in more detail in Section 2.2, is essentially a digital analysis approach supported by aircraft photo and map comparisons. As part of the procurement procedure MITRE directed PSU to test (under subcontract) a (1) purely digital approach (2) a purely photo interpretive (PI) approach of ERTS imagery and (3) combined digital and PI approach. When (3) was found wanting PSU suggested and tested a fourth approach - the use of ERTS CCT's results and aircraft IR color photo comparisons. Because the results of the tests were critical to the to the later development of the Data Analysis Plan and the course of the analysis phases of the investigation, those initial tests of analysis procedures will be described in detail.

2.1.4.1 <u>ERTS Imagery Analysis Test Run</u>. The first step performed at PSU under MITRE direction was the imagery analysis test run: an attempt to use photo interpretive techniques alone as a means of defining separable categories at least for land use and water quality. A portion of Test Site 1, consisting of 144 square miles surrounding Harrisburg, Pennsylvania, was studied. The imagery used was that of 6 September, 1972, namely image number 1045-15243 in the four channels of the MSS.

The photo interpretation was carried out independent of outside aid. There was no special study of the test area, no coordination with other researchers using computer approaches, and no previous study of maps or aerial photos at larger scales. The intent was to determine what could be read directly from ERTS imagery alone. Although interpreters had a traveler's acquaintance with the Harrisburg area, care was taken not to identify items by their geographic location. Graytone variations were recorded, but interpreted only where their shape provided interpretive clues.

The imagery was studied under the following conditions.

1. Direct inspection of the image on a light table under magnifications of 4.5X and 7X, using a direct viewing lens or one lens of a Old Delft stereoscope.

2. Projection of the image by means of a Visucom overhead projector, from 10 feet, onto a flat screen at a magnification of 4X.

3. Projection of the image onto a table by means of a single Kelsh Plotter projector, at a magnification of 4.5X.

4. Projection of a glossy positive 4X enlargement using a Saltzman projector, resulting in a further enlarged scale of 7.5X (or 2 miles to the inch).

The above systems were the only ones available at PSU at the time of this experiment. A search of mapping equipment literature by MITRE indicated that the Bausch & Lomb Zoom Transfer Scope or the Autograph Model 55C Mapograph would permit delineation of the detail desired. (Subsequently, a Bausch & Lomb Zoom Transfer Scope has been used by MITRE and made available for use by MITRE at no cost by the USGS/McLean).

Working at contact scale proved useless for documentation, although considerable detail could be observed with the hand lens. The overhead projector also could not be used, as the projected image could be viewed clearly only from a position of several feet from the screen.

The Kelsh Plotter was second only to the Saltzman in usefulness. It permitted direct projection of the image onto a table, where features could be mapped as observed. However, only a very small portion of the image could be viewed at one time, making it difficult to determine significant graytone signatures and to maintain consistency in delineating them. Mapping by this method is, in addition, a very slow process compared to the Saltzman.

The Saltzman projector appeared to give the best overall image definition combined with rapid tracing of observed features. It's chief drawback is the necessity of using photographic prints rather than the images themselves, resulting in some loss of graytone resolution.

Figures 2-3 through 2-6 are a demonstration of the results of photo interpretation of the four ERTS images, using the Saltzman projector at PSU. The outline on each overlay was a strict recording of what was viewed. No touchup work or editing was done and there was no "second guessing" as a result of support documentation.

The following remarks pertain to the work shown in Figures 2-3 through 2-6.

1. The four images used, representing the four MSS channels of scene number 1045-15243 taken 6 September 1972, were chosen because they were the best representation available for the scene for which data tapes also became available, facilitating later comparison. Better quality images for Test Site 1 are now available, but this experiment has not been repeated.

2. Positive glossy prints of the portion of these images covering Test Site I were made, enlarging the image 4 times. These were projected to a total enlargement of 7.5 times.

3. The overlays were made from the enlargements. Subsequent to this, a second set of photo enlargements at a scale of 7.5X were made, to facilitate interpretation of the overlays. The photo prints to which the overlays are attached, therefore, were not used to obtain the data on these overlays.

FIGURE 2-3
LAND USE CHANNEL 4

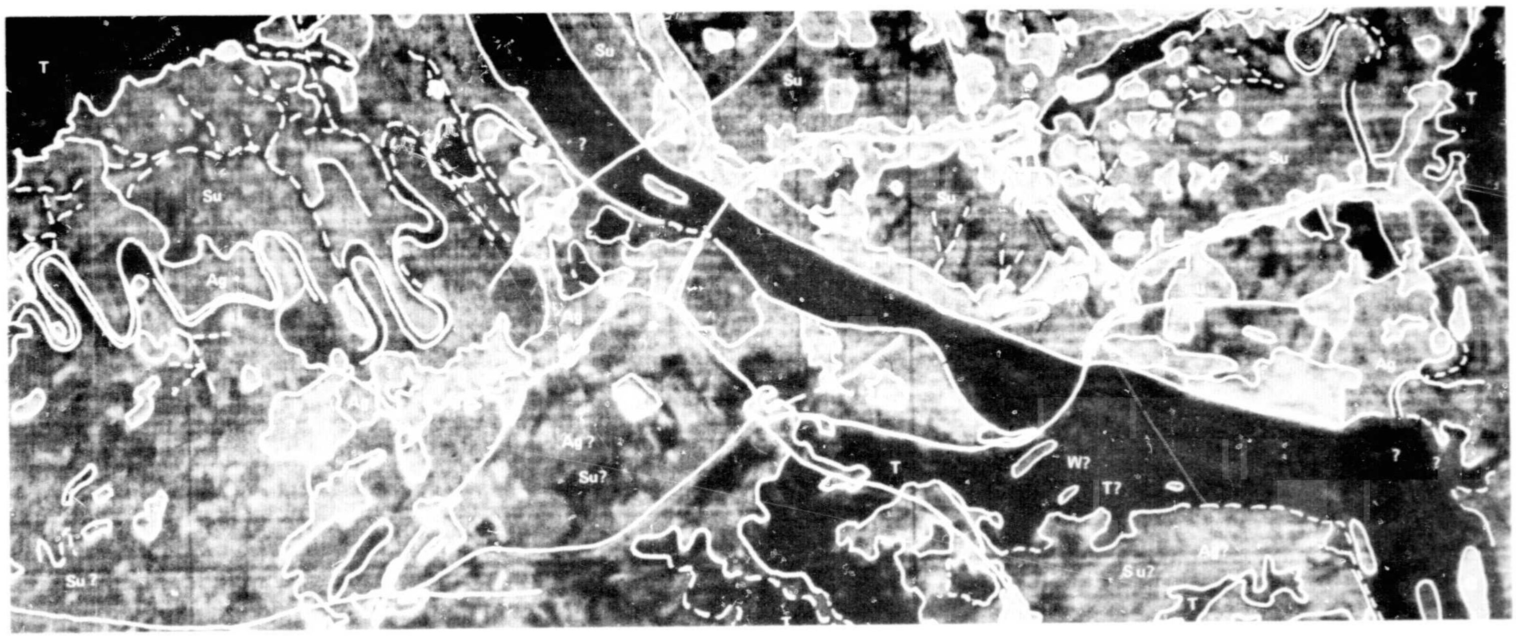


FIGURE 2-4
LAND USE CHANNEL 5

FIGURE 2-5
LAND USE CHANNEL 6

FIGURE 2-6
LAND USE CHANNEL 7

4. Only a small portion of Test Site 1 was chosen for study. This portion was considered to be sufficient to illustrate the problems involved and the results obtainable by photo interpretive techniques alone.

5. The time involved in producing the overlays was as follows:

Channel 4	$1\frac{1}{4}$ hours
Channel 5	$2\frac{1}{2}$ hours
Channel 6	1 hour
Channel 7	1 hour

The results were of such quality that it was not considered worthwhile to attempt to planimeter the areas for quantification of the land use categories.

6. The following symbol key was used for the overlays:

W	Water bodies and drainage
Solid Line (when not category boundary)	Roads
U/SU	Urban/suburban
T	Forest and woodland
Ag	Agriculture
C	Construction or mining
E	Erosion or siltation

It should be noted that for each overlay the above designations were best estimates (determined from shape and/or relative positions) of what the particular graytone outlined most probably represented.

7. No attempt was made to evaluate air quality parameters at this time.

The results of the work done with the Saltzman projector are shown on the overlays of the Figures 2-3 through 2-6 and on Table 2-8. It can readily be seen from both the overlays and the Table that in only a few cases could a feature be uniquely determined by this technique,

TABLE 2-8

RESULTS OF PHOTOINTERPRETATION OF ERTS IMAGERY USING THE SALTZMAN PROJECTOR

Land Use Category	Channel 4	Channel 5	Channel 6	Channel 7	Preferred Channel
Drainage	Incomplete. Islands obscured. Shorelines grade into forest.	Incomplete. Shorelines grade into forest.	Confused with urban.	Some confusion with urban.	Channel 7
Roads	Very incomplete.	Clearly defined where white. Unreliable when parallel to scan lines. Many dark lines could be roads or drainage.	Rarely seen and poorly defined.	Rarely seen.	Channel 5
Urban	Grades into suburban.	Confused with probable bare fields. Otherwise fairly distinct.	Minor confusion with suburban and drainage.	Confused with drainage.	Channels 5 & 6
Suburban	Not differentiable from urban. Confused with agriculture.	Not differentiable from agriculture.	Confused with agriculture.	Fair to poor distinction from both agriculture and urban.	All poor, due to confusion with agriculture.
Forest	Not differentiable from drainage and often confused with agriculture.	Some confusion with drainage.	Confused with agriculture.	Confused with agriculture.	Channel 5
Agriculture	Confused with forest and often with suburban.	Not differentiable from suburban.	Confused with both forest and suburban.	Confused with forest and with portions of suburban.	All poor, due to confusion with forest and suburban.

TABLE 2-8 (Continued)

RESULTS OF PHOTOINTERPRETATION OF ERTS IMAGERY USING THE SALTZMAN PROJECTOR

Land Use Category	Channel 4	Channel 5	Channel 6	Channel 7	Preferred Channel
Construction	Confused with established concrete areas (e.g., airport) and areas of erosion.	Confused with established areas of concrete and with urban.	Indistinct.	Not visible.	Channel 4
Erosion and Siltation	Confused with construction.	Not visible.	Not visible.	Not visible.	Channel 4

and in virtually no case could it be completely delineated.

On no channel was it possible to determine unambiguously areas of suburban development and agriculture. A comparison of results from the four channels reveals widely differing assignments of areas to these two categories, as well as to the category of "forest."

In several areas, on all channels, it was not possible to determine accurately the shoreline of the Susquehanna River. It was discovered later that this difficulty was largely due to the loss of graytone definition on the paper print. For example, restudy of the original transparency for channel 7 revealed a much clearer shoreline in these areas, as well as several islands which had been "lost" on the paper print. (Corrections for these features were not made on the overlays). Some of these "lost" islands are shown on the overlays in the Susquehanna, where these slight tonal changes in the river were originally thought to represent differences in water quality. Other than for these islands, differences in graytones of water areas were not observed, although they were looked for, especially where tributaries entered the main stream.

Only two orders of streams could be seen on ERTS imagery using the Saltzman projector and photo interpretive methods: the Susquehanna River and major streams entering it. A few lesser streams were seen on the original imagery by inspection with the hand lens.

This study has shown that photo interpretive techniques alone, when applied to ERTS imagery, are unsatisfactory as a single means of determining indices for land use categories, for the following reasons.

1. It is not possible, by the means attempted here, to unambiguously delineate areas of land use categories or water quality.

2. Establishment of indices for land use categories requires planimetry of areas. Where areas cannot be clearly outlined they cannot be accurately determined.

3. Up to 2½ hours were spent in mapping a small portion of Test Site 1 in a single channel. Clearly, mapping the entire Test Site in all four channels would take a large amount of time with very limited useful results.

4. A brief inspection of U-2 imagery (flown at 60,000 feet) of the same area indicated that some improvement of photo interpretive techniques could be realized by using U-2 photography to train the photo interpreter to recognize ERTS signatures. This would, however, increase the time requirements for a given area of investigation, and perhaps require additional U-2 flights.

5. Computer assisted photo interpretation was strongly recommended. This appraoch makes area delineation unnecessary, and therefore makes study of ERTS imagery free from delineation restrictions.

6. Previous work done indicated that computer differentiation of areas from scanner data is far superior to that done by the human eye. The role of the photo interpreter, then, is in the identification by shape comparison, of the features exhibited on computer output.

2.1.4.2 Digital Analysis Test Run. The next step in MSS implementation was the MSS digital analysis test run. For this task, an attempt was made to classify and map the test site 1 area as well as possible within a limited time period and without the assistance of photo interpretation and without photographic and imagery materials other than ERTS-1 satellite imagery. The time period was set as two work weeks (10 days). ERTS-1 imagery and USGS 7.5 minute quadrangles of the area were used as support materials. ERTS-1 MSS digital data were used. The processing system described in Appendix A was employed. This project was actually the first time the processing system was used for the production of classification and map products where the emphasis was on production and not on development and testing. In the use of the system, all of the work was done via a remote typewriter terminal (IBM 2741) at MITRE's McLean facility or at PSU connected by phone lines to the PSU Computation Center. (First experiments were from MITRE via terminal to PSU computer). All output (except for the infrequent high-volume printer output) was directed back to the terminal. High-volume printer outputs were directed to The Computation Center and those outputs were collected as they were produced. Most of the analysis work was done by short computer runs to insure rapid turn around time. The tapes were identified as 1009-15244 and correspond to scene 15244 collected on August 1, 1972. The scene covered the southeastern quadrant of the state of Pennsylvania. (Test Site 1). Cloud cover was inconsequential over the area of interest. All four MSS channels were used in data processing; however, channel 7 was rated as poor.

Using the imagery for reference, two subsets of the full scene of data were defined. Each subset was put on a separate tape. The first subset was defined as scan lines 937 through 1150 and elements 2790 through 3010. The second subset consisted of lines 1051 through 1200 and elements 3010 through 3228. Both of the subsets came from the third tape of the four for the scene.

Printer map output is nearly in the same scale as the USGS 7.5' maps so that cross-reference to these maps is quite simple. After the initial use of the ERTS-1 imagery to locate and define the subsets, the imagery was not used further. The reason was that cross-reference to the 7.5' maps was more helpful and simple, whereas cross-reference to the imagery was comparatively difficult and not helpful because of the large scale.

The first step in the analysis was the production of an intensity map for the purpose of assisting in locating patterns and targets in the area of interest. The map was produced for the first subset since target identification was to be centered mainly in the area it represented. A small part of the overall map is presented in Figure 2-7, in which the pattern of Conodoguinet Creek is clearly shown. The creek flows into the Susquehanna River which is shown in the upper right corner of the Figure.

```
  2825|2830|2835|2840|2845|2850|2855|2860|2865|2870|2875|
      |    |    |    |    |    |    |    |    |    |    |
1005 | ------------XXXX----------        ------          |
1006 |---X-XXXX----XXXXX----------           ------      |
1007 |--XXXXXXXX---XXXXX-------------        -------     |
1008 |--XXXXXXXX-XXXXXXXX--------------      --------    |
1009 |XXXXXXXXXXXXXXXXXX-----------------    ---------   |
1010 |-XXXXXXXXXXXXXXXXXX---------------   --   ------   |
1011 |XXXXXXXXXXXXXXXXXXXXX-----XX------   --    ------- |
1012 |XXXXXXXXXXXXXXXXXXXXX-----XX----           --------|
1013 |XXXXXXXXXXXXXXXXXXXXXXXX---XX--           ---------|
1014 |XXXXXXXXXXXXXXXXXXXXXXXXX-----  XXXXXXX    ----    |
1015 |      --XXXXXXXXXXXXXXX------  XXXXXXXXX     --    |
1016 |       --XXXXXXXXXXXXX----XX   XXXXXXXXXX     -    |
1017 |        -XXXXXXXXXXXXX---XX   XXXXXXXXXXXX         |
1018 |---      -XXXXXXXXXXXX----X   XXXXXXXXXXXXX        |
1019 |XXXXX     -XXXXXXXXXX----XX   XXXXXXXXXX---X--     |
1020 |XXXXXXX     XXXX---XX-----     XXXXXXXX---------   |
1021 | XXXXXXX       --X-------      XXXXXXXX---------XXX|
1022 | XXXXXXXX       XXXXX--XX-     XXXXXXX------X-XXXXX|
1023 | XXXXXXXXX       XXXXXXXXX--    --XXXXX----XXXXXXXX|
1024 |  XXXXXXXXX       XXXXXXX---    --XXXXXX---XXXXXXXX|
1025 |  XXXXXXXXXX       --XXXXX---    -XXXXXXX-XXXXXXXXX|
1026 |   XXXXXXXXXX       --XXXXXX--    -XXXXXXXXXXXXXXXX|
1027 |    XXXXXXXXXXX      --XXXXXXXX    -XXXXXXXXXXXXXXX|
1028 |     XXXXXXXXXXX      --XXXXXXXX    -XXXXXXXXXXXXXX|
1029 |     -XXXXXXXXXX-      --XXXXXXXX    -XXXXXXXXXXXXX|
1030 |X    ---XXXXXXXXXX      XXXXXXXXXXX   -XXXXXXXXXXXX|
1031 |X--  ----XXXXXXXXXXX     XXXXXXXXXXX   --X-XXXXXXXX|
1032 |X--   ---XXXXXXXXXXXX     XXXXXXXXXXX   ----XXXXXXX|
1033 |XXXXX   ----XXXXXXXXX---   XXXXXXXXXXXX   --XXXXXXX|
1034 |XXXXXX   ----XXXXXX-----    XXXXXXXXXXXX     XXXXXX|
1035 |XXXXXXXX    ----XX-- ----   -XXXXXXXXXXXXX    XXXXX|
1036 |XXXXXXXXXX   ----     --XXXXXXXXXXXXXXXXXXX   XXXXX|
1037 |XXXXXXXXXXX    -      -XXXXXXXXXXXXXXXXXXXXX   XXXX|
1038 |XXXXXXXXXXXX         --XXXXXXXXXXXXXXXXXXXXX    XXX|
1039 |XXXXXXXXX--XX         --XXXXXXXXXXXXXXXXXXXX    -XX|
1040 |XXXXXXXXX----          XXXXXXXXXXXXXXXXXXXXX    ---|
1041 |XXXXXXXX-----          XXXXXXXXXXXXXXXXXXXX     -- |
      |    |    |    |    |    |    |    |    |    |    |
  2825|2830|2835|2840|2845|2850|2855|2860|2865|2870|2875|
```

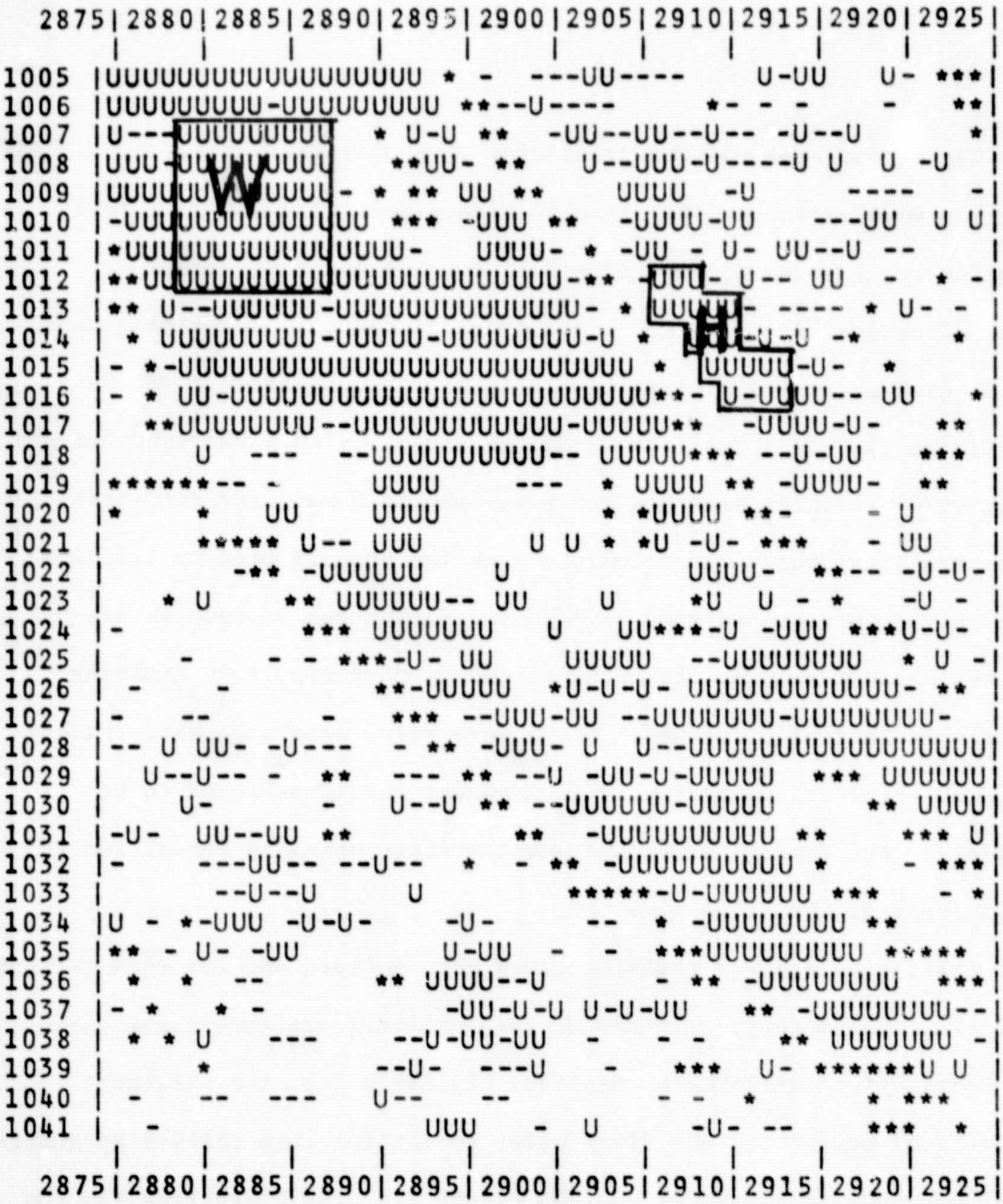
Low brightness	blank
Medium brightness	-
High brightness	X

FIGURE 2-7

BRIGHTNESS MAP OF CONODOGUINET CREEK AREA

The second step was the production of a uniformity map. A small portion of the map is shown in Figure 2-8. The U symbol show areas of local uniformity based on all four channels of spectral data. Clusters of these show broad areas of spectral uniformity which can be used as training areas to obtain spectral signatures of the associated targets. In Figure 2-8, the area labeled W was used for a river water training area and the area labeled H was used for a central urban training area. The asterisks were the symbols used to indicate local high contrast and some obvious boundaries can be seen as expressed by that symbol. By using the uniformity map, five training areas were initially defined. These were river water, forest, railway yards, central urban, and an unknown target which was found to be similar to the forest target and was therefore named as forest for the preliminary digital test run.

Statistics for the training areas were defined and the mean vectors (spectral signatures), standard deviations, variance-covariance matrix, and correlation matrix were computed. In Table 2-9, the pertinent statistical output for the river water target for this three-step supervised approach is presented and, in Figure 2-9, the histograms for the four channels are shown. The historgrams for each channel show the number of observations in each percentile versus the reflectance percentile. For any category, a low standard deviation and/or a bell shaped historgram define a good signature. The variance-covariance was not used in MITRE's analysis; however, since it is computed in the STATS



High local uniformity	U
Medium local uniformity	-
Medium local contrast	blank
High local contrast	*
River water training area	W
Central urban training area	H

FIGURE 2-8

UNIFORMITY MAP OF A PART OF THE SUSQUEHANNA RIVER

TABLE 2-9

STATISTICS FOR THE RIVER WATER TRAINING AREA

MEANS AND STANDARD DEVIATIONS FOR GIVEN CHANNELS

Ch.4	Ch.5	Ch.6	Ch.7
33.19	22.48	17.76	4.78
1.01	1.13	0.67	0.60

VARIANCE-COVARIANCE MATRIX

Ch.4	1.02			
Ch.5	-0.17	1.27		
Ch.6	0.18	0.14	0.45	
Ch.7	-0.01	-0.12	-0.05	0.36
	Ch.4	Ch.5	Ch.6	Ch.7

CORRELATION MATRIX FOR GIVEN CHANNELS

Ch.4	1.0000			
Ch.5	-0.1458	1.0000		
Ch.6	0.2617	0.1809	1.0000	
Ch.7	-0.0240	-0.1723	-0.1345	1.0000
	Ch.4	Ch.5	Ch.6	Ch.7

```
                    HISTOGRAM FOR CHANNEL  1      0.50 -  0.60  MICRONS
                    -------------------------------------------------
                         EACH * REPRESENTS  1  OBSERVATION(S).

32 |*****************
33 |****************
34 |***************
35 |******

                    HISTOGRAM FOR CHANNEL  2      0.60 -  0.70  MICRONS
                    -------------------------------------------------
                         EACH * REPRESENTS  1  OBSERVATION(S).

21 |***************
22 |**********
23 |*****************
24 |************

                    HISTOGRAM FOR CHANNEL  3      0.70 -  0.80  MICRONS
                    -------------------------------------------------
                         EACH * REPRESENTS  1  OBSERVATION(S).

16 |*
17 |*****************
18 |******************************
19 |******

                    HISTOGRAM FOR CHANNEL  4      0.80 -  1.10  MICRONS
                    -------------------------------------------------
                         EACH * REPRESENTS  1  OBSERVATION(S).

 4 |*****************
 5 |********************************
 6 |*****
```

FIGURE 2-9

HISTOGRAMS FOR THE RIVER TRAINING AREA

program, it is printed out. The variance-covariance matrix can be used as input for canonial analysis programs, which also were not used in the MITRE analysis. The correlation matrix is useful when many channels are involved as input. It allows for elimination of channels which show close correlation, i.e., a value around 1.0. The closer the matrix values are to 0.0 the less correlation. A positive number implies direct correlation, and a negative number implies indirect correlation.

Uniform training areas could not be found for many targets; for example, clusters of uniform elements were either nonexistent or too small for making reliable statistical estimates of creek water. Cluster analysis, an unsupervised approach, was used for the identification of targets and their signatures where training areas could not be defined. The output from this program was used to estimate the signature for classification and mapping of large areas.

After an initial set of signatures were obtained, trial maps of blocks of data in the subsets were made. A second stage of target and signature determination was begun on the basis of these maps. The areas which were unclassified by either the supervised or unsupervised approaches were reinvestigated by using the methods applied before a second time. Additional signatures and targets were identified. At this stage, training areas were not limited to just clusters of U symbols but were allowed to include the next level of uniformity (symbolized by - in Figure 2-10). The number of observations and the number of subsamples (subareas) within the training area for each target was substantially

```
      2820|2825|2830|2835|2840|2845|2850|2855|2860|2865|2870|
      |    |    |    |    |    |    |    |    |    |    |
1005 |                   ++     +00 0000XX0XX0        XX*|
1006 |                  -+=++     0+   00XX0X00         0|
1007 |-        -   +      +++       + +   0XX0000        |
1008 |        --    +    -+++       ++     00X0X0  ++    |
1009 |  -    ------         ++ -    0 0+0+    0X0X   0+0+|
1010 |   ++    ------       -           +++  000000X0 +00|
1011 | ++++  ++++ ++- -   ++         -+       0  000XX000|
1012 |       +++                     -+    XXXXXX0 000000|
1013 |          +++++    +  ++----       0X      0X0   0 |
1014 |    ---   ++     ---+   --   -   - 0 ++++++ 0XX  ++|
1015 | --              ---- -  --- -    00++++++++  X0 ++|
1016 |  - -  00         ------- -      0X +++++++++ 0X000|
1017 |    XXXX**X0      - ------      0X0++++++++++  0X00|
1018 |   X0     0XX      --------     0X ++++++-- +  + 0X|
1019 |+-X0  ---- 0X0  -++-------      0X ++++-+ -- +++++ |
1020 |- X0----- - 0*0  +           0  00    +-    +0 0   |
1021 |- - X0------  0XX0                00++++++   +     |
1022 |-- 0X0------   0X0   ------ ---  000 +++           |
1023 |--  XX--------  0*0 0 ---------   00       +  +    |
1024 |    XX0-------   0X0   -------     00   ----    ---|
1025 |    XX0 --------  XX0     -------  0X  ------     +|
1026 |0   0X  -- ------- XX0     ------   X0  -- ---  +++|
1027 |-    XX0 --------    XX     -------- 0X0  ----  +++|
1028 |     0X0     ------   XX     ------   0X0 --  + +++|
1029 |-   - 0X0     -- -    0XX      --   -- 0X0  +++++ +|
1030 |---  - 0X        ---   0XX0  -----  --- 000  ++ ++ |
1031 |--  --  XX      -------  XX0  ---------- 0X0  + +  |
1032 |    --  0XX       ----++++0XX0  ---- ---- 0X0      |
1033 | --- +    0X0      -----+*   0X  -----------0X0   -|
1034 |-          0XX     ----       0X0 -----------0X0   |
1035 |    -++       XX     --  0     0X0  ---------- X0  |
1036 |- -  ----  -- - XX -    XX0      00  ---------- XX0|
1037 |    ---      -   0X0  00X00    ++++0 ----------- X0|
1038 |--  --            0**XXXX00 ++  +==+X0 - ------- 0X|
1039 | ------ -  --      0X**XX00     +===+0X    ------ X|
1040 |--------           0000*XXX0+++=====+ 0X0    --- 0X|
1041 |- ------          000  XXX00+=======++  0X0  + 0XX0|
      |    |    |    |    |    |    |    |    |    |    |
      2820|2825|2830|2835|2840|2845|2850|2855|2860|2865|2870|
```

Creek	X
River	*
Creek shore	O
Urbanized land	+
Open land	-
Unclassified	blank

FIGURE 2-10

CLUSTER ANALYSIS MAP FOR CONODOGUINET CREEK AREA increased to overcome the effect of the decreased uniformity. The 7.5' maps were used in target identification to make sure that all subareas included in a training area were of the same target.

Having obtained these additional signatures, the whole area from both subsets was mapped. Ten to 15 percent of the whole area remained unclassified but the patterns of unclassified elements appeared to be related to some kind of nonurban land use, possibly agriculture. One of the areas by chance fell within the boundaries of the cluster analysis area used for the determination of the creek signature. The cluster analysis had classified the area homogeneously and the pattern matched the pattern of the unclassified area on the large map. The signature for the target named "open land" was taken from that run. It appears as the - symbol in Figure 2-10.

It was believed that heavy construction of a power plant was taking place on Three Mile Island. Three Mile Island is mapped on the 1963 Middletown 7.5' quadrangle as open land, but initial processing indicated that the area is now something other than open land. A cluster analysis was run on the whole island and surrounding water area which resulted in a signature for a target named "building." This signature, in addition to yielding a classification for Three Mile Island, filled in substantial areas in the Harrisburg metropolitan district which had been previously unclassified. From the 7.5' maps, the area appeared to be a heavy industrial and warehouse area.

The final maps produced in the project were based on the set of eleven signatures and have only three to four percent of the total area unclassified. The full set of signatures, names, and symbols are given in Table 2-10.

The Euclidean distances of separation of categories are given in Table 2-11. In general, the separation between pairs of categories is large. A number of notable exceptions exist however, and these are discussed later. A critical distance of 10 was used for every class except for river water which had a value of 15 assigned to it. In the classification scheme an element was assigned to the class for which the Euclidean distance from it to the class signature was smallest if the distance was smaller than the critical distance for the class. If the distance was greater than the critical distance, the classification would be attempted for the next nearest class and so on. If the element could not be assigned to any class under these rules, it was assigned to the "other" category which is used in this report synonymously with "unclassified." Consider the river water, for example. The distance of separation from each of the other categories is, in every case, greater than 15. Therefore, there is no chance of confusion between river water and any other category according to the rules of classification. There are a few other categories for which the same is true based on a critical value of 10. For most of the classes, there exist a few distances which indicate potential confusion. Consider classes 2 and 5 of Table 2-11, rail and urban 1 respectively. The distance of separation between these two classes is only 2.3; therefore, there is a potential for confusion between the two classes. The rest of

TABLE 2-10

CATEGORY SPECIFICATIONS FOR MAPPING CATEGORIES

CATEGORY NAME	NUMBER	SYMBOL	LIMIT
FOREST1	1		10.0
RAIL1	2		10.0
RIVER1	3	W	15.0
GRASS1	4		10.0
URBAN1	5	*	10.0
GRASS2	6	-	10.0
FOREST2	7		10.0
ROOF	8	V	10.0
SUBURB1	9	#	10.0
HIGHWAY	10	@	10.0
CREEK	11		10.0
OPEN LAND	12		10.0
BUILDING	13	+	10.0

UN-NORMALIZED CATEGORY SPECIFICATIONS

CHANNELS-		1	2	3	4
1		29.28	18.76	46.68	27.60
2		37.00	29.45	29.09	10.91
3	W	33.18	22.48	17.76	4.78
4		31.78	21.61	41.06	22.00
5	*	36.13	28.25	29.71	12.58
6	-	32.83	22.83	43.79	22.50
7		28.25	18.21	49.54	29.82
8	V	52.50	55.00	56.00	22.00
9	#	38.74	31.88	48.01	23.88
10	@	40.59	36.50	51.95	25.59
11		33.30	23.52	31.04	13.48
12		33.40	22.74	61.00	35.23
13	+	42.42	37.58	39.20	15.90

TABLE 2-11

SEPARATION DISTANCES FOR MAPPING CATEGORIES

DISTANCES OF SEPARATION FOR CATEGORIES

		1	2	3 W	4	5 *	6 -	7	8 V	9 #	10 @	11	12	13 +
1		0.0	27.6	37.2	8.8	25.5	8.0	3.8	44.4	16.7	21.8	22.0	17.2	26.8
2		27.6	0.0	15.1	18.8	2.3	20.3	31.3	41.7	23.1	28.3	7.7	40.8	14.9
3	W	37.2	15.1	0.0	29.0	15.7	31.5	41.0	56.5	37.4	43.1	15.9	52.9	29.9
4		8.8	18.8	29.0	0.0	16.7	3.2	12.5	42.0	14.3	20.8	13.4	24.0	20.2
5	*	25.5	2.3	15.7	16.7	0.0	18.4	29.2	42.0	22.0	27.4	5.7	39.1	15.1
6	-	8.0	20.3	31.5	3.2	18.4	0.0	11.4	39.6	11.7	18.0	15.6	21.4	19.3
7		3.8	31.3	41.0	12.5	29.2	11.4	0.0	45.2	18.3	22.6	25.7	14.4	29.6
8	V	44.4	41.7	56.5	42.0	42.0	39.6	45.2	0.0	28.1	22.7	45.3	40.1	26.9
9	#	16.7	23.1	37.4	14.3	22.0	11.7	18.3	28.1	0.0	6.6	22.3	20.2	13.7
10	@	21.8	28.3	43.1	20.8	27.4	18.0	22.6	22.7	6.6	0.0	28.4	20.4	16.2
11		22.0	7.7	15.9	13.4	5.7	15.6	25.7	45.3	22.3	28.4	0.0	37.0	18.8
12		17.2	40.8	52.9	24.0	39.1	21.4	14.4	40.1	20.2	20.4	37.0	0.0	33.9
13	+	26.8	14.9	29.9	20.2	15.1	19.3	29.6	26.9	13.7	16.2	18.8	33.9	0.0

Table 2-11 can be interpreted in the way of the above discussion. Three other pairs of classes have small distances of separation which should be mentioned. In addition to the aforementioned problem with the railway signature, it also has a relatively small distance of separation from the creek signature. Whether confusion actually exists or not in classifying rail and creek targets can only be resolved by ground truth. However, there appears to be some confusion of these two targets in the various railway yards, but it is possible that there might be enough sediment, low vegetation, and water in the yards to give a true response for the creek classification. However, because the main purpose of this stage of the test was to determine what degree of classification could be achieved by digital interpretation alone, no attempt was made at this time to verify the classification with better ground truth.

The two other pairs of categories with small separation distances are creek with urban 1 and highway with suburb 1. The reason for the similarity of creek and urban 1 signatures is not known. The similarity of highway and suburb 1 signatures was not unexpected because the initial highway signature was renamed suburb 1 when it gave very good mapping results for suburban areas. The new highway signature was obtained later on and may indeed have been based on very similar targets to the suburb 1 signature. It seems though that the new highway signature is more related to parking lots and similar paved and unpaved areas than it is to the suburb 1 signature. Actual highways are mapped by both symbols.

A number of the vegetation classes are close but, for the present purposes, confusion among these classes is not of particular importance.

With regard to naming the categories, some serious problems exist. Some of the categories are easily named, such as river water and the forest categories. The investigators do not put a great deal of emphasis on the names of other categories because they were named only inferentially with no direct means of being sure of the targets. It is not a simple matter to pick out vegetation signatures in ERTS data simply by looking at the signatures. It is even more difficult to identify other signatures. The 7.5' maps are of limited utility since they do not generally give the kind of information needed to identify a category except on an inferential basis. Ground truth or aerial photographs would likely have been very helpful in specifically identifying and naming the targets, but as noted this portion of the test was on strictly digital interpretation.

Four maps resulting from this effort are shown in Figures 2-11 through 2-14. All four have resulted from the classification scheme described previously. A small part of a typical map is shown in Figure 2-15. The river and islands in the river are readily apparent. The central metropolitan area of Harrisburg, mapped with *'s, can be seen in the upper right portion of the figure. Heavy industrial and warehouse areas, mapped with +'s, can be seen adjoining the downtown area of Harrisburg. Across the river, the Camp Hill urban area, can be seen mapped with #'s. The @'s in Camp Hill possibly indicate parking lots or bare ground, whereas the -'s indicate parks, cemeteries,

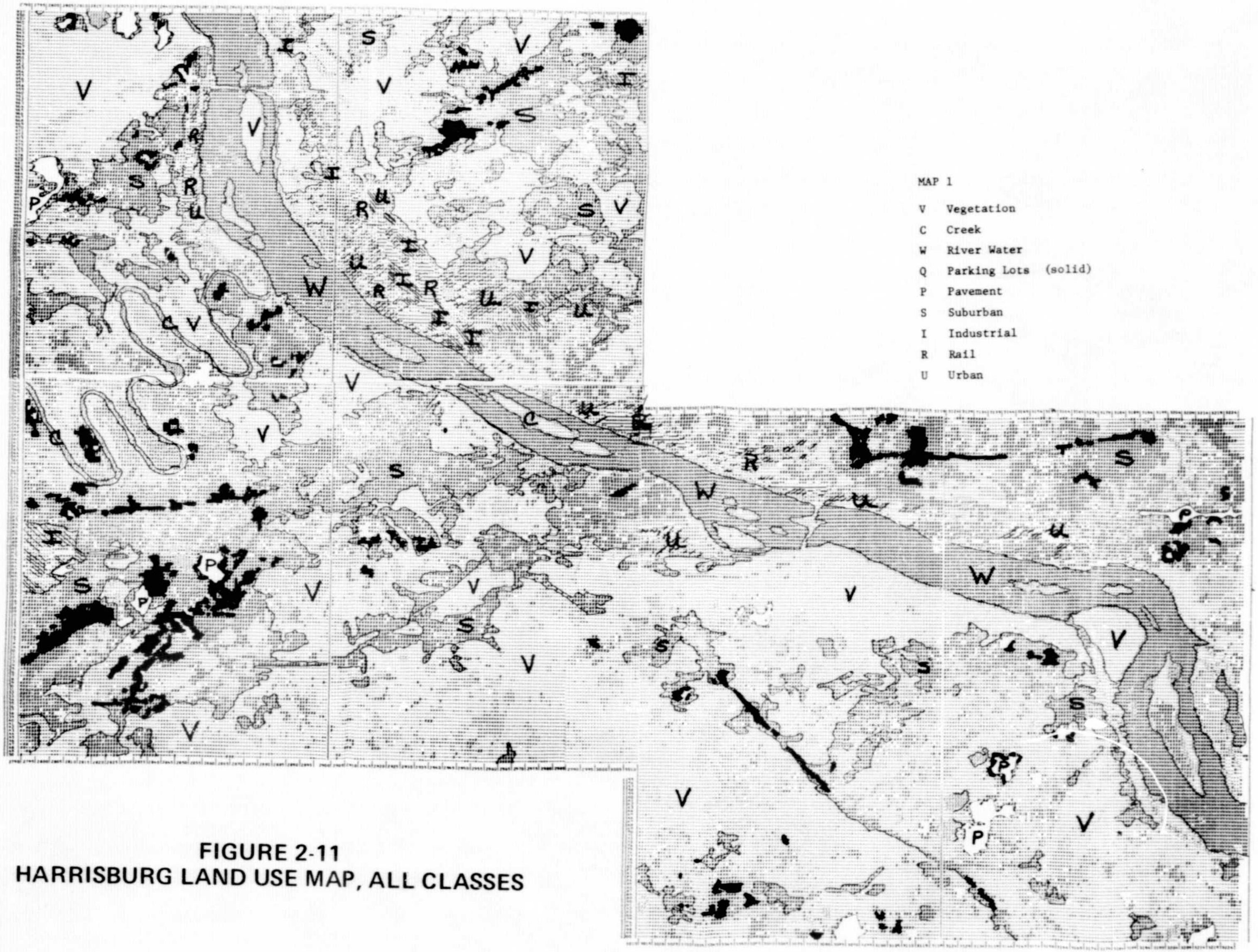


FIGURE 2-11
HARRISBURG LAND USE MAP, ALL CLASSES

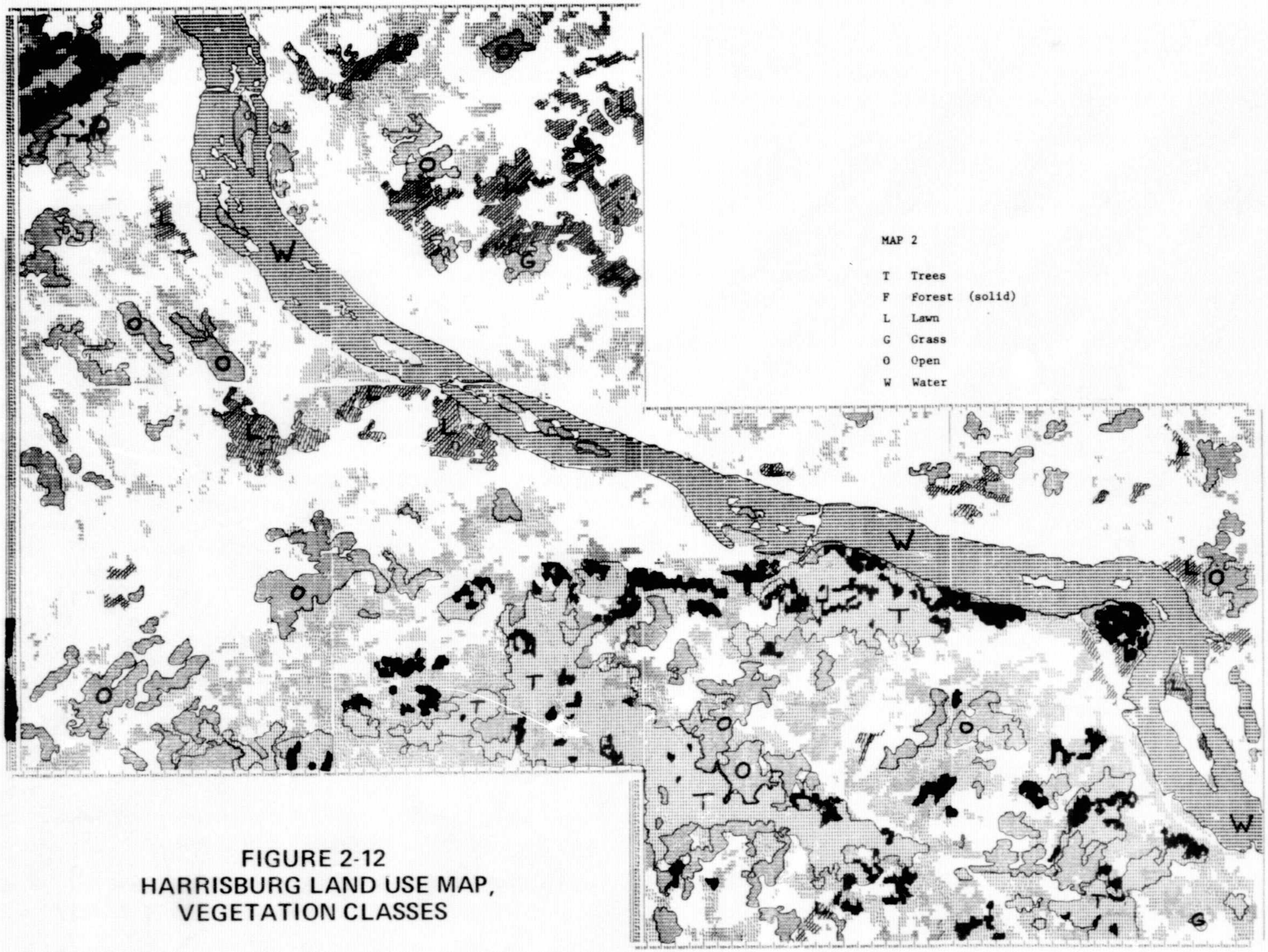


FIGURE 2-12
HARRISBURG LAND USE MAP,
VEGETATION CLASSES

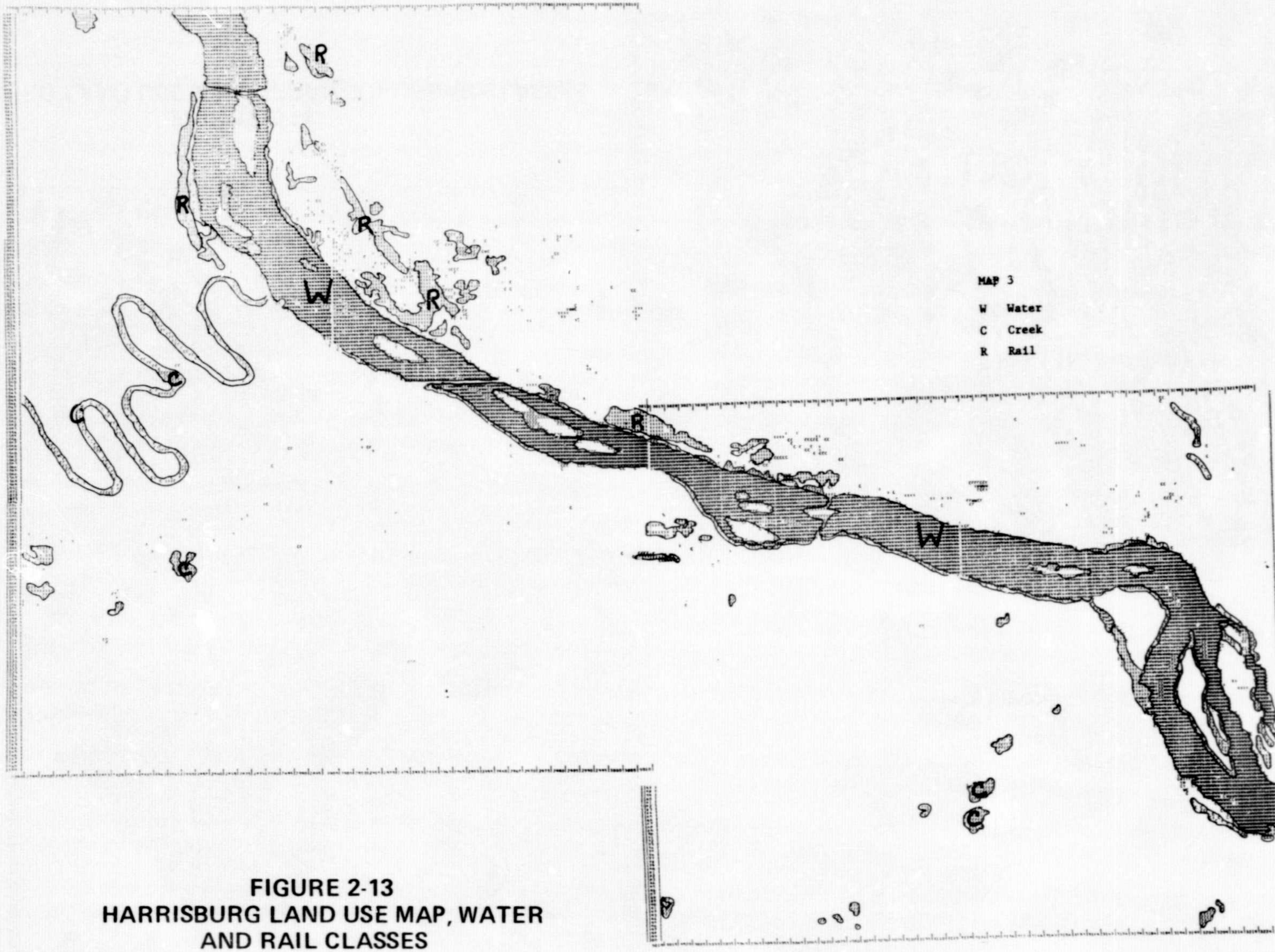


FIGURE 2-13
HARRISBURG LAND USE MAP, WATER
AND RAIL CLASSES

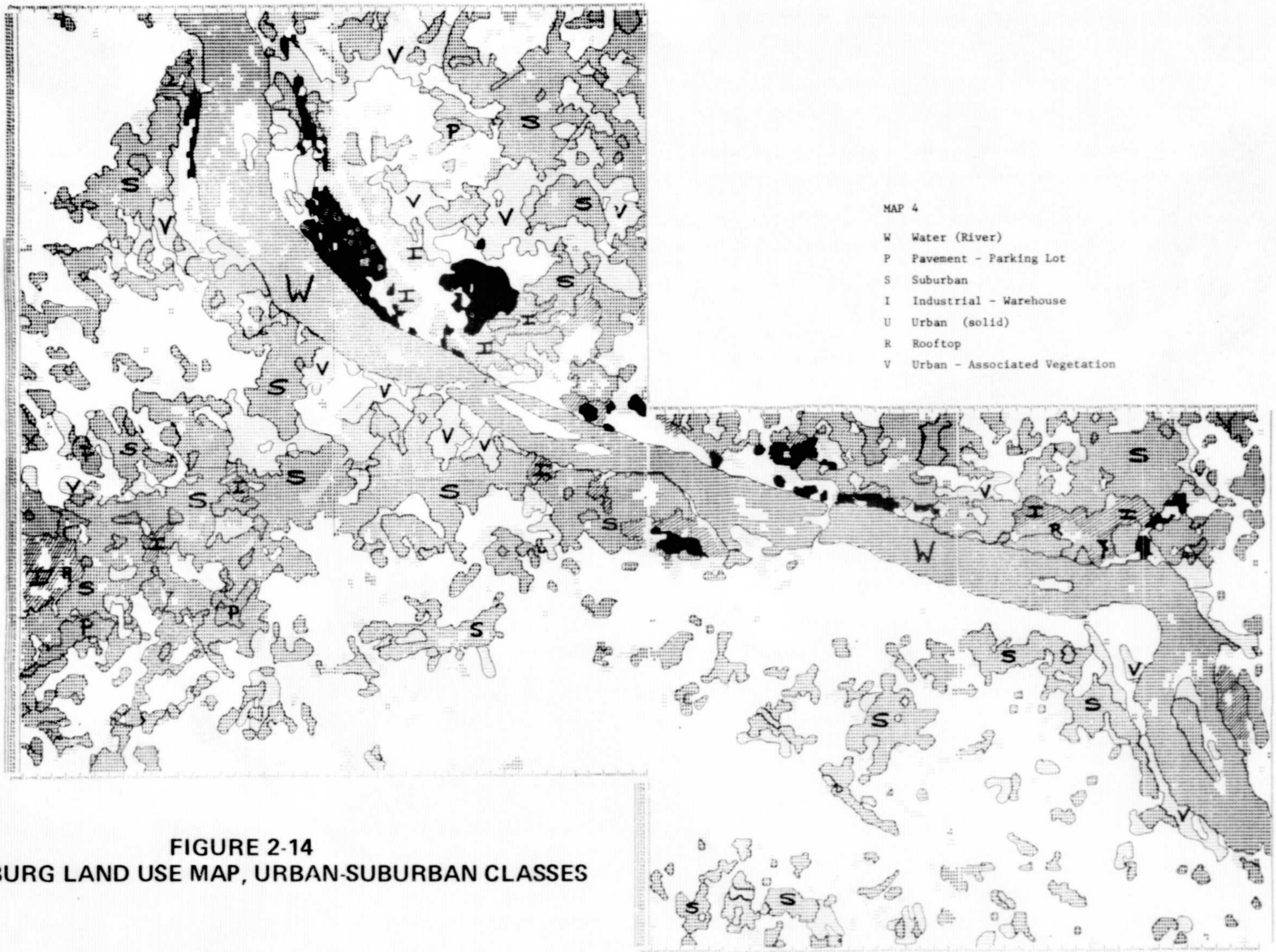
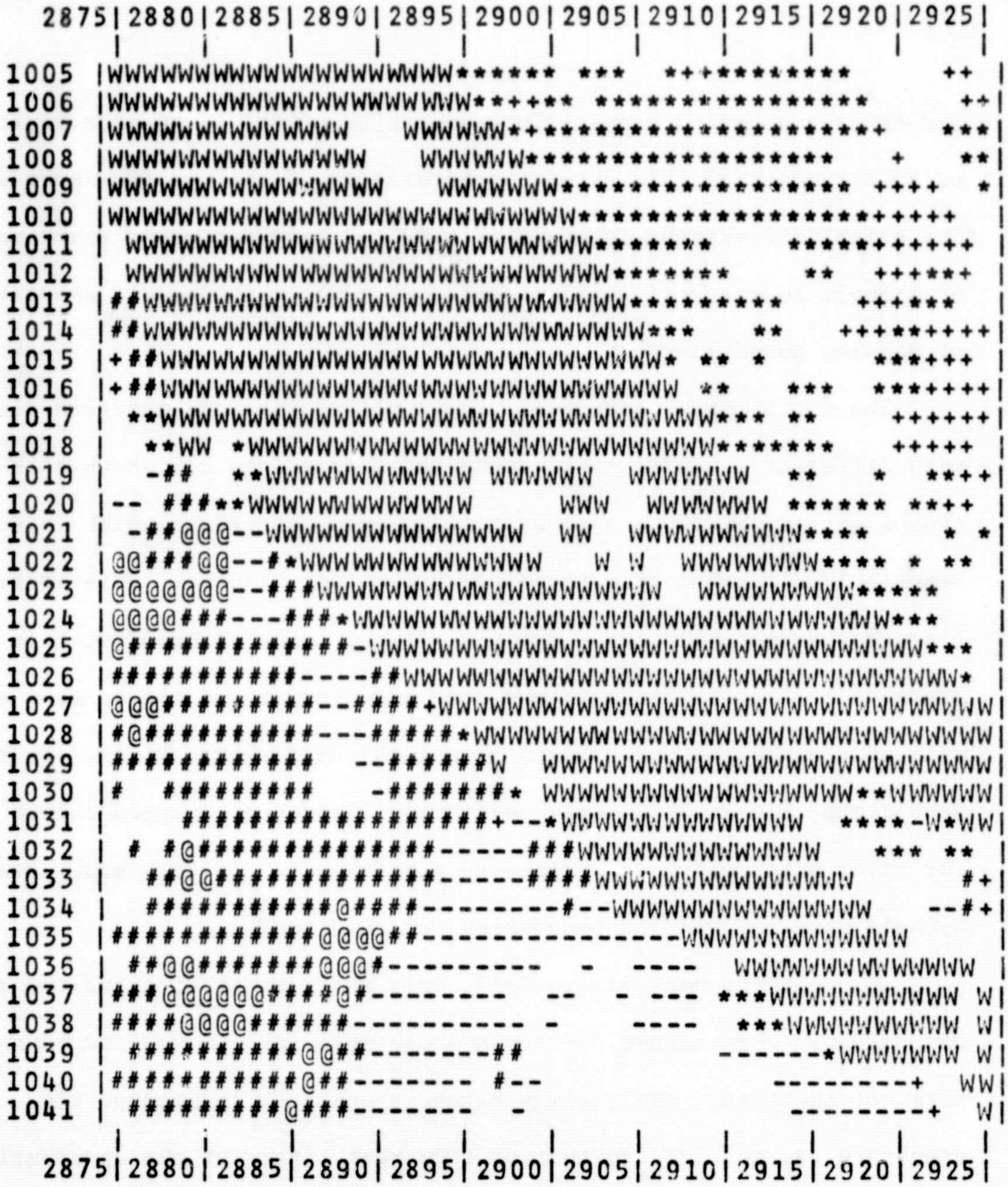


FIGURE 2-14
HARRISBURG LAND USE MAP, URBAN-SUBURBAN CLASSES



Central urban areas *
Suburban areas #
Paved areas @
Industrial and warehouse areas +
River water W
Herbaceous vegetation -

FIGURE 2-15

MAP OF SIX CATEGORIES IN THE HARRISBURG VICINITY and other such green areas. Interpretation of the large maps would be an extension of this brief interpretation of the map in Figure 2-15. The slight differences in the maps resulted from different assignment of symbols to categories, elimination of stray symbols, and smoothing of mapping boundaries.

The first map, Figure 2-11, shows all of the nonvegetation classes with different symbols. The vegetation classes are all shown with the - symbol except for the one vegetation or open area class which is substantially different from the other vegetation classes. This atypical class was mapped with the = symbol. It should be pointed out that the trace of interstate highways and some secondary roads can be seen as well as a number of the bridges across the Susquehanna River. In the second map, Figure 2-12, only vegetation classes are mapped except for river water which was mapped as a reference. In this map, stray symbols were removed and boundaries were smoothed.

In the third map, Figure 2-13, only water categories and the railway category were mapped. Stray symbols were not removed and boundaries were not smoothed. The railway category was left in because its signature was so close to that of the creek. Many of the apparently stray symbols are indeed true according to the 7.5' maps.

The last map, Figure 2-14, consists of only symbols for developed nonagricultural land. Railway symbols have been suppressed and river water was mapped as a reference.

The summary of the mapping results for each subset is given in

Table 2-12. The percentage in each category is the relative acreage in the category. The count for each category is the actual number of pixels classified in the category. The conversion factor to acreage is approximately 1.12 acres/pixel based on the distance of separation between pixels in a line and between lines.

The results of this MSS digital analysis test run ERTS-1 data can be translated to maps using only USGS maps for reference. Such maps agree quite well in general (thematically - not geometrically) with the USGS maps except that the fine detail of the USGS maps cannot be achieved with ERTS-1 data. The ERTS-data-based maps indicate that more meaningful land use categories can be mapped than that which are available from USGS maps. In addition, the limitations of the USGS maps for this type of analysis is demonstrated. The land use portion of USGS maps are obsolete in many areas even over the short period of time from the 1969 publication dates because of the dynamics of land use change in metropolitan areas. The 1963 dates maps are of very limited utility in areas where rapid transitions in land use are in evidence. Because USGS maps are not meant to provide current detailed land use information, the use of these maps alone to support ERTS-data-based mapping is inadvisable. More up-to-date under-flight aircraft photography or imagery is one needed basis of support for interpretation and mapping of ERTS data. In addition to this support, the necessity for timely ground truth to resolve anomalies should be anticipated.

TABLE 2-12

SUMMARY OF CLASSIFICATION RESULTS FOR SUBSET ONE AND TWO

Subset One

SUMMARY

CATEGORY NAME	NUMBER	SYMBOL	LIMIT	COUNT	PER CENT
FOREST1	1		10.0	3655.	8.
RAIL1	2		10.0	887.	2.
RIVER1	3	W	15.0	2956.	6.
GRASS1	4		10.0	1249.	3.
URBAN1	5	*	10.0	1622.	3.
GRASS2	6	-	10.0	6844.	14.
FOREST2	7		10.0	5329.	11.
ROOF	8	V	10.0	130.	0.
SUBURB1	9	#	10.0	11796.	25.
HIGHWAY	10	@	10.0	2738.	6.
CREEK	11		10.0	1119.	2.
OPEN LAND	12		10.0	5303.	11.
BUILDING	13	+	10.0	2241.	5.
OTHER	14		0.0	1425.	3.

Subset Two

SUMMARY

CATEGORY NAME	NUMBER	SYMBOL	LIMIT	COUNT	PER CENT
FOREST1	1		10.0	3335.	10.
RAIL1	2		10.0	554.	2.
RIVER1	3	W	15.0	3735.	11.
GRASS1	4		10.0	659.	2.
URBAN1	5	*	10.0	631.	2.
GRASS2	6	-	10.0	3279.	10.
FOREST2	7		10.0	5494.	17.
ROOF	8	V	10.0	117.	0.
SUBURB1	9	#	10.0	16076.	18.
HIGHWAY	10	@	10.0	1086.	3.
CREEK	11		10.0	817.	2.
OPEN LAND	12		10.0	4795.	15.
BUILDING	13	+	10.0	847.	3.
OTHER	14		0.0	1425.	4.

2.1.4.3 Complementary Imagery/Digital Analysis Test Run. Having attempted to demonstrate the possibilities of ERTS MSS data analysis first by photo interpretation alone, and then by digital analysis alone, MITRE then directed its subcontractors to implement the next logical step which was to combine the two techniques. The MSS complementary imagery/digital analysis test run was the final step in MSS implementation. Since complementary analysis has become generally the standard operating procedure now for land use and water quality, the results achieved during the MSS implementation stage of Phase I should be considered preliminary. (Throughout Phase II, a number of refinements and improvements, have been made with more MSS data becoming available, as noted in Sections 2.2 and 2.3).

For the MSS implementation stage, the 1 August 1972 MSS data tapes were once again employed. The first joint efforts involved a comparative analysis of land use classifications prepared by the separate photo interpretation and digital mapping teams. Initial joint studies involved the use of a Bausch & Lomb Zoom Stereoscope to study infrared color film transparencies taken from U-2 aircraft flying at 65,000 feet in conjunction with computer generated maps. The camera had a 1.75 inch focal length, producing 70 mm format at a contact scale of 1:445,000 (approximatley 1 in. = 7 miles).

The time-consuming nature of comparing the separate photographic image with the computer produced thematic maps quickly forced an attempt to project the photograph directly onto a computer map. This was successfully accomplished with reasonable scale comparison, using an

American Optical Company slide projector, Model D (Delineascope with 8 inch focal length lens and 500 watt illumination).

Because of the distorted nature of the computer map, caused by line and character per inch constraints, only small portions of the projected image could be brought into registry at one time. Clearly identifiable images of a unique nature were used to make these scale adjustments. The projector was mounted on a platform so that the image could be rotated about the projection axis and small adjustments in x and y translation of the photo image could easily be made. Overall scale was adjusted by the projector-to-screen distance.

Obvious targets, such as the Susquehanna River, its islands, and entering major streams were successfully identified. Small ponds, which registered only by single pixels, were properly classified. Some large cultural features, such as parking lots and rail yards, were identified in correct geographic location, but the exact limits of their boundaries were not fully satisfactory. Some vegetative classes were well identified, while others needed improvement. Several agricultural signatures were properly positioned, while others were confused with the signature generated for suburban areas.

A system of directly marking on the computer generated thematic map was used to outline areas for further study for signature improvement. These areas were defined by scan line and element numbers. Further statistical analysis was performed on signatures in these areas. The results were, however, not satisfactory.

It was recognized that the signatures used to create this first series of maps were the result of computer mapping with only USGS 1:24,000 maps as a guide. Some of the signatures were "backed into," rather than determined by the direct approach of benchmark targets selected by photo interpretation. There seemed to be a case for a general attenuation of the quality of information recorded in channels 4, 5, and 6 for this scene, and records showed that channel 7 was distinctly of poor quality. Therefore, when the second run computer processing of signatures was unsatisfactory, it was decided to realign the approach.

The attached flow diagram (Figure 2-16) was generated as a means of coordinating the efforts of the computer mapping and the photo interpretation. It is on the basis of this method, and the image and computer tapes of 11 October 1972, of the Harrisburg Test Area (Image number: 1080-15185) that Phase II (preliminary data analysis) has proceeded, with improved complementary MSS imagery/digital analysis emerging as the optimum approach. The Bausch Lomb Zoom Transfer Scope replaced the more cumbersome devices used in Phase I.

2.1.5 Planning to Maintain Currency with ERTS Developments

A last and obvious task of the planning and preparation phase concerned planning to maintain currency with other investigators in the same or related fields. This task was accomplished by two means: a continual review of current literature in the field, and attendance at conferences on remote sensing and the environment.

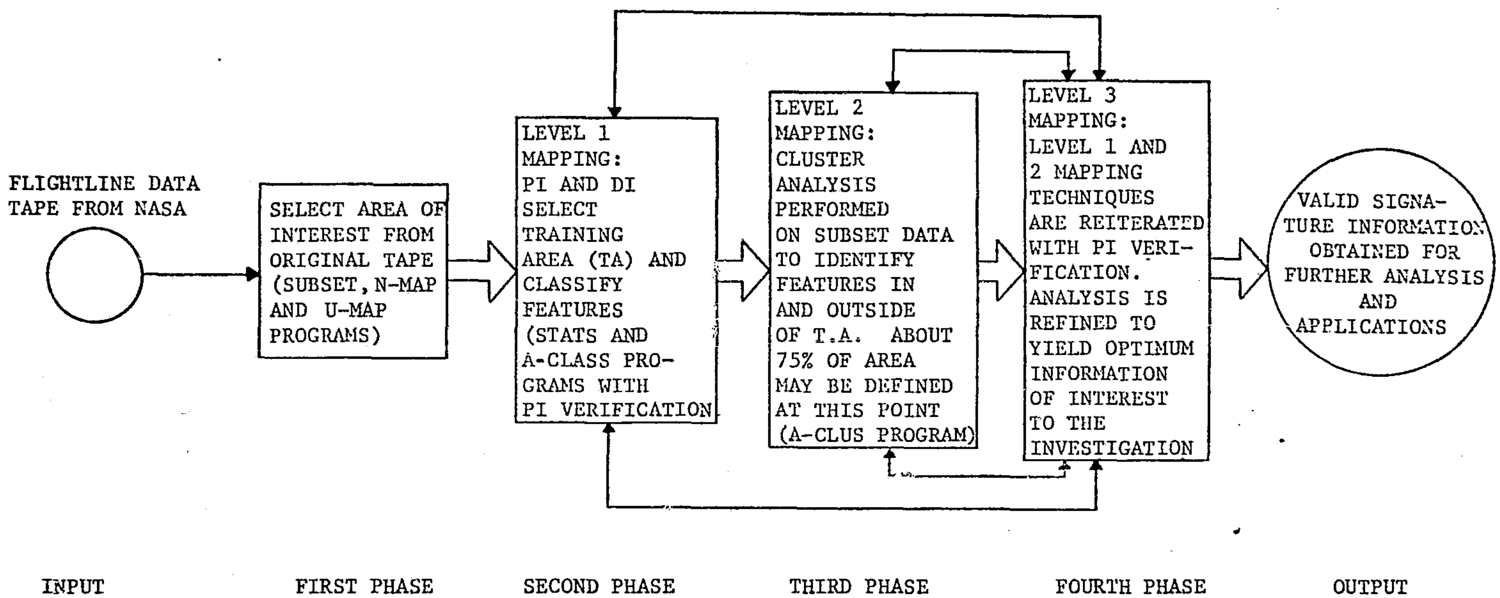


FIGURE 2-16

ERTS MSS DATA ANALYSIS SYSTEM

Note: PI = Photo Interpreter

DI = Digital Interpreter

In addition to the many periodicals on remote sensing, land use, water pollution, air pollution, etc., which were available through the MITRE library facilities, extensive use was made of the National Technical Information Service (NTIS) to obtain recent technical papers in the field. NTIS was especially helpful in rapidly obtaining copies of the Type II reports of other investigators in related fields. This enabled MITRE to maintain the desired currency in ERTS state-of-the-art, and also to solicit from and provide information to investigators at the same stage of development in related investigations.

Even more useful as sources of near real time information in the field were the conferences and symposia which were conducted during the course of the MITRE investigation. Since these conferences often brought together the principal investigators in the area of MITRE's investigation, they offered unique opportunities for interchange of ideas and full discussion of results frequently lacking in formal papers. The following is a list of conferences in which MITRE personnel participated:

- September 1972 - ERTS-1 Symposium on Significant Results (First post launch quick-look symposium at GSFC)
- March 1973 - Symposium on Significant Results Obtained from ERTS-1 (By GSFC. Important progress reported in all fields of investigation. MITRE paper on mesoscale air quality work presented and included in proceedings).
- October 1973 - Conference on Machine Processing of Remotely Sensed Data (By LARS, Purdue U. Important papers on all fields

of ERTS investigation).

- October 1973 - Second Conference on Remote Sensing of the Environment (By EPA at NERC, Las Vegas, Papers on current remote sensing developments in the environmental fields).
- December 1973 - ERTS-1 Symposium on Significant Results Obtained (By GSFC. Many final and near-final reports by investigators).

2.2 Phase II - Preliminary Data Analysis

2.2.1 Phase II - Land Use Preliminary Data Analysis

After successfully using 1 August 1972 MSS data for land use classification during the planning and implementation of Phase I, the land use analysis of Phase II exclusively employed the 11 October 1972 data for the Test Site 1 area. Intensity maps (N-MAP) were produced using 3, 5 and 10 intensity levels. Using the map with 10 levels, MITRE found that major geographical features (rivers, creeks, islands) and some highways could be identified. Additional areas were located by projecting recent NASA provided U-2 photography (26 July 1972 overflight of Harrisburg) on the intensity maps.

Next uniformity maps (U-MAP) were run. Only large uniform areas were chosen as target areas. Not all areas could be named since they were not near any major geographical features. These areas were then named X_1 through X_n. A statistical analysis (STATS) was then run on these target areas and signatures were developed.

In parallel the photo interpreter had chosen areas from the U-2 photographs that were thought to be good training areas. The unsupervised classification program (D-CLUS) or cluster analysis was run on these areas. Such areas included runway, quarry and many other small targets.

Once signatures were developed for all categories a process of condensing signatures began. Classes were condensed by producing distance of separation tables from the classification program D-CLASS. The rules to condense signatures became: combine any signature whose distance of separation is less than 1.0 providing (a) they are of the same type (i.e., forest with forest, but not forest with field) or (b) one or both is an unknown class (X_1 through X_n). Signatures were combined in all cases by taking a weighted mean. Some cases occurred where one signature X was close to signature Y, Y was close to signature Z, but X and Z were not close enough to be combined. A subset table of distance of separation was constructed for these signatures and they were combined as closely as possible.

Confusion seemed to arise especially around the Condoguinet Creek area between suburban and field, and in Harrisburg with the railroad and industrial signatures. These could not be resolved at this time and the areas were assigned confusion symbols for mapping.

As a result of these manipulations, 56 land use signatures remained. It was clear that many still described the same land use features. Consequently, artificially different categories were merged by assigning the same symbol for mapping. The final classification map was not produced before Phase II ended.

2.2.2 Phase II - Water Quality Preliminary Data Analysis

Several attempts were made to identify water quality parameters through complementary MSS imagery/digital analysis. ERTS-1 MSS data for both 1 August 1972 and 11 October 1972 were processed and analyzed for the Harrisburg Test Site. However even with supplementary data from recent high-altitude aircraft over-flights of the area, all efforts to classify gradations in water quality were unsuccessful. It was concluded that the Susquehanna River in the vicinity of Harrisburg presented too heterogeneous a target to serve as a useful training area for ERTS-1 water quality investigation. The shallowness of the river at that point and the abundant presence of rock outcroppings, islands, and vegetation added to analysis difficulties. It was agreed that a more suitable training area would have to be located if this stage of the water quality investigation were to progress.

Imagery one frame removed from the test area for 11 October (1080-15192) showing the general Washington-Baltimore area appeared to be more suitable. A color composite of the scene clearly shows a large turbid plume on the Potomac River originating north of Washington and dissipating south of Quantico, Virginia with several gradations of turbidity apparent in the imagery. Although this training area was not actually in MITRE's test area, it was felt that analysis of this frame showing extreme turbidity would be very useful as a training device for later analysis of water quality in the Harrisburg test site. (Verbal approval to move this test area was received from the NASA Technical Monitors). In

In addition, the Washington-Baltimore frame shows a less distinct plume at the mouth of the Susquehanna in Chesapeake Bay. Once parameter identification was successful in the training area, analysis could move to the Susquehanna mouth; and then proceed upstream to water quality targets such as the Holtwood, Conowingo and Safe Harbor Dams and the Brunner Island effluent all in MITRE's Test Site 1.

The first intensity map (N-MAP) of the area showed several types of water within the boundaries of the Potomac, especially around Quantico, and this was chosen as the training area for developing signatures of water quality. A cluster analysis (D-CLUS) was run using a sample size of 150 pixels and a critical distance of 4.5. The resulting map, Figure 2-17, displays the levels of turbidity from IV (high turbidity) to I (clearest water).

With the success that was encountered at Quantico, it was decided to investigate other areas along the Potomac where the plume could be seen in the imagery. In particular the following were selected:

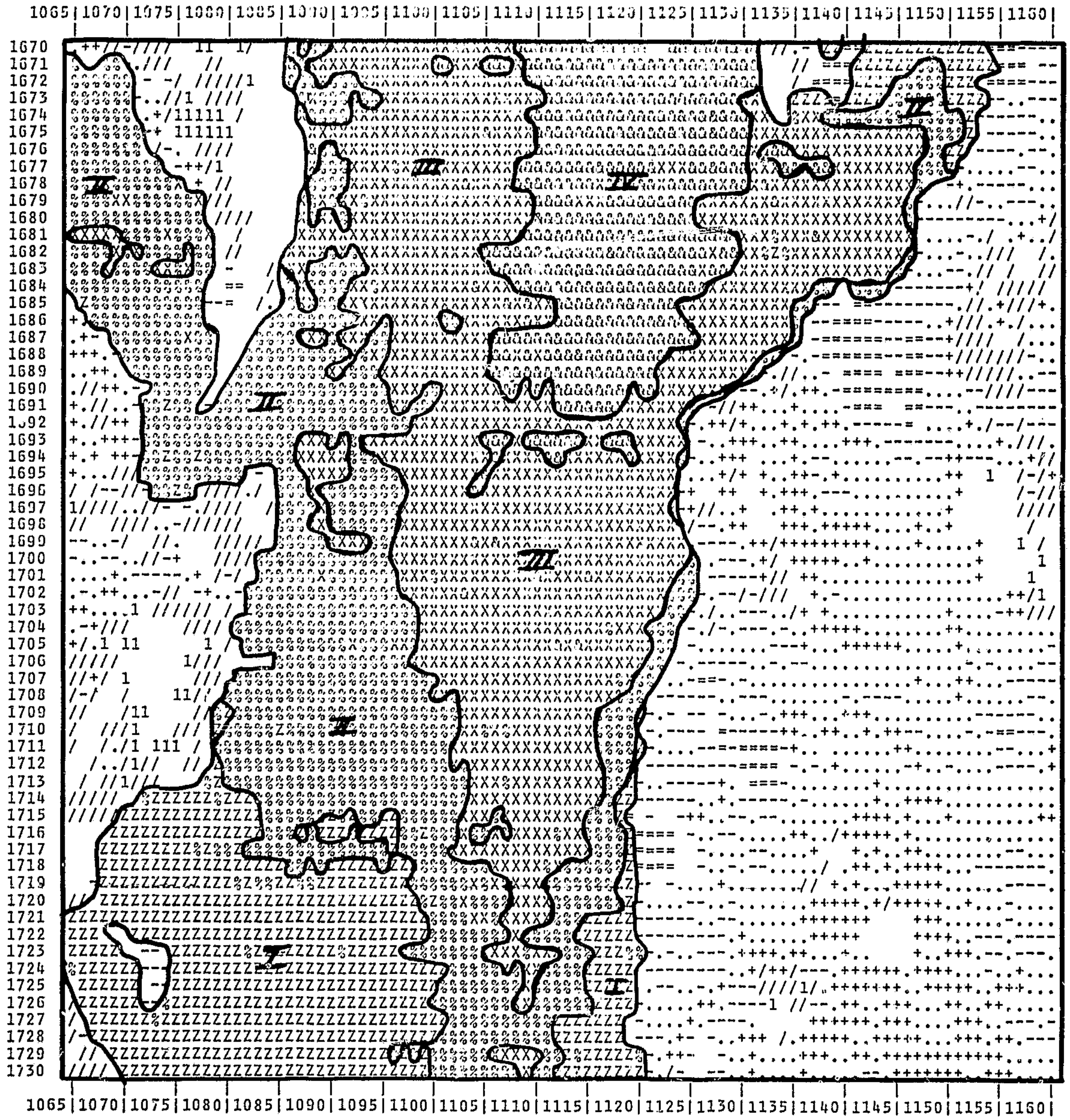


FIGURE 2-17
QUANTICO WATER QUALITY—FOUR LEVELS
11 OCTOBER 1972

TABLE 2-13

SELECTED POTOMAC RIVER TRAINING AREA

TRAINING AREA	RIVER MILE
Popes Creek	42.0
Cedar Point	49.0
Maryland Point	56.4
Clifton Beach	61.7
Quantico	67.5
Mason Neck	79.0
Fort Hunt	86.0
Wilson Bridge	90.8
Hains Point	94.7

Using the supervised classification program MITRE applied the signatures obtained from the Quantico analysis to Clifton Beach and Maryland Point. At both points, however, only a single water category could be identified though these new sights were less than 12 miles down stream. Since this contradicted what could be seen from the images it was decided to change the limiting parameters of the cluster analysis of Quantico and develop new signatures.

With the critical distance reduced to 1.0 and the sample size expanded to include 900 pixels, six categories of water were identified at Quantico this time. Figure 2-18 shows the breakdown with VI representing the most turbid, decreasing to level I which is again the clearest water. Despite this refinement of signatures, the application of these signatures to Clifton Beach and Maryland Point less than 12 miles away

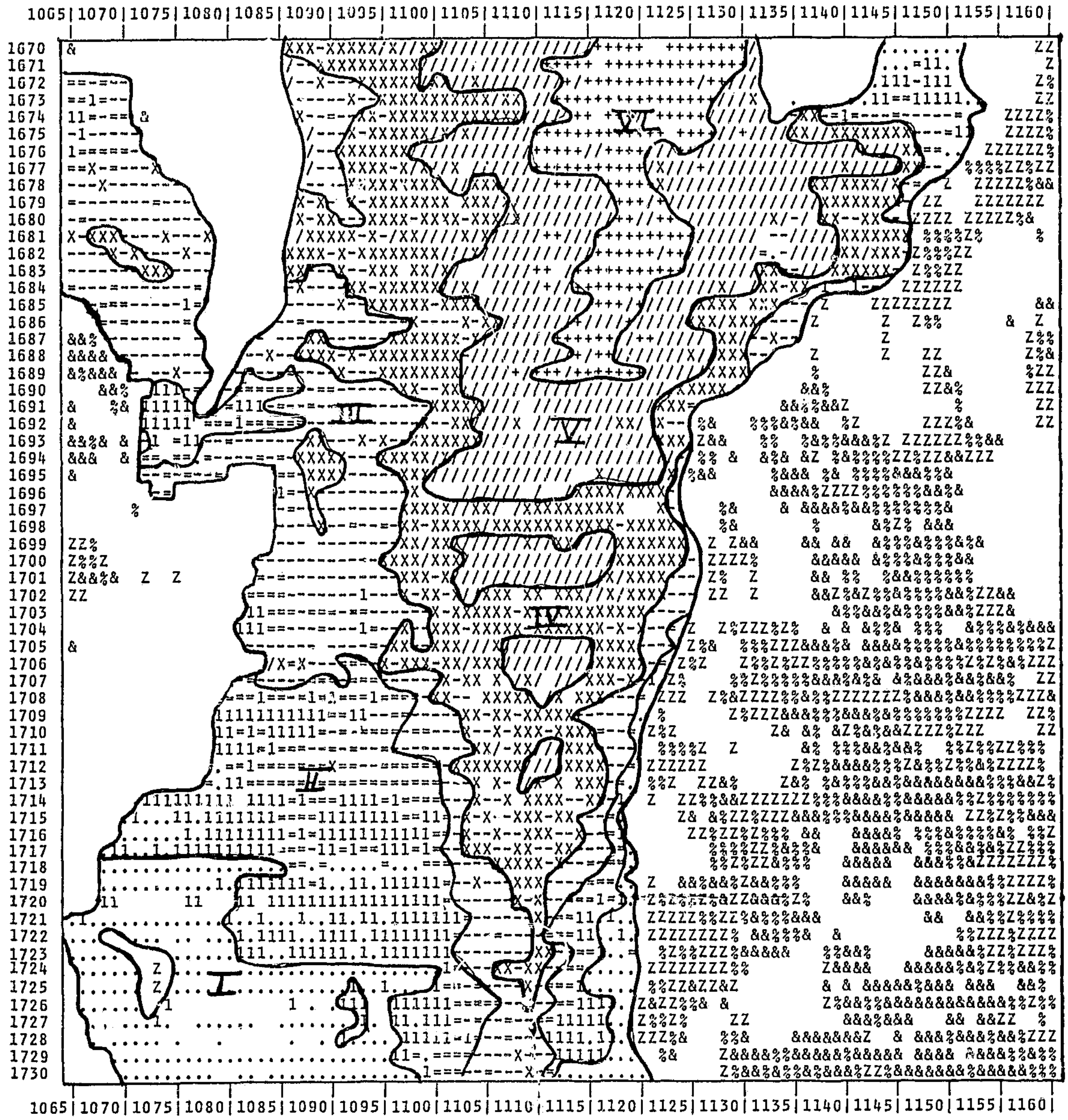


FIGURE 2-18
QUANTICO WATER QUALITY—SIX LEVELS
11 OCTOBER 1972

still resulted in the classification of just one water category.

The next attempt to solve this anomaly was to vary the MSS channels that would supply input for the programs. It is generally held that channels 4 and 5 are better for water investigation, so a cluster analysis for Quantico was run for channel 4 alone and for channels 4 and 5. The results when applied to Clifton Beach were the same as above, i.e., only one level where several levels could be seen in the MSS image. At this point the ERTS image was rechecked at Clifton Beach as was the original 4-channel intensity map of the Potomac scene. It was found that the gradations of water seen on the image were evident on the intensity map at Quantico but not at Clifton Beach. Therefore, separate MSS channel intensity maps of Clifton Beach were run to see if the turbidity would show up in the smaller population. Figures 2-19 are 2-20 and MSS channels 4 and 6 respectively.

Analysis of these maps showed a horizontal (east-west) pattern every sixth vertical (north-south) line down the image. A closer study of the maps pointed to the possibility that the poor results were due to this every sixth line striping. A cross-ckeck with the images, this time looking specifically for striping, proved this to be quite evident in each channel and throughout each image. Since the striping intensity changes were of the same order as the turbidity is the east-west direction the striping had to be eliminated.

In order to overcome the problem, the suspect lines were discarded using the separate channel intensity maps (those indicated by a dot (•))

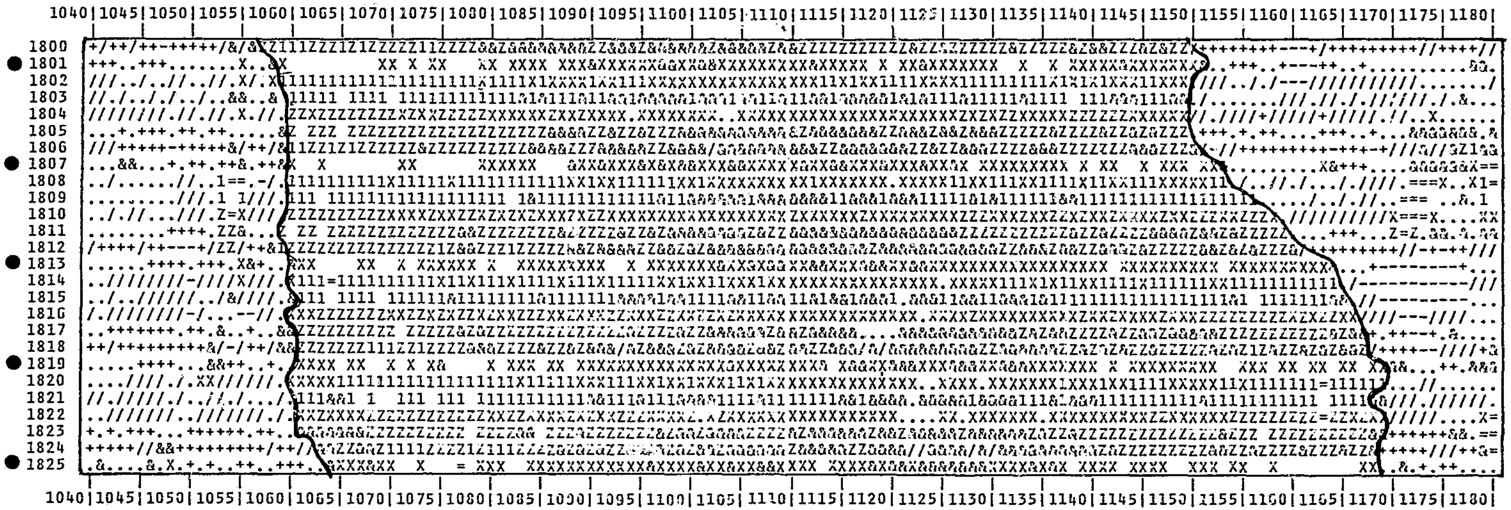


FIGURE 2-19
CLIFTON BEACH CHANNEL 4
INTENSITY MAP WITH STRIPING

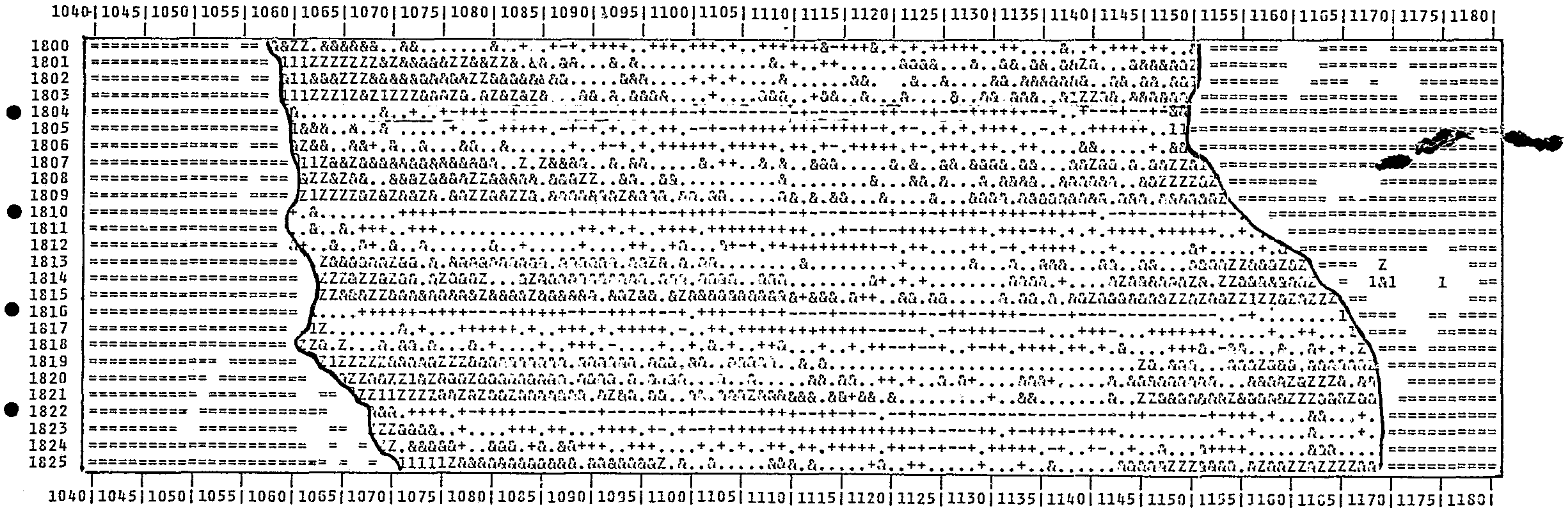


FIGURE 2-20
CLIFTON BEACH CHANNEL 6
INTENSITY MAP WITH STRIPING

in Figures 2-19 and 2-20. The intensity program was then rerun on the reduced population. This produced a small improvement in the map with two categories of water being identified. However, the improvement was overshadowed by the fact that each of the four channels had striping in a different set of lines. Therefore, three out of every five lines had to be eliminated if all four channels were to be used for the analysis. This method, therefore, proved to be completely impractical because much of the turbidity information was also being discarded.

At this point a check was made with NDPF User Services, Mr. Robert Feinberg. Mr. Feinberg knew of software that was being developed by GE to correct the striping and he agreed to have MITRE's tapes reprocessed. It was decided that both the Potomac scene (1080-15192) and the Harrisburg, Pennsylvania area (1080-15185) would be redone; the latter being our prime test area for water quality and land use.

While the reprocessing was being done, it was decided to run separate MSS channel intensity maps of Quantico. The purpose was to develop signatures from the reduced population which could be compared to signatures from the tapes with striping and the corrected tapes. However, the same problem that arose with Clifton Beach was encountered, that is losing too much of the population for the results to be considered worthwhile. It was decided to wait for the corrected tapes before any other analysis for water would be done.

MITRE realized that it was striping that was overshadowing the data on 21 March 1973. The decision to stop the water analysis came on

26 March 1973 after consultation with Mr. Feinberg at GSFC. The corrected tapes were received on 7 May 1973. The first intensity maps that were run, however, showed no distinction between land and water. Mr. Feinberg was again contacted and on 14 May 1973 MITRE received acknowledgement that the tapes had been processed incorrectly and that they had to be redone. Shortly after this, a discussion was held with Mr. Saul Portner and Mr. Paul Heffner of GE to discuss the exact nature of our problem. It was decided that a third set of input tapes should be generated as GSFC and these were received by 15 June 1973.

By the time the corrected tapes were received MITRE's air quality and land use analysis were in their final stage, i.e., Phase III. However, the water quality analysis was stalled in Phase II waiting for the tapes without striping. Also, it must be appreciated, all results in this report on land use and air quality for 1 August 1972, 11 October 1973, and 9 January 1973 must be considered suspect, because the software fix applied to input tapes by GSFC to remove the sixth link striping did not become operational until April 1973[1].

2.2.3 Phase II - Air Quality Preliminary Data Analysis

The Phase II air quality analysis proceeded at two levels: (1) determine what ERTS could detect in microscale analysis and (2) mesoscale analysis, respectively. The microscale analysis was to detect point sources of air pollution in the ERTS imagery and develop plume signature information

[1]NASA/GSFC, Generation and Physical Characteristics of the ERTS MSS System Corrected Computer Compatible Tapes, July 1973, p. H-1.

if possible. Because this analysis was performed in conjunction with the analysis of microscale water quality targets, it has been discussed in Section 2.3.4 below. Mesoscale air quality analysis in Phase II was a test of the usefulness of ERTS data in measuring total air pollution burden, or total turbidity, over a given point. The eventual objective would be large areas such as test sites (~100 sq. km.) statewide (1000 sq. km.) and perhaps global monitoring of background air pollution by satellite.

2.2.3.1 Background to the Mesoscale Air Quality Analysis. Over the past decade, new air pollution control legislation and increased surveillance activity at the Federal, state, and local level has resulted in a considerably better understanding of the dynamics of microscale (~50 sq. km.) air pollution burden in urban and industrialized regions. As more and better air quality data for urban areas have become available, many air quality display computer simulations have been attempted. A large number of these simulations follow a semi-deterministic approach where the pollution emissions of an urban area are mathematically modeled both areally and temporally. Transport and diffusion simulations of these emissions are performed taking into account local weather conditions and in some cases terrain. Displays of the air quality resulting from such simulations are then compared with measured in-situ air quality and the models are then fine tuned for more faithful representations of the quantitative value of air quality. Models for handling total particulates (settleable and suspended), oxides of sulfur, carbon monoxide, etc. exist and follow the general simulation procedure described above. Experience with total suspended particulates (TSP) has shown that there is a considerable difference between calculated and measured values in the urban area and that it is largely a constant offset which is called background TSP. This background TSP is found to vary across the United States but is generally on the order of one-half of the annual average urban values monitored. It is this variable background of TSP that the MITRE investigation refers to as the mesoscale air quality.

The coverage of this mesoscale air quality has been far less complete than is the case for microscale air quality, although there has been rising interest in the extent of national and world-wide mesoscale air pollution burden and the effects of its increase and movement on the earth's biosphere. In response to this interest, the National Oceanic and Atmospheric Administration (NOAA) in conjunction with EPA and the U.N. World Meteorological Organization, has in operation a world-wide array of air turbidity measurement sites. Approximately 50 of these sites are located in the United States. Since it was found during Phase I that NOAA could make available the U.S. Turbidity Network data on a timely basis, it was determined that those data would substitute for exact ground truth for investigating the use of ERTS-1 for developing mesoscale air quality indices. A study[1] also made available by NOAA showed an analysis of several years of Turbidity Network data and the relationship of those data to mesoscale weather movements and

---

[1] Flowers, McCormick, and Kurfis "Atmospheric Turbidity over the U.S., 1961-1966" Journal of applied Meteorology, Vol. 8, No. 6, December 1969.

rainfall, as well as variability of turbidity across the nation, which was useful in interpreting the data from the turbidity network.

The initial concept of relating satellite data to a ground data measure of mesoscale air quality derived in part from the work of Clodman and Taggart.[1] Their investigation compared APT pictures from the ESSA 2 satellite with synoptic weather maps and ground observations in an attempt to correlate large hazy air masses on the pictures with days of probable high air pollution. On a number of occasions when no major frontal areas were evident in the eastern U.S. and atmospheric water vapor was negligible, large areas of hazy air were observed in the satellite pictures. After correlation with ground data on ceiling and visibility, the investigators concluded that the satellite pictures were showing mesoscale air pollution covering several states. An objective of the MITRE analysis, based on this conclusion, was to quantify this gross detection of mesoscale air pollution using ERTS and Turbidity Network data.

2.2.3.2 Mesoscale Air Quality Experiment Design. A basic assumption behind the mesoscale air quality analysis was that there exists a direct relationship between the upwelling earth-atmosphere radiance and the mesoscale air quality, and that the ERTS measure of overall reflectance variation from inert objects can be related to turbidity measurements

---

[1]Clodman and Taggart, "The Movement of Large Scale Air Pollution Areas as Determined by Satellite Photography." Unpublished paper for the Director, Meteorological Services Research Branch, Atmospheric Environmental Service, Downsview, Ontario, Canada, 1972.

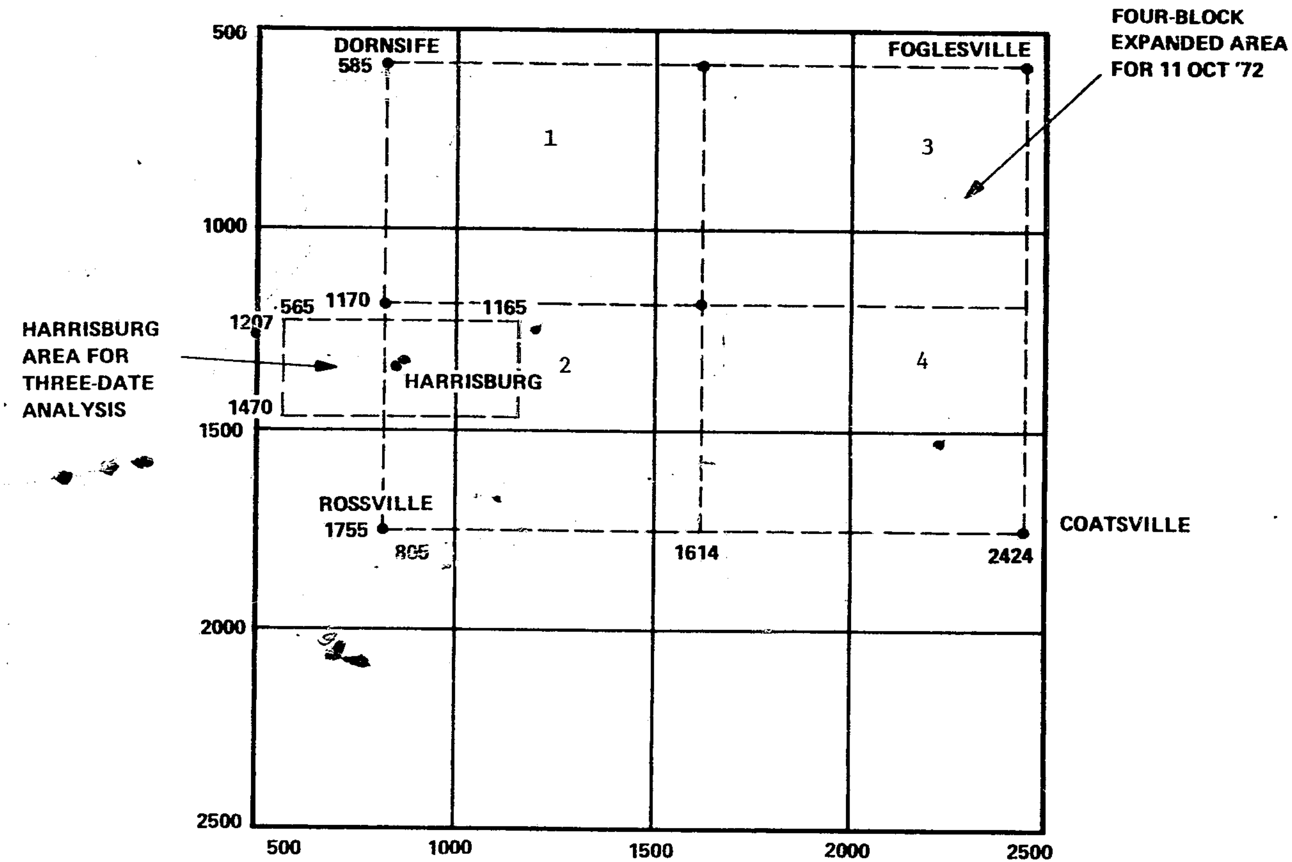
and therefore to mesoscale air quality. Initially in the Phase II portion of the investigation, the main effort was to gather and plot ERTS and interpolated Turbidity Network data for coverage dates over the Harrisburg test area of Test Site 1, and to see if any correlation appeared to exist. Criteria for data used in the analysis included the following:

- Turbidity measurements used would be those taken as near to 10:00 A.M. as possible to coincide with the approximate time (10:15 A.M.) ERTS is directly over the test area.
- Only those ERTS coverages where the test area was cloud free would be used. (NOAA Turbidity measurements using Volz sunphotometers are only made when there is a cloud free line of sight from observer to the sun).
- Since sunphotometer measurements are made at 500 nanometers, only ERTS Channel 4 (0.5 - 0.6 micrometers) was to be used.
- To minimize the reflectance effect of ground water variation, ERTS coverage dates were not used if there was significant precipitation in the test area within a week of the coverage date.
- The test area centered on Harrisburg was selected since much of that area was urban and river, thereby reducing reflectance variation attributable to growing season.
- A larger area surrounding the Harrisburg test area was also analyzed in four portions, or blocks, to determine if there

was a significant variation in Channel 4 reflectance throughout the Test Site 1 area. (Figure 2-21 shows the line and element boundaries of the Harrisburg test area and the larger four block test area).

Based on these criteria, three ERTS coverage dates met the requirements for correlation analysis during Phase II: 1 August 1972, 11 October 1972, and 16 November 1972. The data used for these dates were derived from a straightforward computation of average grayness for the test area in Channel 4. The intensity map program (described in Appendix A) was used to compute the grayness statistics.

The derivation of the turbidity data for the Harrisburg test area was somewhat more complex because there was no Turbidity Network site located within the test area. Because data for three good ERTS coverages were already on hand for the Harrisburg test area with four more coverages on order, it was decided during Phase II not to move the preselected test site to an area which did contain a sunphotometer site. Rather, since turbidity data were available for a number of stations surrounding Test Site 1 it was decided to interpolate the values for the Harrisburg test area. This was accomplished by constructing a rough gradient of values from the data from the surrounding stations, combined with the East Coast meteorological synoptic map for the day and the rain information from the preceding week and the local Harrisburg airport meteorologist's report. Figure 2-22 shows the stations reporting data for the calculations (the Salem, Illinois; Greensboro, North Carolina; and Caribou, Maine sites were later dropped



*ELEMENT BOUNDARIES SHOWN ARE SPECIFICALLY FOR THE 11 OCTOBER 1972 MSS DATA. BOUNDARIES TEND TO CHANGE SLIGHTLY FOR DIFFERENT DATE'S COVERAGE OF THE "SAME" AREA.

FIGURE 2-21

AIR QUALITY TRAINING AREAS

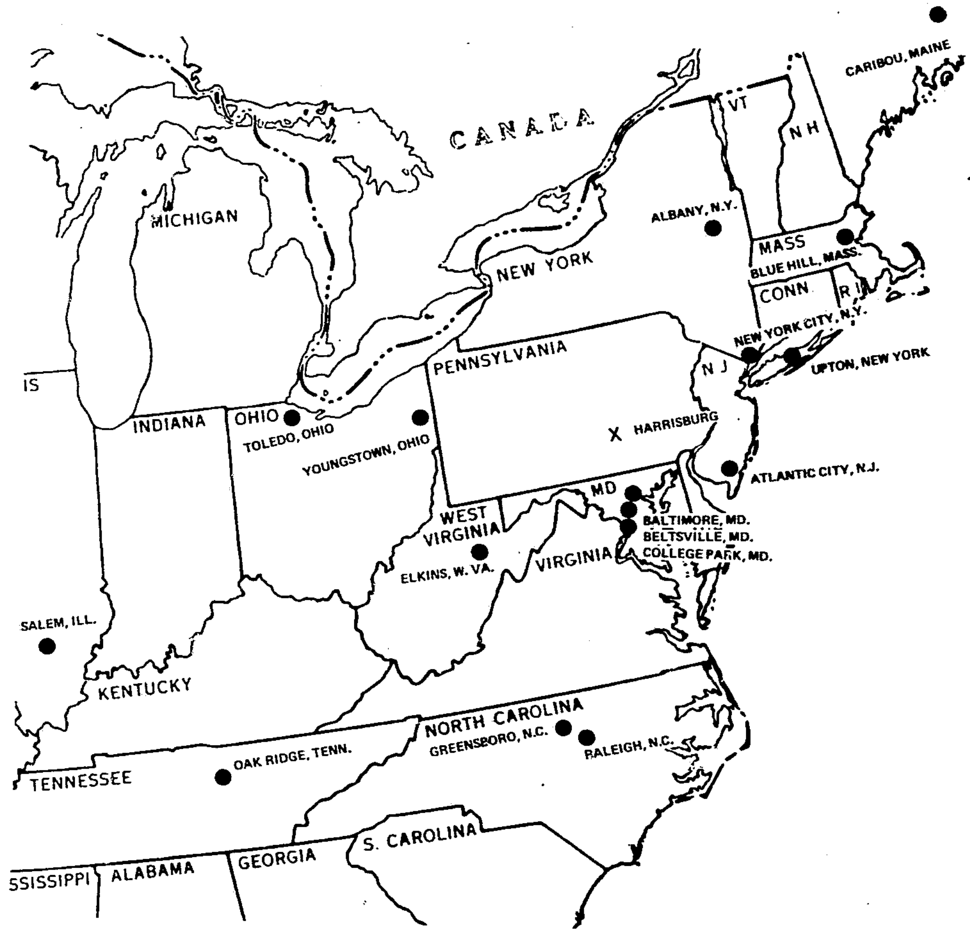


FIGURE 2-22

TURBIDITY NETWORK STATIONS
REPORTING DATA FOR THE MITRE ERTS-1 INVESTIGATION

and not used for the interpolation calculations). In this manner it was possible to estimate what the turbidity value would have been for the Harrisburg test area for each date for which ERTS data were available.

2.2.3.3 <u>Preliminary Phase II Air Quality Results</u>. By the end of Phase II, reflectance data for three dates of ERTS coverage for the Harrisburg test area had been calculated. Additionally enough turbidity data were received to allow calcualtion of turbidity at the test area for four dates for which ERTS data were either on hand or ordered. Table 2-13A and Figure 2-23 show the comparison of ERTS and Turbidity Network data. In Figure 2-23 the ERTS data is plotted as a band of ± one quantum of the computed average grayness after it was learned from NASA that prior to April 1973 there could have been a maximum error of two quanta inherent in the CCT's[1]. With only three points of ERTS data and four of the Turbidity Network to compare at that point, firm conclusions on the correlation of ERTS average grayness and turbidity would have been premature. Nevertheless the preliminary correlation trend illustrated in Figure 2-23 was sufficiently encouraging to justify continuation of the mesoscale air quality investigation into Phase III, the Continuing Data Analysis Phase.

2.2.4 <u>Revisions to Data Analysis Procedures</u>

In the course of the Phase II preliminary analysis, practical

---

[1] NASA, Generation and Physical Characteristics of the ERTS MSS System Corrected Computer Compatible Tapes, GSFC, July 1973, p. H-1.

TABLE 2-13A

ERTS AND CALCULATED TURBIDITY DATA FOR HARRISBURG TEST AREA

ERTS-1 Average Intensity (CH.4)		Calculated Turbidity (B_{500})
1 August 1972	35.1	0.220
6 September 1972	-	0.165
11 October 1972	23.7	0.151
16 November 1972	25.8	0.190

11 October 1972

Block 1	22.4
Block 2	24.0
Block 3	23.0
Block 4	23.9
Average	23.3

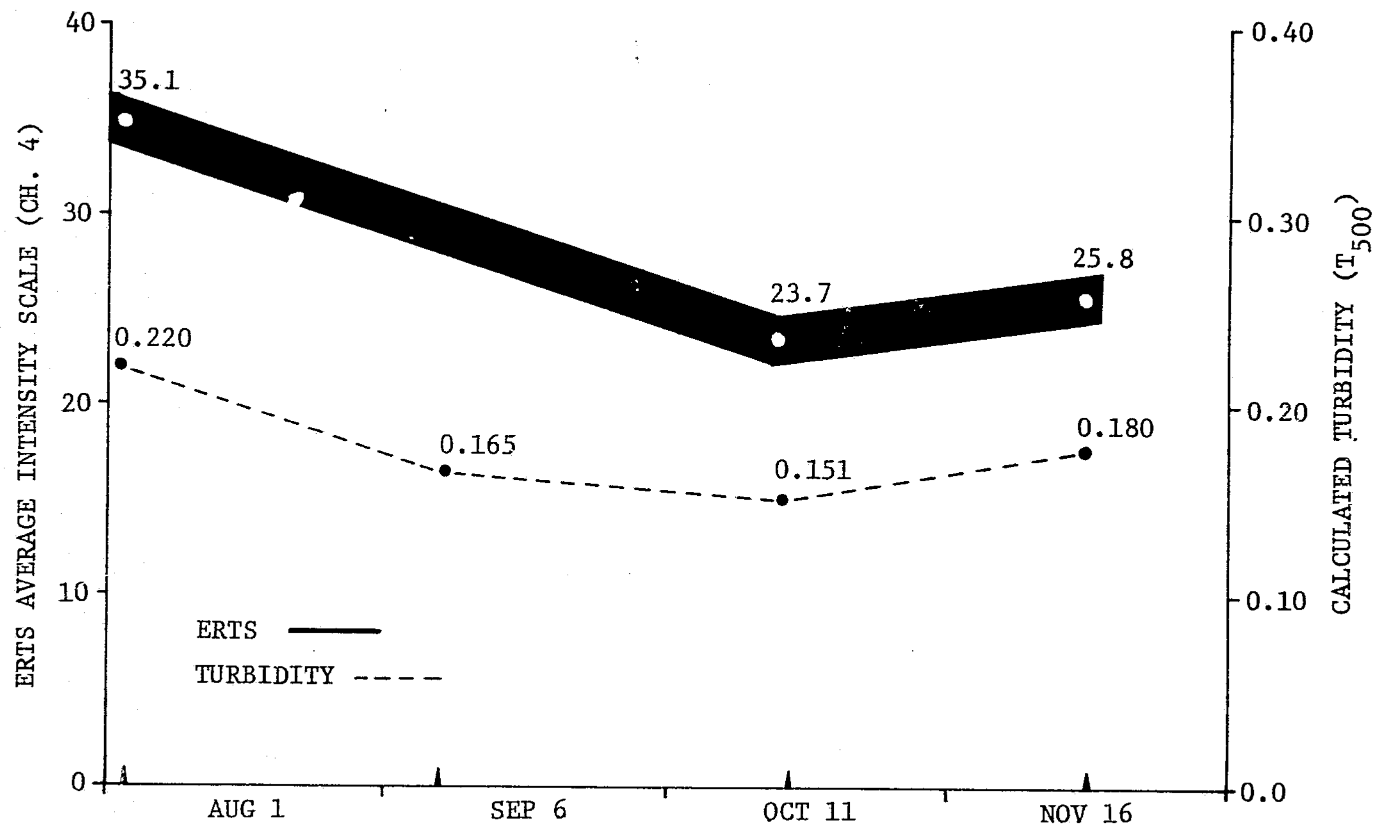


FIGURE 2-23

COMPARISON OF ERTS-1 AVERAGE INTENSITY VARIATION WITH CALCULATED TURBIDITY VARIATION OVER THE HARRISBURG, PENNSYLVANIA TEST SITE experience in analyzing the ERTS and ground truth data led to several revisions to the tentative analysis procedures which had been established in the Phase I planning period. While these revisions have been incorporated in the formal Data Analysis Plan which is discussed in Appendix A, it will be useful here to point out the specific changes which were made.

2.2.4.1 Computer Product Output at MITRE via Terminal. As initially conceived, digital analysis of ERTS CCT's would be conducted under MITRE's direction with the PSU MSS analysis software at the PSU's computation center. However, toward the end of Phase I when analysis procedures were being tested, it was found that this arrangement would not be satisfactory for two principal reasons. First, the time required to transmit instructions, perform the digital analysis, and ship the analysis results from PSU to MITRE was too great, especially when errors requiring reprocessing were discovered when computer products arrived at MITRE. Secondly, having MITRE analysts direct the digital analysis by PSU personnel, and then review the outputs, was felt to be less beneficial than providing the MITRE analysts with actual hands-on experience in applying the analysis software to the ERTS data. Consequently, the decision was made to install a remote terminal at MITRE to access the ERTS CCT's at the PSU computation center. This arrangement has worked exceptionally well, and the ERTS data analysis of Phases II and III has been conducted by MITRE analysts via the remote terminal approach.

2.2.4.2 Desirability of Shifting All Data Processing to the MITRE Computer Center. Since the terminal operation was working so well, a study was made of the feasibility of procuring all the software documentation from PSU and performing the analysis directly with MITRE's IBM 360-45 system. However, an investigation of the costs showed that the PSU IBM 370-165 was faster and less expensive, so the decision was made to continue to use the PSU system via the remote terminal. Additionally, the software documentation was procured so that a backup system would be available at MITRE if required.

2.2.4.3 Aircraft Photography Requirements. Initially, it was hoped that digital analysis and signature development would proceed with reference required only to the ERTS imagery, USGS 7.5 minute quadrangle maps, and other easily obtained ground truth for verification. The initial system tests in Phase I and the preliminary analysis of Phase II clearly demonstrated, however, that more detail was needed for signature development than that which was provided by the imagery and the maps alone. As just one example, it was generally not possible to distinguish some fields from certain forests on the ERTS imagery and USGS maps, and consequently it was not at first possible to develop and verify land use signatures for field and forest in the digital analysis. To achieve investigation objectives in land use classification, better ground truth in the form of more detailed maps (more detail the 7.5' quads) and/or aircraft photography was required. Fortunately, in terms of time and cost, recent NASA U-2 false color 70 mm photography was already available for both Test Sites. U-2 overflights on 26 July 1972 over Test Site 1 and on 25 January 1973 over Test Site 2 proved to be most valuable. This photography proved to be extremely useful to develop signatures in training areas and to verify classification throughout the Test Site, and the use of some aircraft photography or other very reliable current ground truth became an integral part of the evolving data analysis system.

2.2.4.4 Use of the Zoom Transfer Scope. The Phase I testing of photointerpretive techniques which would aid digital analysis indicated that one of the most useful tools that would allow direct enlargement of images and projection onto maps is the Bausch and Lomb Zoom Transfer Scope. Early in Phase II MITRE learned that the USGS had a Zoom Transfer Scope in operation at its McLean, Virginia office. Arrangements were made with USGS for MITRE to use this equipment on a time sharing basis without cost to the investigation. The Zoom Transfer Scope, used with USGS maps, computer maps, and the NASA U-2 photography especially, has been a very effective tool for fast and relatively easy signature development and direct classification verification.

2.2.4.5 Data Analysis Plan (DAP) Development. As a natural outcome of the Phase I planning and implementation, reinforced and refined by the preliminary ERTS I data analysis performed during Phase II, the MITRE DAP evolved and was formalized in February 1973 in accordance with contract requirements. When approved by NASA, the DAP formed the data processing and analysis framework for the remainder of the MITRE investigation (March 1973 - February 1974).

The objectives that the Data Analysis Plan addressed are the following:

- Land use trends for Test Site 1 and 2.
- Air Quality/turbidity mesoscale trends over Pennsylvania for the August 1972 - October 1973 time period.
- Water quality along the Susquehanna River for one overflight date - 11 October 1972.
- Specifications for an operational monitoring system using an ERTS-type system and selected analysis software for all three media.

The MITRE Data Analysis Plan is included in its entirety in Appendix A.

2.3 Phase III - Continuing Data Analysis

The completion of the Data Analysis Plan marked the end of Phase II (Preliminary Data Analysis) and the start of the final Phase III (Continuing Data Analysis). The planned schedule of work for Phase III was basically that shown in Figure A-4 from the Data Analysis Plan. However, in the course of the Phase III analysis, several developments discussed with the NASA Technical Monitor and Scientific Monitor resulted in the conclusion that more schedule flexibility was required, and consequently some changes were made to the Phase III schedule and investigation approach. The main thrust of these changes was as follows:

- Because an inherent CCT problem of every-sixth-line striping was inhibiting water quality analysis, that portion of the investigation was for a time suspended. After this problem was corrected analysis resumed, but since by then the investigation was well into Phase III, the analysis resumed on the Susquehanna within the Test Site 1 rather than in the Potomac training area. (The striping problem is discussed under Section 2.2.2 and Appendix B).
- A more careful examination of the mesoscale air quality analysis indicated the preliminary results which had appeared encouraging may not have accounted for significant interferences and differences between ERTS measurements and Volz sumphotometer measurements to allow direct comparison of data. The examination showed that while correlation could potentially be developed from the data it was a more complex operation than anticipated and would require more time than was available in the remainder of the investigation. It was therefore mutually agreed by MITRE and NASA to concentrate the time remaining in Phase III on land use analysis. (A full description of the mesoscale air quality analysis is found in Section 2.2.3).
- Because land use analysis enjoyed the most success in meeting investigation objectives, it was agreed that the majority of the Phase III effort would be allotted to that area. Additionally, because strip mining activity is a prevalent feature of Test Site 2, a special land use analysis was performed there concentrating on strip mines, refuse banks, and reclamation classification.

The following schedule, Figure 2-24, is the actual schedule of work performed during Phase III, which reflects the foregoing changes.

2.3.1 Phase III - Land Use Continuing Data Analysis

The objectives of the land use analysis as stated in the Data Analysis Plan were as follows:

- Classify land use in Test Site 1 and Test Site 2 for three dates of ERTS coverage.
- Perform trend analysis comparing ground truth to ERTS data and comparing several ERTS coverages.
- Investigate the development of signature variation algorithms to allow application of a set of signatures to different coverage dates.

In the course of the investigation the following were accomplished:

- Land Use classification in Test Site 1 for five coverage dates, Test Site 2 for three coverage dates, and a strip mining area for three coverage dates.
- Comparison of ERTS classification for one date with regional planning commission classification.
- Comparison of four ERTS coverages for trend analysis.
- Signature areal transfer analysis.
- Signature algorithm analysis.

The work which led to these results is reported in detail in the following sections.

2.3.1.1 Classification of the 11 October 1972 Coverage for Test Site 1. The procedures discussed in Section 2.2.1 had resulted in virtually

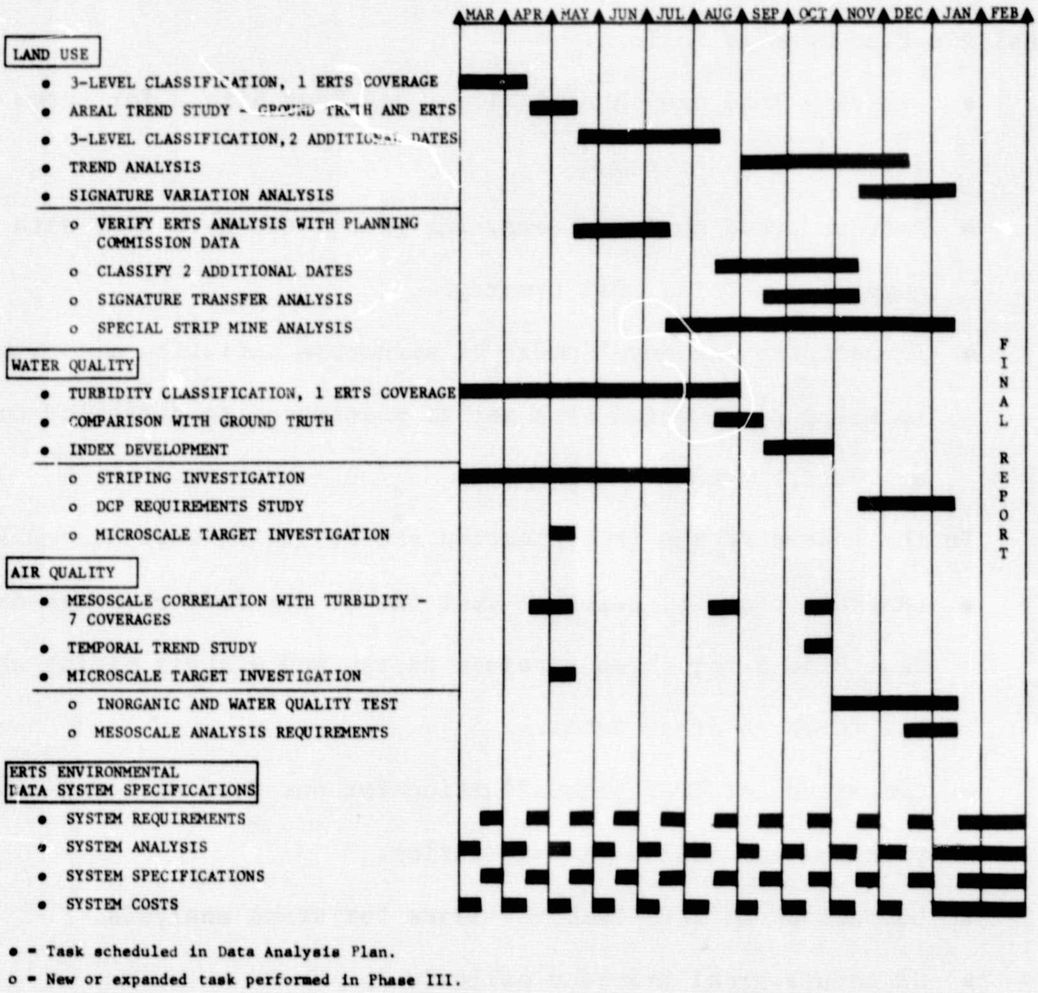


FIGURE 2-24

PHASE III: CONTINUING DATA ANALYSIS SCHEDULE

FIGURE 2-24
PHASE III: CONTINUING DATA ANALYSIS SCHEDULE

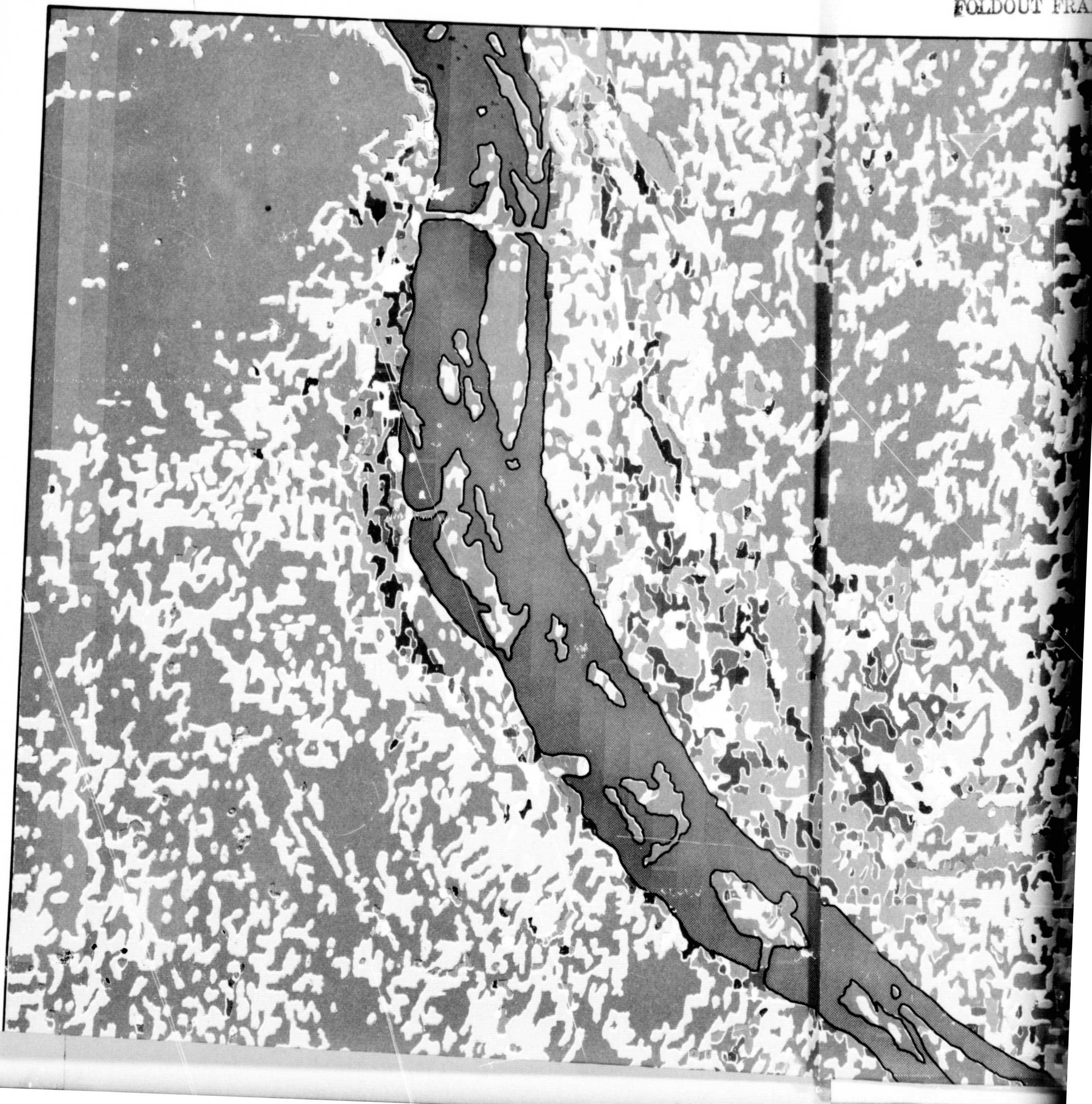
a complete full scale classification of Test Site 1 during the preliminary analysis phase. The first task of Test Site 1 land use in the continuing analysis phase was production of the classification map showing 17 categories of land use. These categories were further merged to six general land use classifications, and the map was manually color coded to compare with maps produced by the local planning commission. Figure 2-25 shows the final color coded map based on the 11 October 1972 ERTS coverage.

In an effort to find a quicker, yet equally efficient, means of covering the Harrisburg area, intensity maps for 11 October 1972 were run using every fourth line and element (4 x 4) and every other line and element (2 x 2). In the 4 x 4 case it was found that the resolution was too poor and landmarks such as the Condoguinet Creek were lost. The 2 x 2 case not only maintained the resolution needed for the analysis but also could be run in less computer time. (The conclusion that 4 x 4 analysis was unacceptable for the very heterogeneous Harrisburg area would of course not necessarily hold for land use analysis in areas having larger more homogeneous land, e.g., a midwestern agricultural area.)

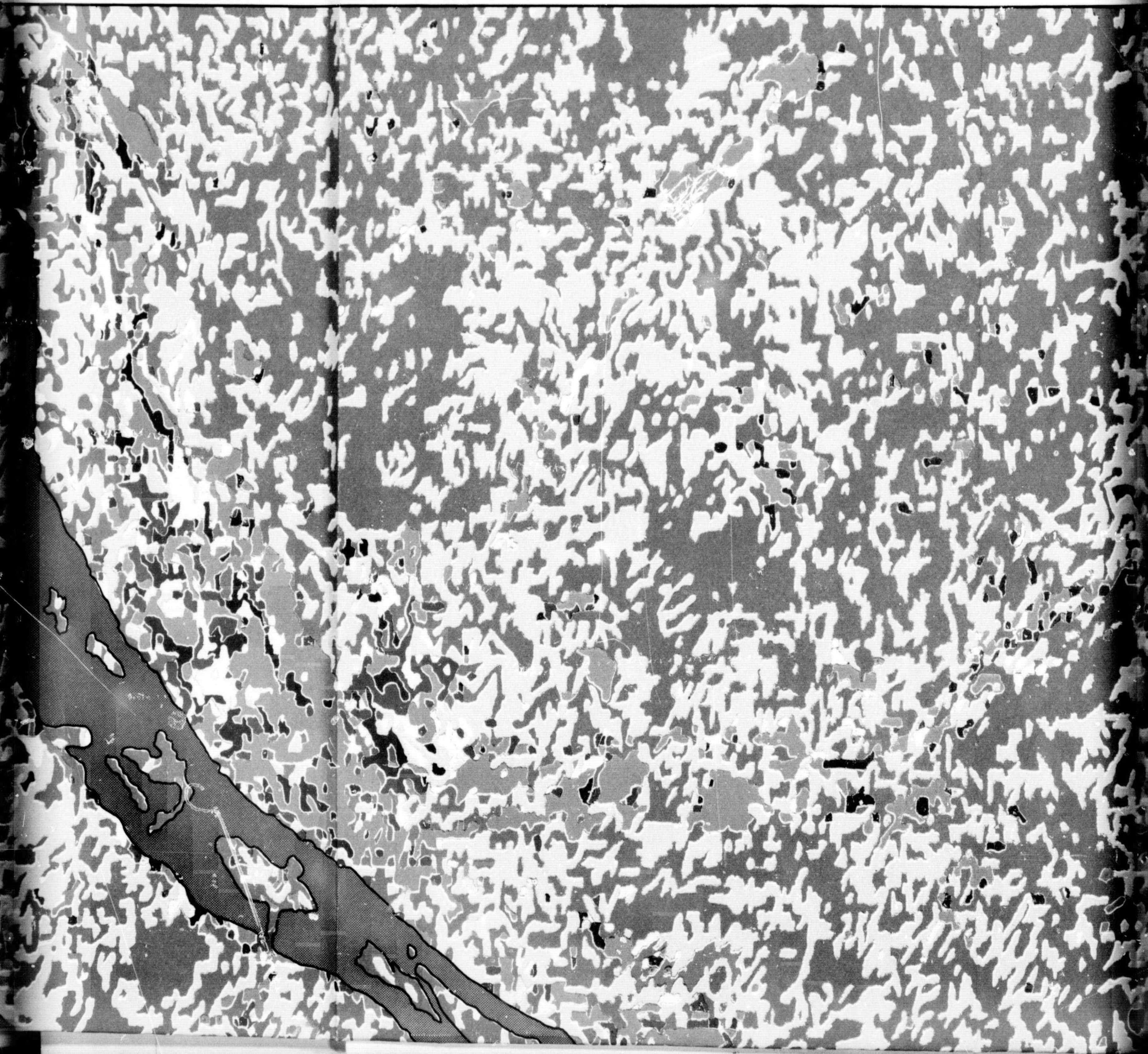
When the corrected tapes, without striping, were obtained from NASA (See Section 2.2.2) it was decided to redo the analysis for the 11 October 1972 frame using every other line and element. The signature development used the same tools as described in the DAP, with the exception that a greater emphasis was put on the clustering techniques (D-CLUS). Areas were chosen to be clustered by projecting the U-2

FOLDOUT FRAME

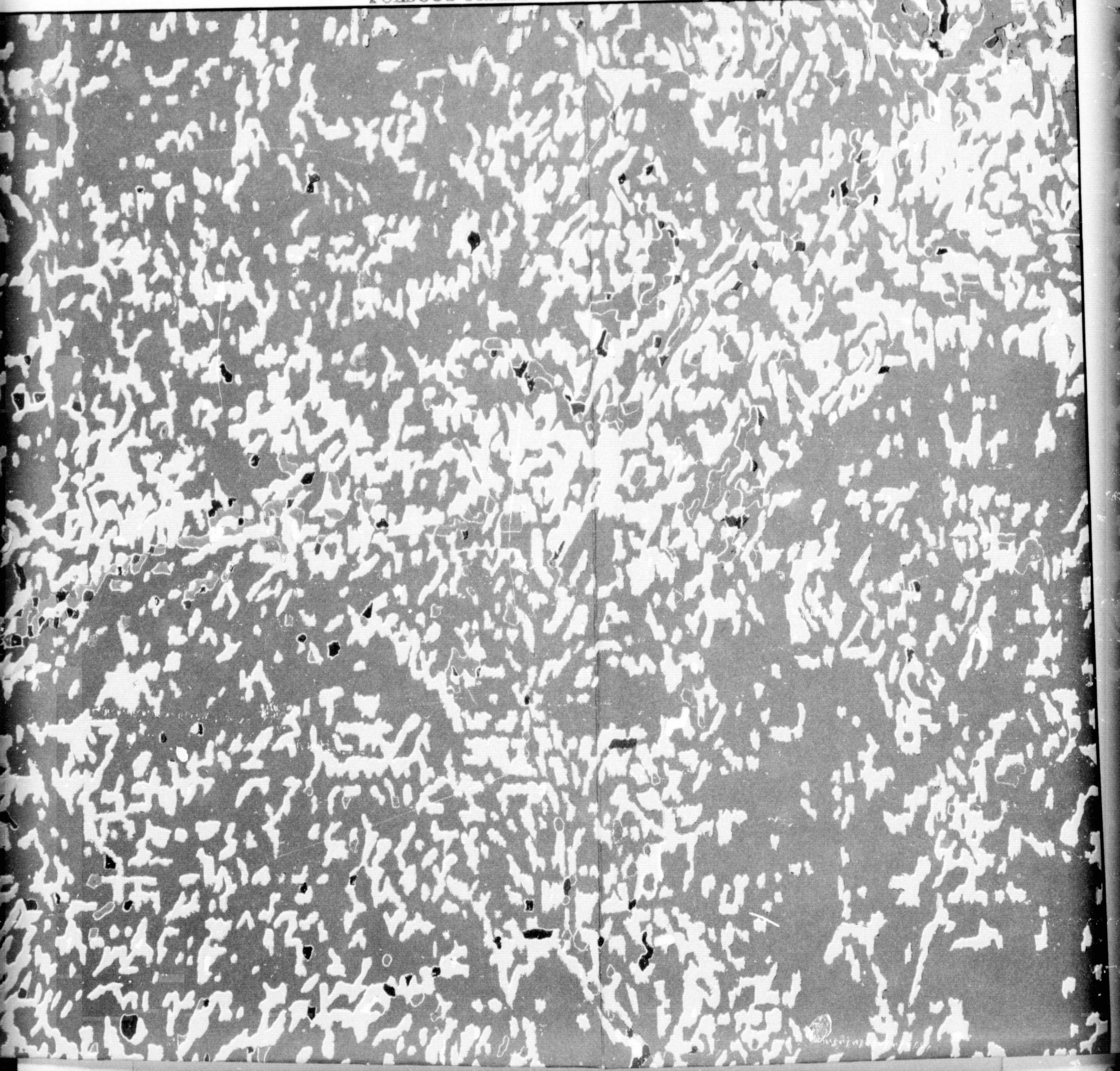
FOLDOUT FRA



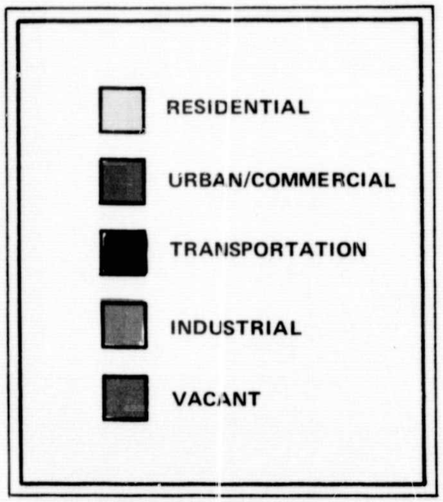
FOLDOUT FRAME 2

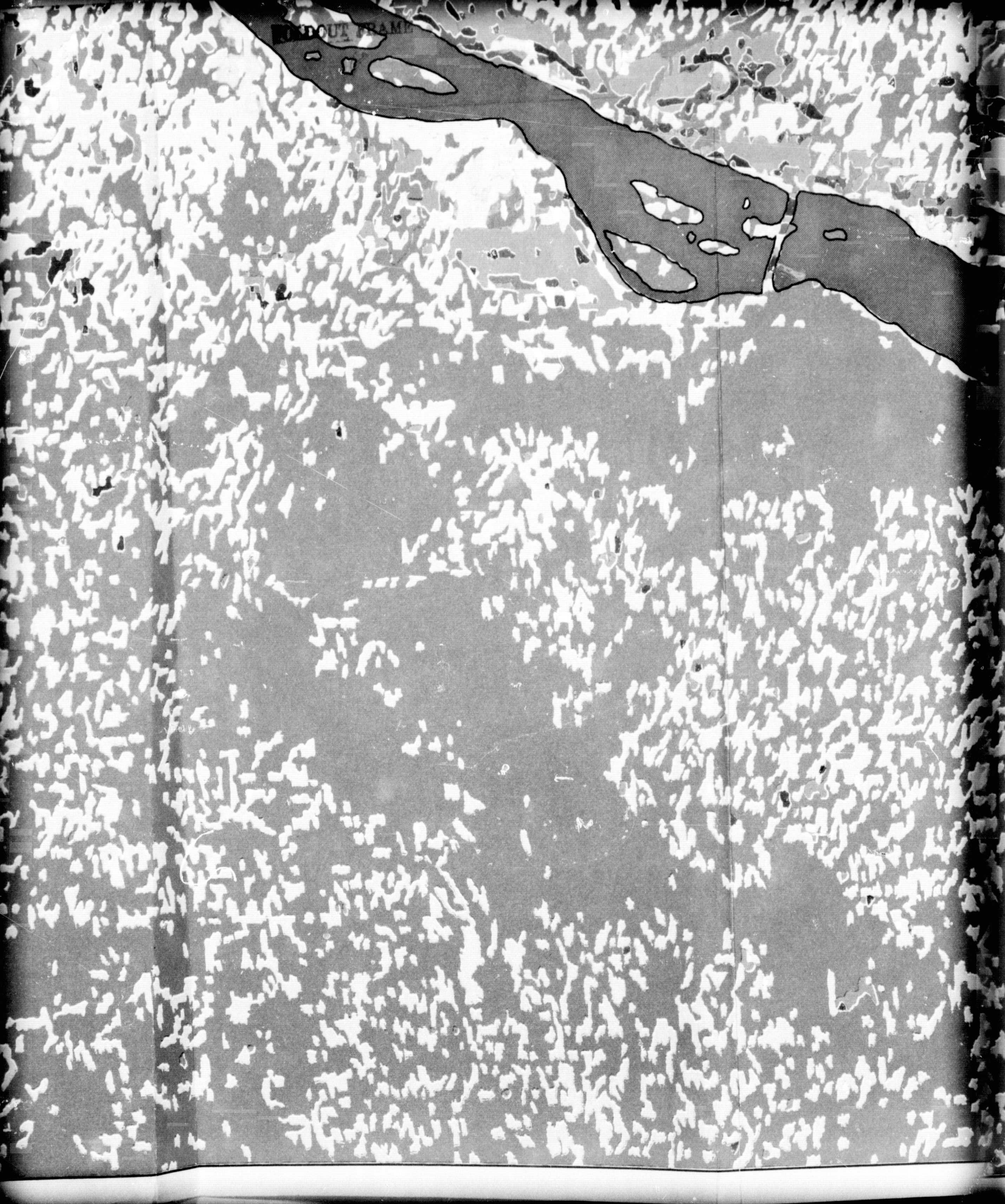


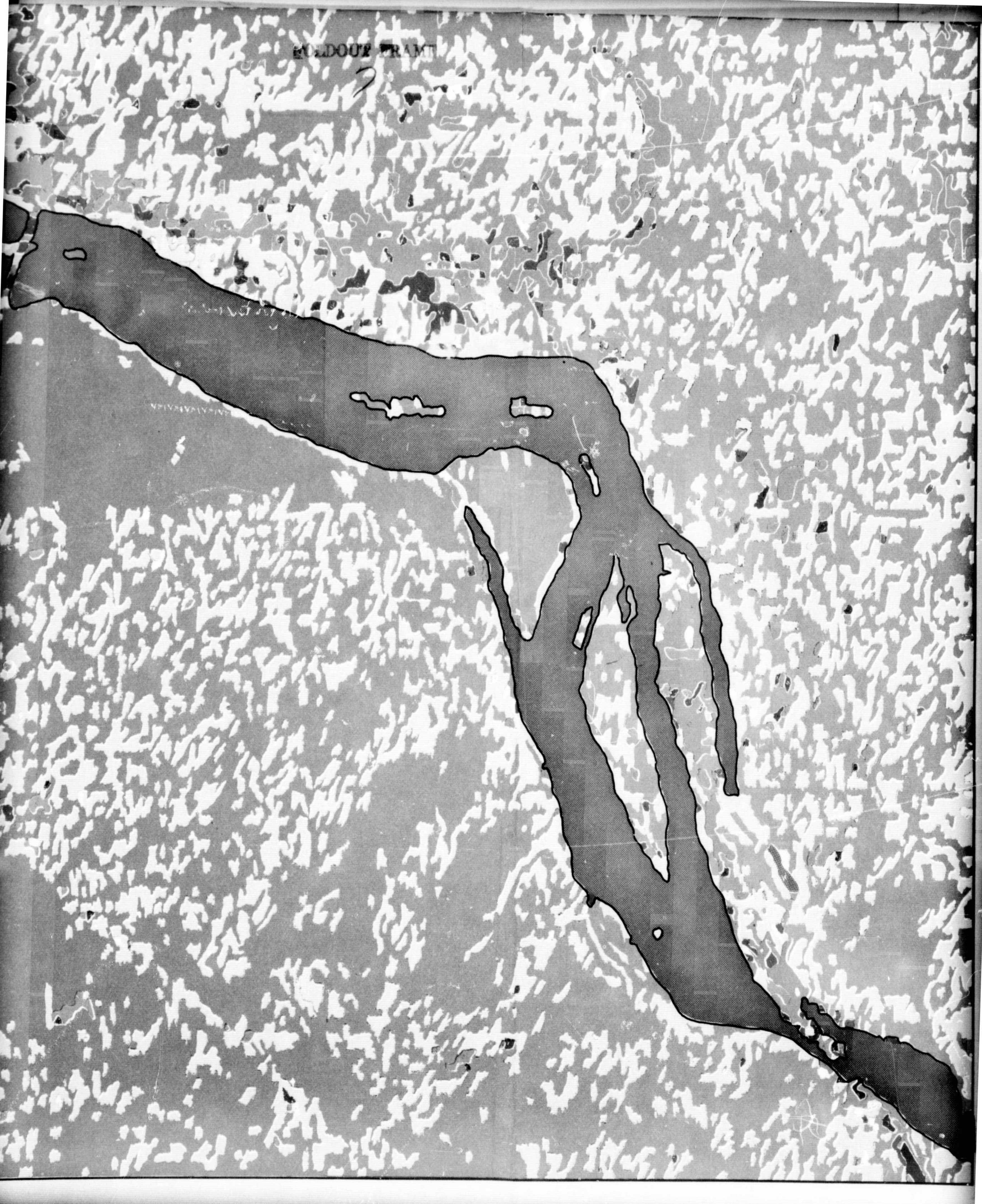
FOLDOUT FRAME 3



FOLDOUT FRAME 4

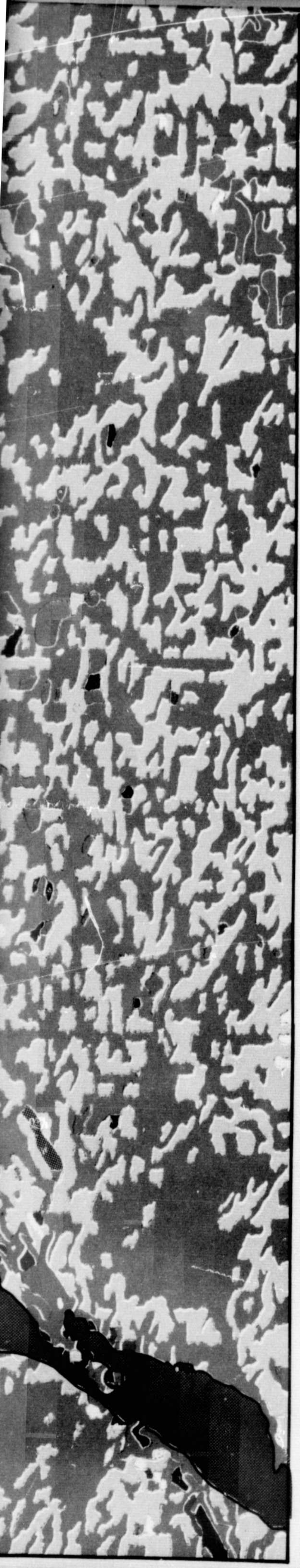






FOLDOUT FRAME

8



PRECEDING PAGE BLANK NOT FILMED

ERTS–DERIVED LAND USE IN THE
HARRISBURG TEST SITE
11 OCTOBER 1972

photography on the first run intensity maps. Once clusters were run for all areas, the signatures were inserted into the classification program for the Distance of Separation Tables. Signatures were then combined and refined where necessary, followed by the use of the classification program (D-CLAS) to map the land use. This land use map was then compared to the U-2 photos using the ZTS. Areas were outlined that needed refining or further clustering. This process continued until the entire Harrisburg area was classified correctly.

With the signatures developed for the 2 x 2 map, a comparison was made with the original signatures to evaluate this process. The classification program was again used; this time the signatures developed from the 2 x 2 map were inserted with those developed from the 1 x 1 map. Table 2-14 lists the distance of separation for similar categories.

For most cases the distances are close enough to be combined, implying the signatures are very similar. The largest distance was for the category runway. This was because the 1 x 1 map did not have a signature for runway; instead it had a highway signature. This was chosen for the comparison because it was the closest to runway, hence, the 5.2 distance. Otherwise the signatures for the 2 x 2 map were so similar to the 1 x 1 it was felt that the resolution could be maintained using 2 x 2 signatures.

The signatures that were used to classify 11 October 1972 can be found in Table 2-15. Figure 2-26 is the land use classification map of the Harrisburg area and overlay outlining major areas of interest.

PRECEDING PAGE BLANK NOT FILMED

TABLE 2-14

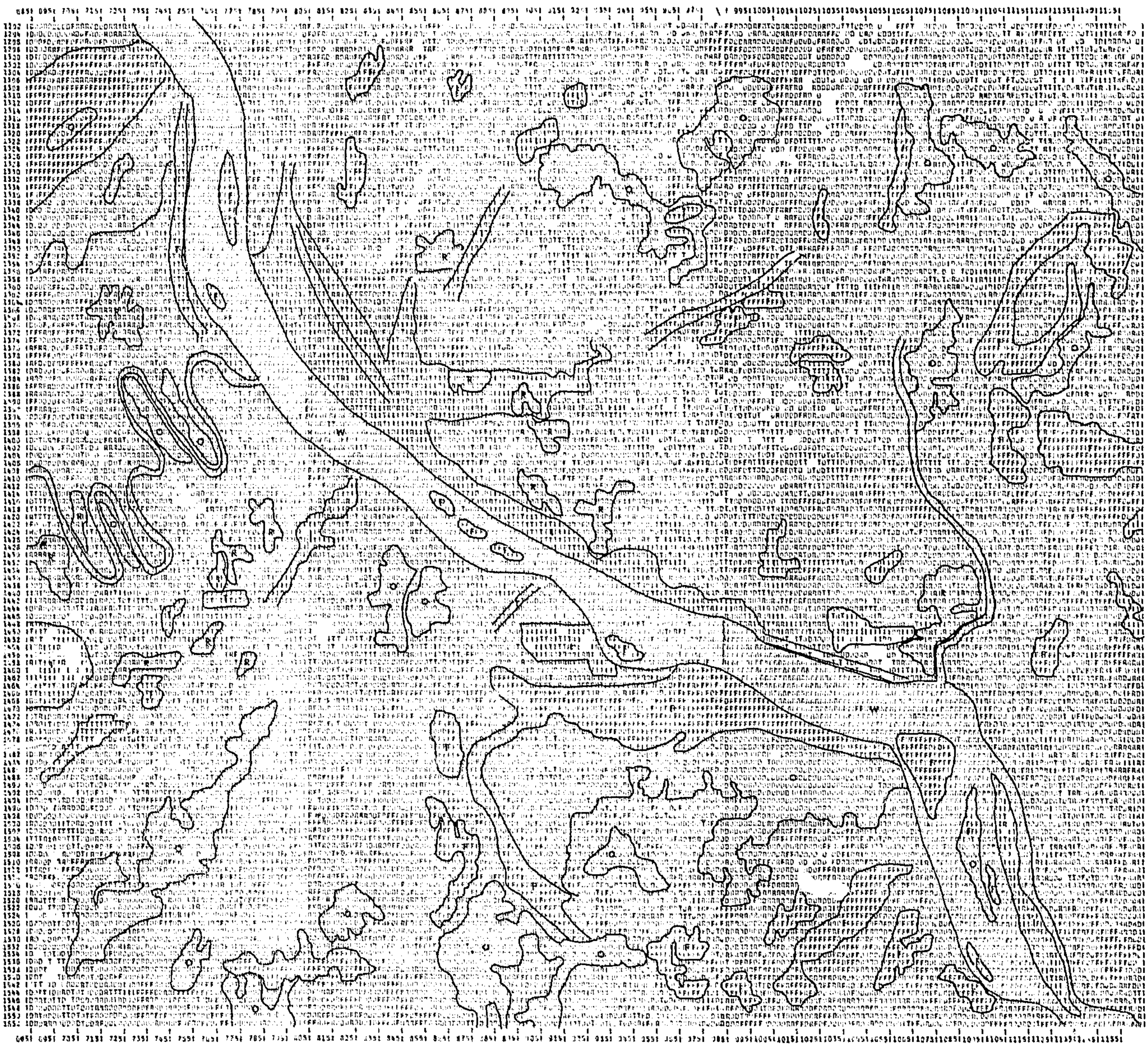
DISTANCE OF SEPARATION COMPARISON

Category	Distance of Separation
Water	1.6
Creek	0.7
Runway	5.2
Rail Yard	2.4
Forest	0.9
Residential	0.9
Residential	3.9
Residential	1.5
Bare	2.4
Industrial	3.6
Agriculture	1.3
Open Land	1.3
Building	2.7

TABLE 2-15

SIGNATURES FOR LAND USE - 11 October 1972

CATEGORY	CHANNEL 4	CHANNEL 5	CHANNEL 6	CHANNEL 7
Water	19.46	10.50	6.88	1.14
Creek	21.20	13.40	15.60	7.00
Runway	32.33	30.33	38.33	19.83
Rail	25.19	18.88	18.21	7.49
Rail	21.75	15.30	16.09	6.81
Forest	19.80	11.06	28.12	17.69
Residential	25.50	19.10	20.45	9.10
Residential	23.27	16.18	30.18	16.64
Residential	25.46	19.04	27.73	14.04
Bare	22.17	14.83	33.33	20.67
Industrial	25.74	19.52	21.94	9.75
Agriculture	25.32	20.09	29.50	16.36
Open Land	23.84	17.13	30.48	17.13
Building	32.00	27.69	24.56	9.69



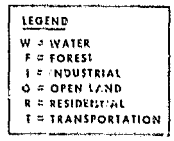


FIGURE 2-26
LAND USE CLASSIFICATION—HARRISBURG
11 OCTOBER 1972

The map is classified using six categories: water, transportation, industrial, open land, residential and forest. Transportation includes both airports (Harrisburg State Airport and the old Olmstead AFB runway), and all three marshalling yards (on the west side of the Susquehanna River across from Harrisburg, in Harrisburg, and east of Harrisburg). Water classifies the Susquehanna River, the Condoguinet Creek and Swatara Creek. The category industrial includes urban, industrial and commercial areas. Open land classifies agriculture, bare ground and open land. Forest and residential are self-explanatory.

For all land use overlays only large areas have been highlighted; there was no attempt to outline all areas. For October in particular industrial areas such as the New Cumberland General Depot, U.S. Naval Depot in Mechanicsburg, the power plant on Three Mile Island and the general Harrisburg area are classified correctly. Rail yards are properly classified as transportation. The forest and areas of open land agree with those categories from the U-2 photography. Residential did not generally appear in large groups like water or forest. This particular category is scattered throughout most of the area that is blank on the overlay and therefore not easy to outline. In general, all six categories were compared with the U-2 photography and found to be correct.

2.3.1.2 Correlation of ERTS 11 October 1972 with Tri-county Regional Planning Commission (TRC) Ground Truth Data for the Harrisburg Test Site. Because one overall objective of the MITRE investigation is to develop land use trend information useful to local, regional, and state planners, an important part of the Continuing Analysis Phase has been dedicated to demonstration that ERTS-1 Data will be a potentially valuable complement to land use information obtained from conventional sources at the local level. Showing a significant correlation between the current ERTS-1 land use analysis and the existing land use information now available to the state, regional, and local planners, is the first essential step in demonstrating the usefulness of ERTS data as an input to the land use planning process. Showing that the ERTS data can be made available to provide land use updates more frequently than conventional means, and with less expenditure of resources, will demonstrate that ERTS is not only a useful tool, but a cost effective one as well.

In reports of the results of other ERTS-1 land use related investigations reviewed to date, correlation is generally accomplished by defining aerial photography and maps produced from photography as ground truth, and checking the results of ERTS imagery interpretation and digital analysis techniques against this ground truth. In most cases, the scale employed has been very small (1:250,000), and the land use classifications have therefore necessarily been generalized. Several examples are the work of John Place, USGS, analyzing land use in the Phoenix Quadrangle in Arizona[1], Simpson and Lindgren at Dartmouth

---

[1] Place, John L., "Change in Land Use in the Phoenix Quadrangle, Arizona, Between 1970 and 1972," Symposium of Significant Results Obtained from ERTS-1 (NASA, Washington, D.C., 1973) pp. 899-906.

College classifying land use on a state-wide basis in New England[1], and Ernest Hardy at Cornell University classifying a 6,300 square kilometer area in New York state[2]. While these and similar investigations are of unquestionable value, and verification of ERTS analysis against microscale ground truth appears to yield high correlation, the MITRE land use investigation has sought a more specific focus for metropolitan land use analysis. As Alexander indicated in his report of ERTS application in the CARETS area[3], ERTS results will not only be useful in Federal, state, and large regional land use classification as anticipated, but his analysis also shows level of classification in some areas which can prove useful to local planning staffs in smaller, more specific metropolitan areas. MITRE has therefore applied ERTS land use analysis techniques in two Test Sites at a scale of approximately 1:24,000 and then correlated the results with the actual land use data presently employed by planners in the area of the test sites. Success in this effort demonstrated that ERTS is not only a valuable tool for a synoptic appraisal of present land use and trends over large areas, but is a source of timely complementary information for land use planning at specific local levels as well.

---

[1] Simpson and Lindgren, "Land Use of Northern Megalopolis," ibid. pp. 973-980.

[2] Hardy, Ernest, "ERTS Evaluation for Land Use Inventory," Report No. NASA-CR-133139 of 13 June 1973 (NASA, Washington, D.C.).

[3] Alexander, Robert, "Land Use Classification and Change Analysis Using ERTS-1 Imagery in CARETS," op. cit., pp. 923-930.

An approximately 18 mile square area in Test Site 1, centered on the Harrisburg, Pennsylvania metropolitan area, was selected for detailed ERTS-derived land use analysis and correlation with the best available local land use studies. Working at first with the ERTS coverage of 11 October 1972 (frame 1080-15185), land use category signature development has proceeded according to the Data Analysis Plan. The minimum area interpreted is approximately one acre, as compared, for example, to about 60 acres for the Cornell University analysis referenced earlier.

When the first complete classification of the Harrisburg area based on ERTS data was completed (See preceding Sections), the next step was to develop the structures for evaluating the results against the land use data available from local planners. The basic source of ground truth, as determined early in the investigation in consultation with Commonwealth of Pennsylvania and local planners, has been the Tri-County Regional Planning Commission (TRC) directed by Mr. Oliver Fanning. The Commission has planning responsibility for the counties of Cumberland, Dauphin, and Perry and is headquartered at Harrisburg. From continually updated tax maps and spot field surveys, TRC compiles acreage by land use for all municipalities in the tri-county area according to the following categories:

- Residential
- Industrial
- Transportation Terminals

- Transportation Facilities
- Retail
- Wholesale and Storage
- Services
- Public and Semi-Public
- Vacant

From these data, generalized color-coded land use maps were prepared for the entire area. Figure 2-27, reproduced with the permission of Mr. Fanning, is an example of a currently available area-wide land use map. It is these two sources--the township-by-township acreage data and the maps--that form the basis of ground truth for testing the land use classification information analyzed from the ERTS data.

In order to structure a valid basis for comparison of ERTS and TRC results, two conditions were essential. First, both ERTS coverage and ground truth data must cover precisely identical geographic areas; and secondly, ERTS land use signature categories must be defined as exactly as possible to coincide with TRC categories. The first task, then, was to project the boundaries of all municipalities surveyed by TRC onto the digital thematic map of land use symbols produced by analysis of ERTS MSS data tapes. Although some difficulties were encountered with the inherent distortion of computer output maps, this was compensated for and a corrected acetate overlay of municipality boundary lines was produced from a 1:24,000 state plane coordinate

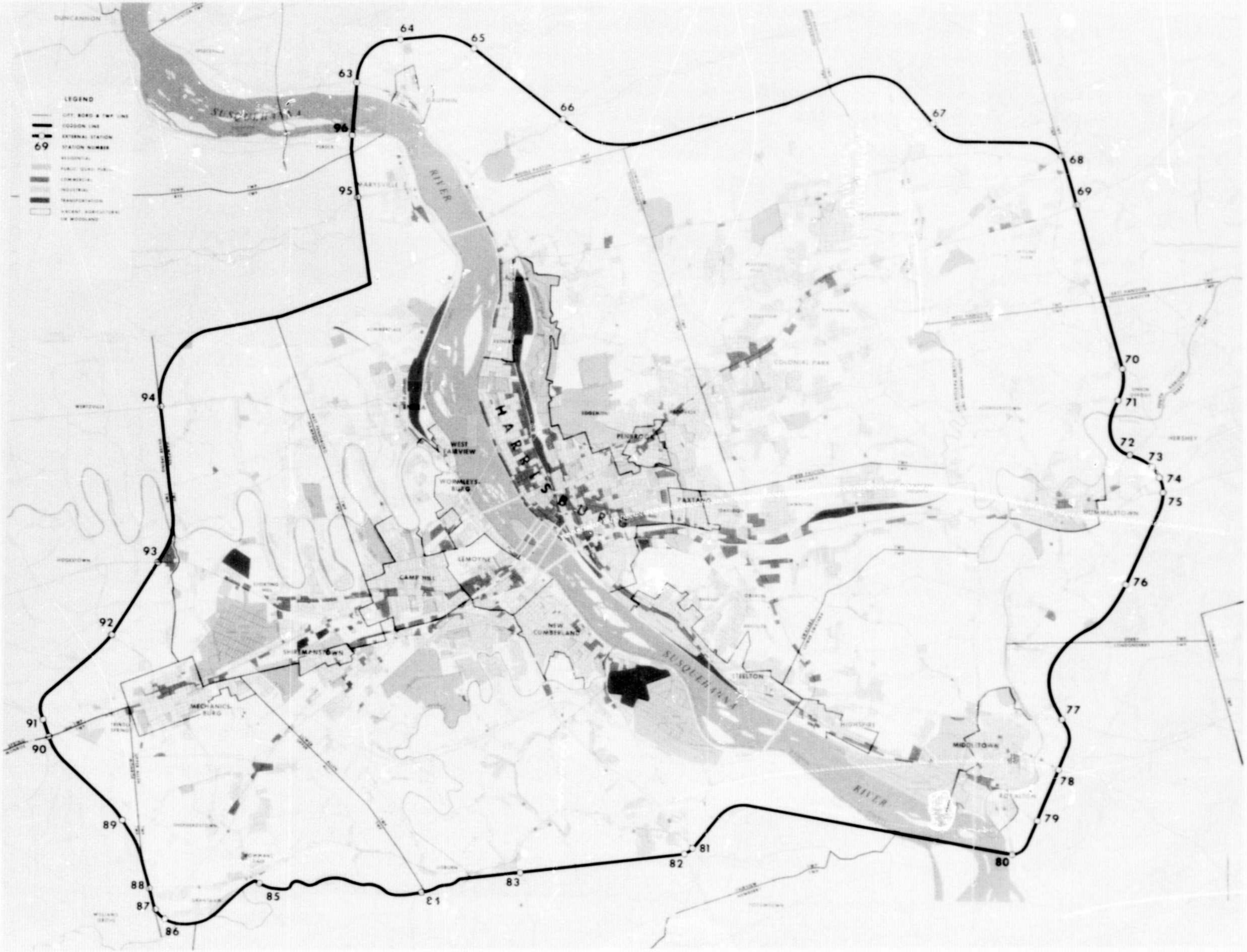


FIGURE 2-27
TRI-COUNTY LAND USE MAP
FOR HARRISBURG AREA

map of the area provided by TRC. It was found that 18 municipalities of Dauphin and Cumberland Counties lay completely within the area of the ERTS-derived land use map, so these were selected as the area for testing ERTS correlation. The 18 municipalities, with TRC land use acreage, are shown in Table 2-16. Once the correlation test area was selected, the boundary overlay and the ERTS-derived land use map were used for a manual tabulation of ERTS land use symbols for each municipality and for the total area. Results of the tabulation are shown in Table 2-17. The final step to achieve geographical identity was to convert the ERTS symbol counts to acres so that comparisons could be made with the TRC data. At the 1:24,000 scale employed in the ERTS data analysis, each symbol (pixel) is equivalent to approximately 1.094 acres,[1] with small additional corrections (calculated by MITRE to be a factor of about 0.013) necessitated by variance from nominal orbit of the spacecraft and variance of distance between the spacecraft and Test Site 1 attributable to the oblateness of the earth. It was felt that a simplified method of symbol-to-acre conversion determination was warranted for this analysis. Accordingly, the boundaries of the 18 municipalities and the total area were planimetered for total acreage, so that the ratio of planimetered acreage to total ERTS symbol counts would yield an average factor for converting ERTS symbol counts within

---

[1]Goddard Space Flight Center, ERTS Data Users Handbook, Document No. 71 SD 4249. (Each Pixel is 56 meters x 79 meters).

TABLE 2-16
SITE 1 LAND USE ACREAGE COMPARISON

MUNICIPALITY	SOURCE	LAND USE CATEGORY: URBAN	LAND USE CATEGORY: RESIDENTIAL	LAND USE CATEGORY: TRANSPORTATION	LAND USE CATEGORY: VACANT	TOTAL (DIFFERENCE)
1. CAMP HILL	ERTS TRC	105 200	742 1224	12 9	537 227	1396 1659 (- 263)
2. EAST PENNSBORO	ERTS TRC	241 202	2034 2695	688 274	4175 2714	6638 5884 (+ 754)
3. HARRISBURG	ERTS TRC	1694 1114	1439 2043	432 329	1366 1531	4932 5016 (- 84)
4. HIGHSPIRE	ERTS TRC	101 61	220 305	11 4	187 163	519 533 (- 14)
5. HUMMELSTOWN	ERTS TRC	59 118	349 524	3 86	465 439	876 1165 (289)
6. LEMOYNE	ERTS TRC	164 265	340 521	14 39	512 247	1027 1072 (- 45)
7. LOWER ALLEN	ERTS TRC	209 354	2303 2643	69 88	3477 3896	6088 6980 (- 898)
8. LOWER SWATARA	ERTS TRC	611 75	2843 1095	267 427	5030 4890	8752 6488 (+ 1246)
9. MIDDLETOWN	ERTS TRC	193 133	511 953	19 82	506 359	1229 1538 (- 209)
10. NEW CUMBERLAND	ERTS TRC	39 44	575 1086	1 13	468 212	1083 1356 (- 273)
11. PAXTANG	ERTS TRC	17 24	107 172	– 2	141 74	265 272 (- 7)
12. PENBROOK	ERTS TRC	26 55	158 270	– 1	99 57	282 382 (- 100)
13. ROYALTON	ERTS TRC	12 3	85 91	2 1	95 141	195 236 (- 41)
14. SHIREMANSTOWN	ERTS TRC	– 7	103 197	1 5	58 22	165 230 (- 65)
15. STEELTON	ERTS TRC	422 491	237 340	78 30	242 251	979 1111 (- 132)
16. SWATARA	ERTS TRC	614 1127	2834 3413	154 746	4441 4049	8044 9335 (- 1291)
17. WEST FAIRVIEW	ERTS TRC	16 9	58 138	2 1	80 34	153 181 (- 28)
18. WORMLEYSBURG	ERTS TRC	21 30	246 257	18 1	183 66	467 353 (+ 114)
TOTAL AREA (DIFFERENCE)	ERTS TRC	4542 4309 (+ 233)	15182 17970 (- 2788)	1271 2135 (- 864)	22060 19380 (+ 2680)	43092 43795 (- 703)

*TRC: TRI-COUNTY REGIONAL PLANNING COMMISSION, HARRISBURG, PA.

TABLE 2-17

ERTS - 1 PIXEL COUNTS AND CALCULATED ACREAGE FOR THE

FOUR COMPARISON CATEGORIES, BY MUNICIPALITY

	URBAN		RESIDENTIAL		TRANSPORTATION		VACANT		TOTAL	
	PIXELS	ACRES	PIXELS	ACRES	PIXELS	ACRES	PIXELS	ACRES	PIXELS	ACRES
1.	95	105.2	670	741.7	11	12.2	485	536.9	1261	1396.1
2.	218	241.3	1837	2033.6	170	188.2	3771	4174.5	5996	6638.2
3.	1530	1693.7	1300	1439.1	390	431.7	1234	1366.0	4455	4932.1
4.	91	100.7	199	220.3	10	11.1	169	187.1	469	519.2
5.	53	58.7	315	348.7	3	3.3	420	464.9	791	875.7
6.	148	163.8	307	399.8	13	14.4	462	511.4	930	1029.6
7.	189	209.2	2080	2302.6	62	68.6	3141	3477.1	5499	6088.0
8.	552	611.1	2568	2842.8	241	266.8	4544	5030.2	7905	8751.7
9.	174	192.6	462	511.4	17	18.8	457	505.9	1110	1228.9
10.	35	38.7	519	574.5	1	1.1	423	468.3	978	1082.7
11.	15	16.6	97	107.4	-	-	127	140.6	239	264.6
12.	23	25.5	143	158.3	-	-	89	98.5	255	282.3
13.	11	12.2	77	85.2	2	2.2	86	95.2	176	194.9
14.	-	-	93	103.0	1	1.1	52	57.6	149	165.0
15.	381	421.7	214	236.9	70	77.5	219	242.4	884	978.7
16.	555	614.4	2560	2833.9	139	153.9	4012	4441.3	7266	8044.2
17.	14	15.5	52	57.6	2	2.2	72	79.7	138	152.8
18.	19	21.0	222	245.8	16	17.7	165	182.7	422	467.2
T	4,103	4,541.9	13,715	15,252.6	1,148	1,270.8	19,928	22,060.3	38,923	43,091.9

categories and for each municipality. The data for the conversion calculation are shown in Table 2-18.

Having achieved a reasonably common geographical basis for comparing ERTS and TRC land use data, MITRE then found it necessary to define ERTS and TRC land use categories as precisely as possible so that valid classification comparisons could be made. This has proven to be a complex and difficult task. The main problem was that the TRC data were apparently classified more on an administrative basis, whereas the ERTS data is based on the different spectral characteristics within the test area. For example, tax information and surveys enable TRC to classify land uses such as retail, wholesale and storage, services, and public and semi-public facilities. For these uses in the Test Site, ERTS data are amenable to the development of signatures which indicate building complexes at several density levels, but ground truth is clearly required to discriminate between public buildings and private commercial buildings. On the other hand, since TRC relies heavily on tax maps for land use data, farmland and all other land not developed for residence, commerce, industry or transportation is put into the general category of "vacant". In these areas classified vacant by TRC, ERTS data analysis had signatures for the categories of river, creek, forest, field and denuded area. As the TRC staff has stated, the more specific description and quantification of vacant land by ERTS will add valuable information for the planning of future development in the presently vacant areas.

TABLE 2-18

RELATIONSHIP OF ERTS - 1 PIXEL COUNT TO

PLANIMETERED ACREAGE IN TEST SITE 1

MUNICIPALITY	PLANIMETER ACREAGE	ERTS COUNT
1. CAMP HILL	1355.9	1261
2. EAST PENNSBORO	6290.5	5996
3. HARRISBURG	5045.4	4455
4. HIGHSPIRE	521.4	469
5. HUMMELSTOWN	908.8	791
6. LEMOYNE	1006.9	930
7. LOWER ALLEN	6412.1	5499
8. LOWER SWATARA	8288.2	7905
9. MIDDLETOWN	1287.4	1110
10. NEW CUMBERLAND	1068.7	978
11. PAXTANG	272.6	239
12. PENBROOK	287.7	255
13. ROYALTON	189.0	176
14. SHIREMANSTOWN	159.9	149
15. STEELTON	1170.5	884
16. SWATARA	8126.2	7266
17. WEST FAIRVIEW	207.2	138
18. WORMLEYSBURG	493.4	422
TOTAL COUNTS, TEST SITE 1	43091.8	38923

∴ ERTS-1 PIXEL TO ACRE CONVERSION FACTOR:

$$\frac{43091.8}{38923.0} = 1.107$$

Following discussions with the TRC staff to determine what specific uses were included in their nine categories, and analysis of the signature information derived from ERTS data, it was determined that five common categories would best serve for the comparison of land use acreage. The five common categories are as follows:

1. Industrial - includes all ERTS signatures for industrial and the total TRC industrial category.
2. Urban - includes the ERTS signatures for urban area and the TRC categories for retail, wholesale and storage, services, and public and semi-public.
3. Vacant - includes the total TRC vacant category and the ERTS signatures for forest, field, and denuded area (TRC did not include river and creek area in their land use acreage).
4. Transportation - includes the ERTS signatures for transportation (railroads and paved runways) and the TRC categories of transportation facilities and transportation terminals.
5. Residential - includes the total TRC residential categories and the ERTS signatures for suburbs.

After several preliminary comparisons were made using these five common categories, it was found that ERTS signatures in the urban and industrial categories were frequently confused. Apparently the present state of analysis is not adequately developed to discriminate consistently between building complexes which are commercial/institutional and those which are industrial in use. Consequently, the industrial and urban categories were merged as urban for correlation purposes, as shown in Table 2-16.

With a common geographical basis established and reasonably common category definitions determined, all the TRC and ERTS data were retabulated into the four correlation categories. When this was completed, an initial scan of the results showed one major discrepancy and several smaller anomolies. The major problem was that for nearly every municipality and for the test site as a whole, the ERTS total acreage for all categories was over 30 percent greater than the TRC total acreage. A re-calculation by planimeter of the total acreage in each municipality and in the total test site confirmed that the ERTS totals were correct, and that TRC totals were low by fully one-third. Obviously some category or categories of land use in the area were not being included in the TRC counts. The smaller anomolies affected the apportionment of acreage among particular municipalities and could very possibly have been the result of annexations or other boundary changes not reflected on the map used for projecting the boundaries of the 18 municipalities. In any event, no explanation for the discrepancies was apparent in the planning studies and other data provided by TRC, so a conference was held in Harrisburg to discuss the problems point by point with the TRC staff.

The conference with the TRC staff was very valuable, both for clarifying discrepancies and for providing an opportunity to review ERTS land use analysis progress with individuals who will be the ultimate users of the information developed. On the first question regarding a possible 30 percent or more acreage undercounting by TRC, the answer was forthcoming after a review of the methods used by TRC in gathering land use data. Because acreage was computed from parcels listed in tax records and maps, sidewalks, streets, highways and rights-of-way generally were not counted in any category as part of total land use by TRC. The planning staff estimated that the streets, sidewalks, and highways for the area under consideration would amount to about 30 percent of total acreage. Since the ERTS data analysis had minimum interpretation resolution of about one acre, streets, sidewalks, and highways were incorporated into the broader land use category signatures in the ERTS results. Apportioning the street, sidewalk, and highway acreage among the TRC categories, then, would allow a valid basis of comparison of the ERTS and TRC data.

Unfortunately, only the 1967 land use data and maps already on hand were available, and these gave no indication of right-of-way acreage. (The TRC offices are located on Front Street adjacent to the Susquehanna River, and the disastrous flooding caused by Hurricane Agnes in June 1972 destroyed all more recent data, which included street and highway surveys as well as updated land use). Some individual municipalities could provide estimates of annual amounts of paving materials used on rights-of-way, but there was apparently no reliable way of determining how the acreage was apportioned among the urban, residential, transportation, and vacant categories. In general, the TRC staff agreed that nearly all of the right-of-way acreage should be allocated to the urban and residential categories, since rights-of-way were included in the transportation category, and probably less than one percent of the vacant category would be comprised of streets, sidewalks, and highways. The problem, then, became how most reasonably to allocate the right-of-way acreage (about 10,000 acres) between the urban and residential categories.

The solution ultimately arrived at, and concurred in by Commonwealth of Pennsylvania and TRC planners, was to apportion the acreage between the two categories by a coefficient for the urban and for the residential categories which would result in the optimum statistically significant apportionment for all 18 municipalities and for the total test area. The specific method used to reconcile the difference was a University of California multiple linear regression analysis package[1], which in summary computed the sequence of 18 regression equations to arrive at the best fit for all 18. The results of the computation are shown in Figure 2-28. These results show that increasing urban acreage by a factor of 2.09320 and increasing residential acreage by a factor of 1.79877, while leaving transportation and vacant acreage unchanged, will result in the best allocation of street, sidewalk, and highway acreage between the urban and residential categories for all 18 municipalities.

---

[1]Dixon, W. J., ed., BMD - Biomedical Computer Programs (University of California Press, 1968), pp. 233-257.

VARIABLES IN EQUATION

VARIABLE	COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT	0.0)		
URBAN 2	2.09320	1.78487	1.3753 (2)
RESIDL 3	1.79877	0.44922	16.0337 (2)

SUMMARY TABLE

STEP NUMBER	VARIABLE ENTERED	VARIABLE REMOVED	MULTIPLE R	RSQ
1	RESIDL 3		0.8972	0.8050
2	URBAN 2		0.9058	0.8205

FIGURE 2-28

EXERPT OF RESULTS FROM REGRESSION ANALYSIS COMPUTATION

To ensure that this allocation procedure was not only statistically significant, but realistic in terms of the actual proportion of right-of-way acreage in metropolitan areas, a meeting was held with officials of the Urban Planning Division of the Department of Transportation in Washington. Their studies and analysis generally confirm that heavily developed downtown areas of cities (which would conform to the urban category definition) will have about 50 percent of their surface area in streets, sidewalks, and highways. MITRE's calculations show that 52 percent of urban acres consisted of right-of-way acreage. The residential category would be comprised of a lesser percentage of right-of-way acreage, and the allocation computations show 44 percent for this category. Further information obtained at a later date from Harrisburg city officials via Commonwealth of Pennsylvania planners also corroborated the finding that street, sidewalk, and highway acreage made up about 50 percent of the land in the city, which further indicates that the statistically derived coefficients of 2.09320 and 1.79877 are reasonable in terms of the actual occurring proportion of right-of-way acreage in metropolitan areas. In the absence of any actual acreage data for the 18 municipalities in the test area and with virtually no other means available for measuring how many acres of streets, sidewalks, and highways should be apportioned to each land use category, MITRE's method of allocation is considered valid for arriving at a common acreage basis for correlation testing.

The several other discrepancies discussed at the conference with the TRC staff were also clarified, and a detailed description of the corrections required may be found in MITRE Corporation Memorandum D22-M-1835 of 6 August 1973. In general the corrections fell into three main categories:

1. Boundary change among the 18 municipalities that were reflected in TRC acreage tabulations but not on older maps which were used to project the boundaries onto the ERTS computer maps.
2. Classification by TRC of one large airport and several large parks as public land, which caused their acreage to be merged incorrectly with the urban category for comparison purposes. These acres were subsequently reassigned to the transportation and vacant categories, respectively.
3. Human error in manual symbol counting and planimetering in several smaller municipalities with very irregular boundaries. These errors were minor and are considered to have been averaged out over the total 18 municipality test area.

All of the above corrections and adjustments were made to the basic data, including the allocation of the approximately 10,000 right-of-way acres to the TRC urban and residential categories for each municipality. Table 2-16 shows the category-by-category, municipality-by-municipality comparison of ERTS and TRC land use acreage. As expected, correlations are much better for the total test area than for any of the individual 18 municipalities.

Table 2-19 shows the summary of correlations for the entire test area including all 18 municipalities. With the exception of the transportation category, the ERTS acreage compares very closely in all areas,

TABLE 2-19

COMPARISON OF ERTS - 1 WITH TRC* SURVEY DATA

TEST SITE 1

	URBAN	RESIDENTIAL	TRANSPORTATION	VACANT	TOTAL TEST SITE
TRC DATA (ACRES)	4309	17970	2136	19380	43,795
ERTS DATA (ACRES)	4542	15182	1271	22060	43,055
ACRES IN DISAGREEMENT	+ 233	- 2788	- 865	+ 2680	6,566
PERCENT AGREEMENT	94.6	84.5	59.5	86.2	85.0

* TRI-COUNTY REGIONAL PLANNING COMMISSION (HARRISBURG, PA.)

and the overall skill score, as indicated, is 85.0 percent. One reasonable explanation of why the transportation category does not show a higher correlation has since been provided by TRC. The TRC transportation acreage counts include bus and truck terminal buildings in addition to railways and airports. Because Harrisburg is a major highway transshipment point for New York, Philadelphia, Baltimore, Washington, and points west, there are a large number of truck terminals in the test area. These terminal buildings, depending on their size and location, would probably be classified by ERTS as urban, with large open parking areas classified as vacant. If a method is found for accurately quantifying the required adjustments, then the ERTS urban acreage can be reduced, transportation and vacant increased, and the skill score as a result would be higher. In any event, in light of the requirement for using 1967 acreage data and a 1965 land use base map for ground truth, in addition to the requirement to adjust the ground truth for the inclusion of street, sidewalk, and highway data, the results clearly are significant enough to show that ERTS data analysis does provide a new tool for accurate land use inventory on a local metropolitan scale.

2.3.1.3 Land Use for Harrisburg Test Site - 9 January 1973. The first attempt to look at the 9 January 1973 data involved the computation of an intensity map. However, an error was encountered in trying to subset the area of interest. Mr. Feinberg of GSFC was contacted and he referred the problem to Mr. Bill Watt of GSFC. Mr. Watt asked to have the copies of that data since no other investigators had reported errors. He found the problem (i.e., double end of file at beginning of tapes) and had a new set copied from the master. However, in trying to subset those tapes there was still an error. This time Mr. Watt decided to check the master and found that the ID records at the beginning of the tape were garbled. With that problem discovered a corrected set of tapes was sent and the processing was begun on the January data.

The first attempt to classify January involved the direct substitution of the 11 October 1972 signatures into the classification program. This was to see if any of the signatures could be directly transferred. It was found, however, that this did not work at all. So signatures had to be developed specifically for January (Table 2-20).

In order to classify the Susquehanna River entirely several (six) water signatures had to be developed. This is due to large chunks of ice in the river. Other signatures were developed as for October. The final classification map is shown in Figure 2-29.

The area of possible confusion for January resulted from the category creek showing up in areas where there was no water. However, with snow and ice in the area this could have been the true response of the target.

2.3.1.4 <u>Land Use for Harrisburg Test Site - 9 April 1973</u>. The land use analysis for 9 April 1973 presented no special problem, (Table 2-21 and Figure 2-30). The category residential was the most difficult to classify correctly. Eight different residential signatures were needed, with one for each major area. Although some of the categories

TABLE 2-20

SIGNATURES FOR LAND USE - 9 January 1973

CATEGORY	CHANNEL 4	CHANNEL 5	CHANNEL 6	CHANNEL 7
Water	33.87	30.00	22.87	5.75
Water	32.80	27.40	19.80	5.20
Water	21.68	16.53	10.80	2.58
Water	19.47	13.33	8.34	1.90
Water	23.82	19.50	12.78	3.02
Water	25.38	21.03	14.19	3.16
Creek	16.61	11.58	9.45	3.93
Creek	14.93	8.65	6.63	1.50
Runway	20.67	16.25	14.43	5.50
Runway	20.87	17.73	19.47	9.07
Rail	16.80	11.96	8.98	3.07
Residential	19.87	16.35	18.43	9.17
Residential	22.88	19.82	22.24	10.71
Trees	14.93	9.21	8.39	3.46
Trees	16.86	12.42	12.32	5.74
Urban	19.01	14.47	12.94	5.18
Building	33.55	33.77	31.05	13.00
Industrial	17.74	12.80	10.46	4.01
Agriculture	20.21	17.69	18.30	9.07
Open Land	19.39	15.63	16.13	8.08
Open Land	24.60	22.56	23.84	11.08
Open Land	21.00	20.83	18.83	8.17
Bare	18.00	15.36	18.17	10.17

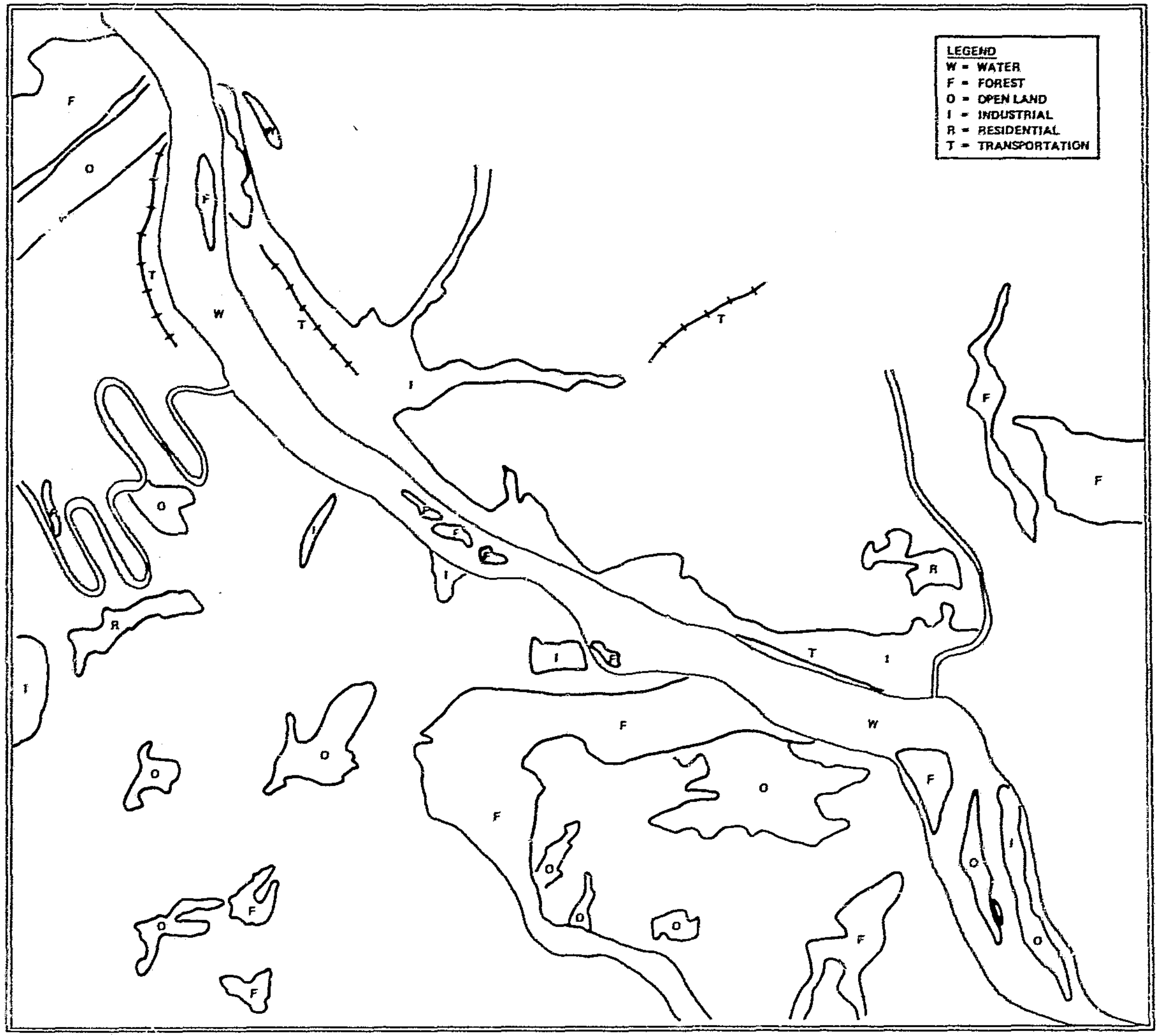


FIGURE 2-29
LAND USE CLASSIFICATION—HARRISBURG
9 JANUARY 1973

TABLE 2-21

SIGNATURES FOR LAND USE - 9 April 1973

CATEGORY	CHANNEL 4	CHANNEL 5	CHANNEL 6	CHANNEL 7
Water	31.17	26.33	15.11	2.74
Water	29.52	24.60	15.29	3.76
Water	31.94	28.07	18.13	4.20
Creek	31.83	27.14	22.84	7.83
Creek	28.65	24.00	20.96	8.08
Rail	27.86	22.91	19.73	7.85
Rail	21.17	22.47	22.18	10.07
Runway	32.67	27.86	39.05	20.86
Runway	42.20	38.00	47.40	24.40
Trees	26.88	22.08	29.22	15.83
Trees	26.87	23.16	26.15	13.79
Trees	25.39	21.85	24.28	12.59
Residential	40.65	37.41	40.43	19.60
Residential	42.00	39.67	43.67	20.83
Residential	37.87	37.98	44.54	22.91
Residential	32.91	30.82	45.27	24.09
Residential	29.35	25.74	25.81	12.39
Residential	39.41	35.24	35.69	16.45
Residential	40.50	43.50	47.50	24.00
Residential	30.39	24.07	48.16	27.80
Urban	33.54	29.70	30.93	14.85
Industrial	38.47	33.42	34.80	16.07

TABLE 2-21 (Continued)

SIGNATURES FOR LAND USE - 9 April 1973

CATEGORY	CHANNEL 4	CHANNEL 5	CHANNEL 6	CHANNEL 7
Bare	31.57	30.29	38.00	20.00
Agriculture	33.08	31.88	27.66	19.43
Bare	31.70	29.75	35.48	18.81
Open Land	29.38	24.38	46.05	26.48
Open Land	31.70	26.51	44.21	24.46
Open Land	31.47	27.87	28.87	13.73

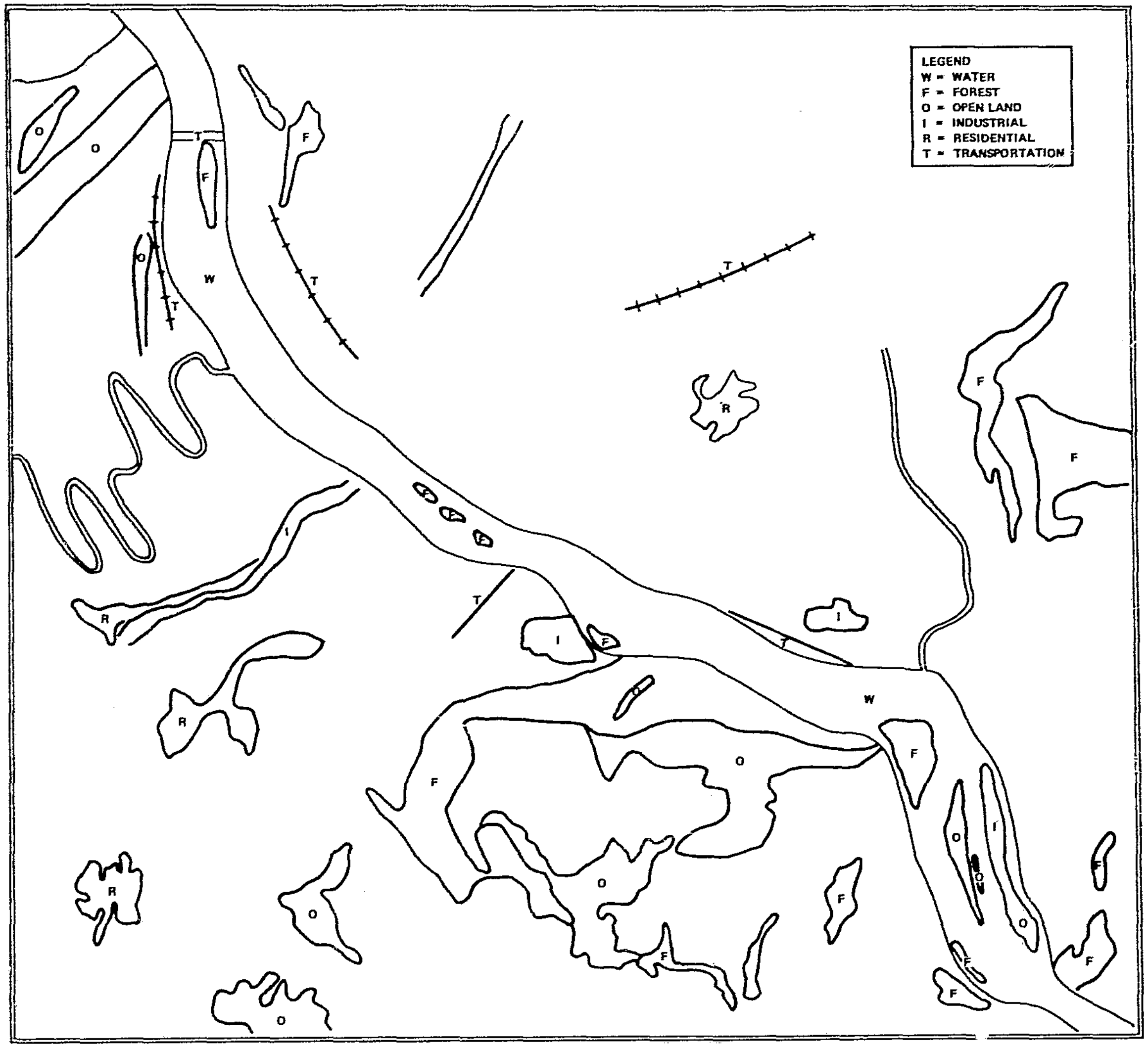


FIGURE 2-30
LAND USE CLASSIFICATION—HARRISBURG
9 APRIL 1973

could have been combined, they were left un-combined in order to get the most precise classification for residential.

2.3.1.5 Land Use for Harrisburg Test Site - 8 July 1973. There were no special problems working the 8 July 1973 data. The signatures are included in Table 2-22, and the classification map is Figure 2-31. All major areas described in October section are also mapped out in July. In order to check the land use shifts from October through July, computer map comparisons were run.

2.3.1.6 Land Use Trend Analysis. For four of the five land use dates analyzed, the areas that were classified were chosen to include, as close as possible, the same boundaries. Therefore, each class can be compared from month to month using the percent of total area classified of the respective classes. Table 2-23 shows this breakdown.

TABLE 2-23

PERCENT DISTRIBUTION OF LAND USE CLASSES, HARRISBURG

	AUGUST 1972	OCTOBER 1972	JANUARY 1973	APRIL 1973	JULY 1973
Water	8	8	8	8	8
Industrial	5	6	8	6	6
Transportation	7	8	6	8	8
Residential	28	20	20	19	17
Forest	20	17	20	17	18
Open Land	28	40	38	41	41
Other	3	2	0	2	3

TABLE 2-22

SIGNATURES FOR LAND USE - 8 July 1973

CATEGORY	CHANNEL 4	CHANNEL 5	CHANNEL 6	CHANNEL 7
Water	36.83	26.82	20.18	5.31
Water	38.71	28.83	22.25	6.00
Water	36.00	27.00	30.67	13.00
Creek	38.17	28.55	33.86	14.21
Rail	38.30	29.92	30.48	12.14
Rail	37.72	29.44	33.64	13.68
Runway	40.34	30.88	51.61	26.34
Runway	46.00	40.33	52.27	25.13
Industrial	39.04	31.01	34.14	14.91
Urban	45.55	39.09	35.22	13.27
Building	49.93	46.36	42.29	16.36
Urban	47.42	38.83	47.93	22.12
Residential	42.30	32.39	45.96	21.74
Residential	38.96	30.10	51.41	27.37
Trees	33.43	22.51	50.98	29.50
Trees	30.33	18.74	57.09	34.76
Agriculture	42.43	39.09	57.35	28.78
Agriculture	38.19	28.04	58.41	31.85
Bare	42.30	29.15	65.61	35.91
Open Land	39.95	28.57	50.81	26.91
Bare	40.62	29.76	60.67	33.14
Open Land	30.61	19.00	60.82	36.98

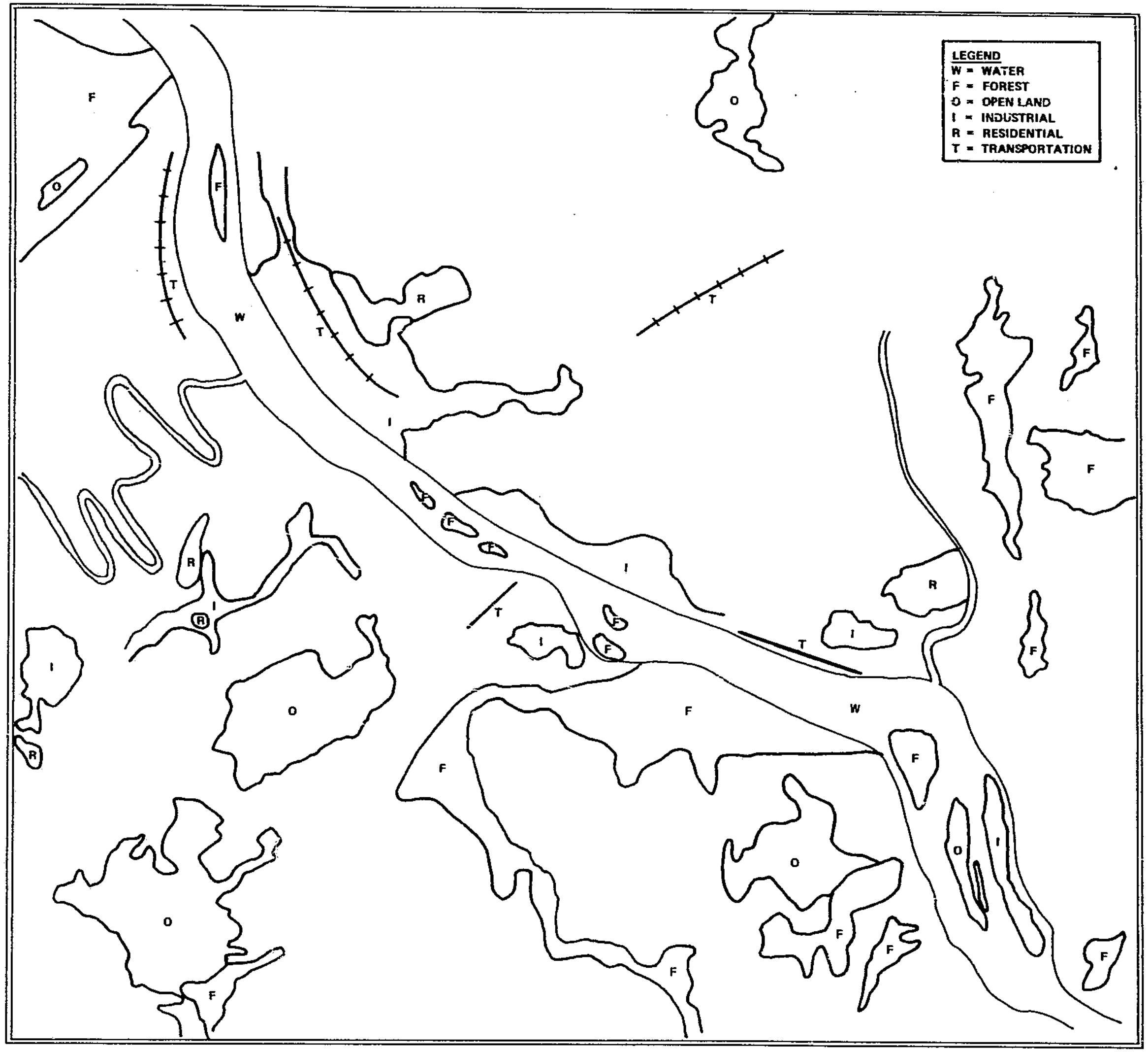


FIGURE 2-31
LAND USE CLASSIFICATION—HARRISBURG
8 JULY 1973

August has been included to complete the table for all dates considered. This is the only month for which the boundaries are different. Only 90% of the test area was covered, thus the percentage is expectedly different from the rest. Notice that for October 1972 through July 1973 no category changed more than 3%. Since the time lapse is short, the amount of this change that is due to land use shift is negligible. The remainder then, is due to a combination of the following: (1) the application of new regression coefficients to the CCT data after April 1973 to eliminate radiometric striping, (2) the fact that the CCT's are not geometrically corrected for effects such as skew as a function of earth rotation, and/or (3) the variability of the oscillating flat mirror (this scans the crosstrack field of view) which causes the data of the CCT to reflect the distance covered on the ground inaccurately.

Besides this comparison, a special program was run to compare the output date by date. In this test, July 1973 was used as a base date. All other dates were merged one by one with the July data. Then the map comparison program (MAPCOMP) was applied to each data set. In short, MAPCOMP classifies the data in the same way as the DCLASS program. Then the output is compared according to the symbol assigned by DCLASS. The digital map of the area then shows five levels of comparison where (1) symbol 1 equals symbol 2 (2) symbol 1 does not equal symbol 2 (3) symbol 1 equals other (i.e., the pixel was unclassified), symbol 2 does not equal other (ie., pixel was classified)

(4) symbol 1 does not equal other, symbol 2 equals other (5) symbol 1 and symbol 2 equal other. The results of the comparison are as follows:

TABLE 2-24

PERCENT DISTRIBUTION OF MAP COMPARISONS

	JULY VS. OCTOBER	JULY VS. JANUARY	JULY VS. APRIL
1	45	41	39
2	49	56	56
3	2	3	2
4	2	0	2
5	0	0	0

The map comparison on the whole does not show the agreement that is shown by the comparison in Table 2-23. This in part is due to the fact that every other line and element is being used. For example, the MAPCOMP program could be classifying pixel $x_{i,j}$ (i line, j element) from map 1 and comparing it to either $x_{i,j}$, $x_{i+1,j}$, $x_{i-1,j}$, $x_{i,j+1}$ or $x_{i,j-1}$ of map 2. That is to say that if the lines and elements for map 2 are not covering the same area as map 1 then the targets that MAPCOMP are trying tc compare could be as much as 70 meters removed from one another. (Geometric errors of hundreds of meters in bulk CCT's is more than enough to explain the lower scores of Table 2-24). In an area that is uniform there is no problem; however when boundary lines are crossed pixel x of map 1 will probably not be the same as pixel y of map 2 and this will result in low comparison percentages.

There is also a problem inherent in using bulk rather than precision processed tapes. Precision data, also available from GSFC, may eliminate some distortion; however, the MITRE investigation made use of bulk processed CCT's exclusively.

The final attempt to compare the land use classifications consisted of map comparisons of July versus October. These maps were generated using the MAPCOMP program; however, only the signatures of the specific categories were compared. Confusion could arise since there are classes which have similar responses, i.e., forest and grassland, and when only one signature is used then the signature classifies both open land and grassland. For the regular classification maps, this does not happen since all signatures are used.

The results are included as Figures 2-32 through 2-37. For five of the figures (other than water) the Susquehanna River and the Condoguinet Creek have been included as reference. The summaries for these six maps are given in Table 2-25. Classes 1-5 are the same as previously described.

TABLE 2-25

OCTOBER VS. JULY INDIVIDUAL LAND USE COMPARISON

	WATER	TRANSPORTATION	RESIDENTIAL	INDUSTRIAL	FOREST	OPEN LAND
1	8	4	45	9	19	72
2	0	0	0	0	0	0
3	3	15	34	18	29	7
4	2	9	7	7	3	9
5	87	72	13	66	46	13

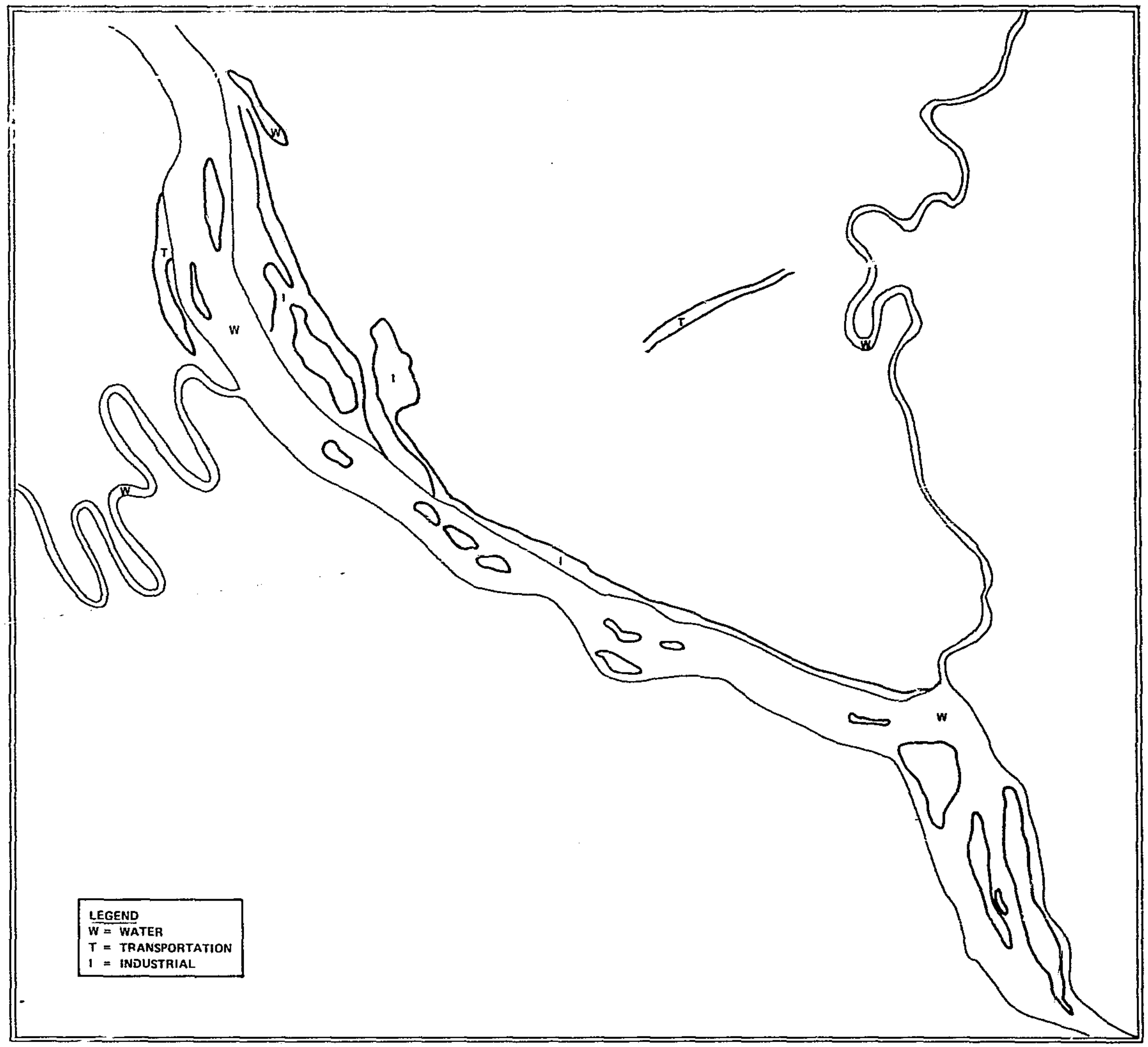


FIGURE 2-32
OCTOBER vs. JULY—HARRISBURG
MAP COMPARISON FOR WATER

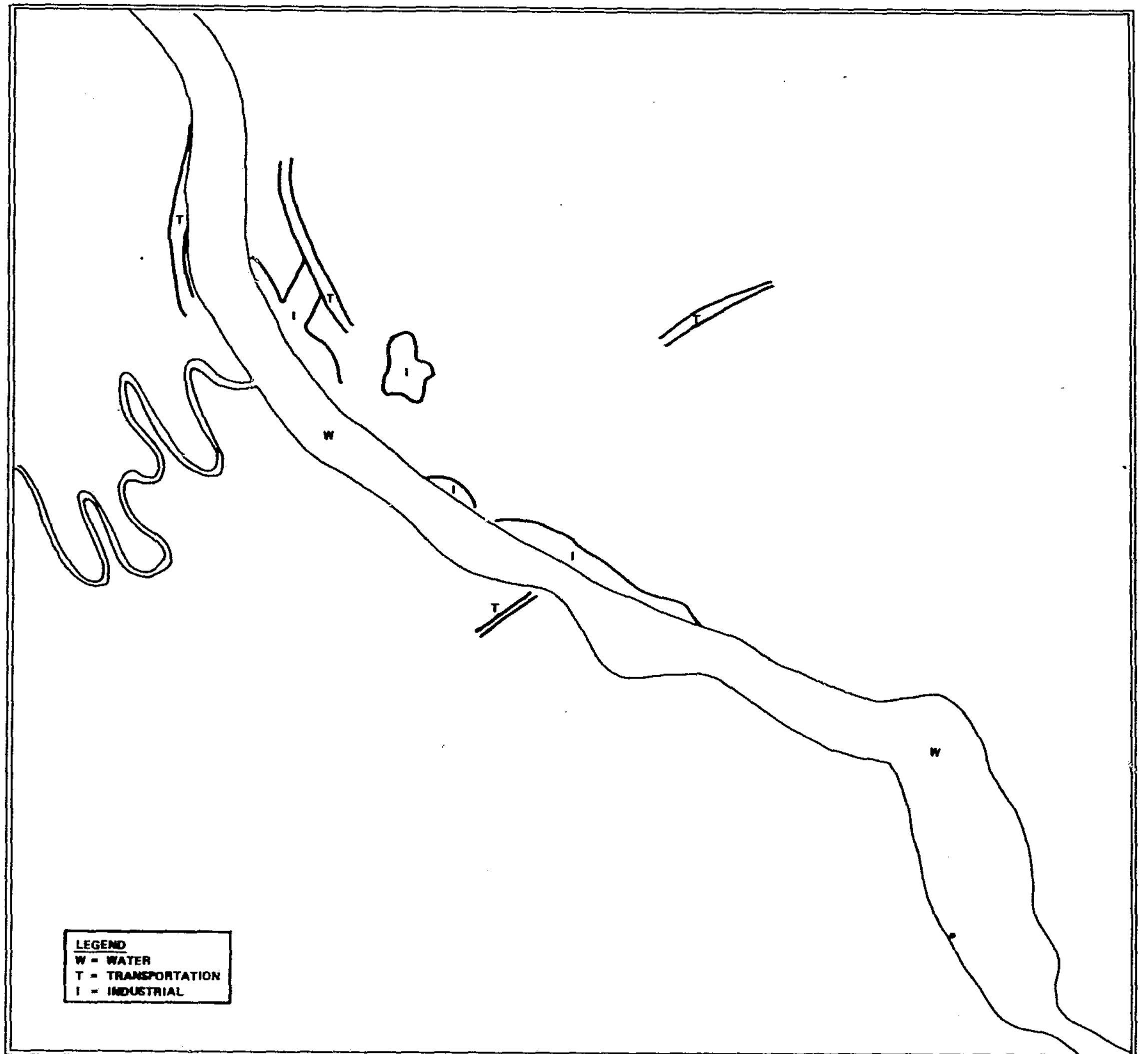


FIGURE 2-33
OCTOBER vs. JULY—HARRISBURG
MAP COMPARISON FOR TRANSPORTATION

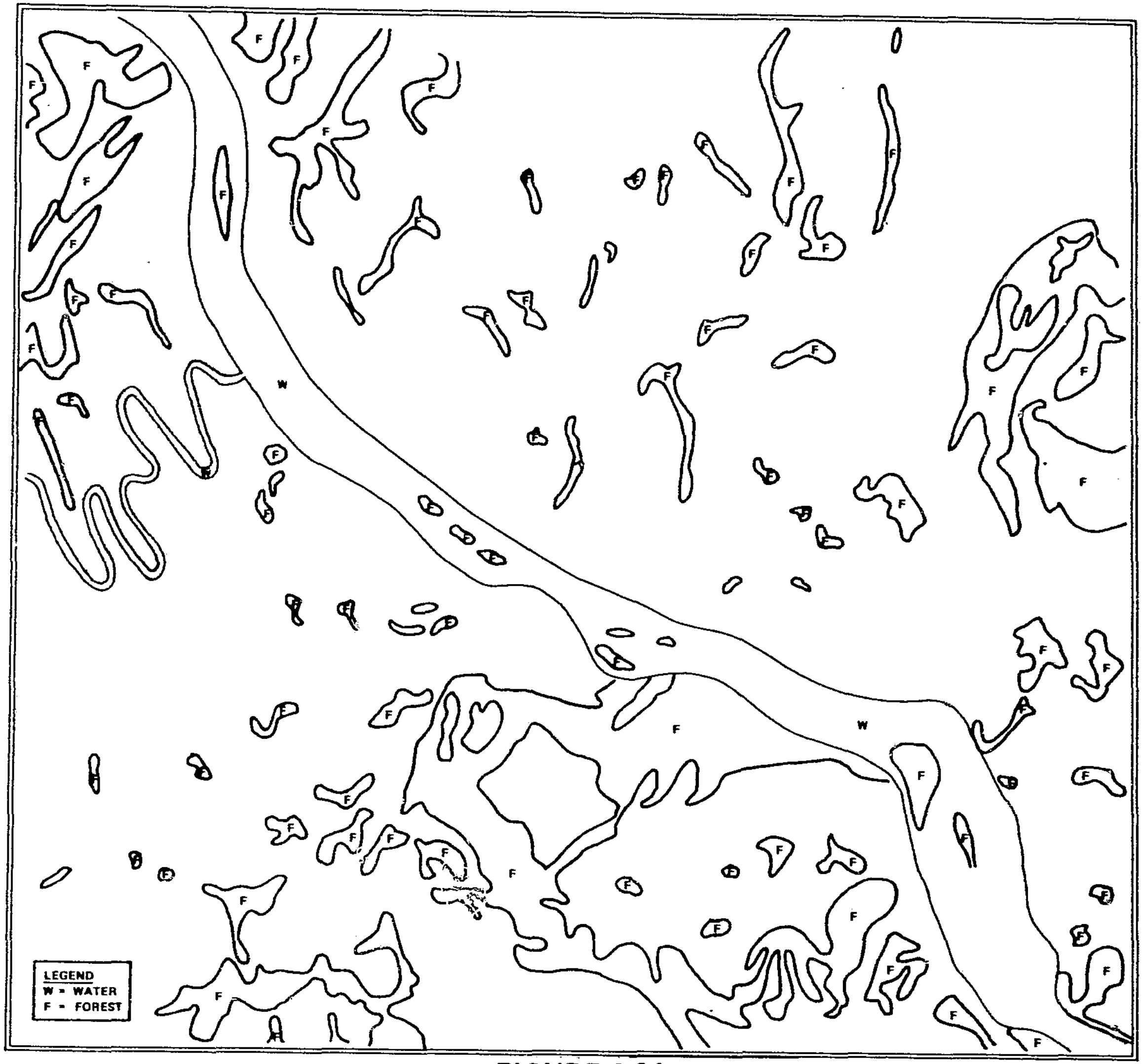


FIGURE 2-34
OCTOBER vs. JULY—HARRISBURG
MAP COMPARISON FOR FOREST

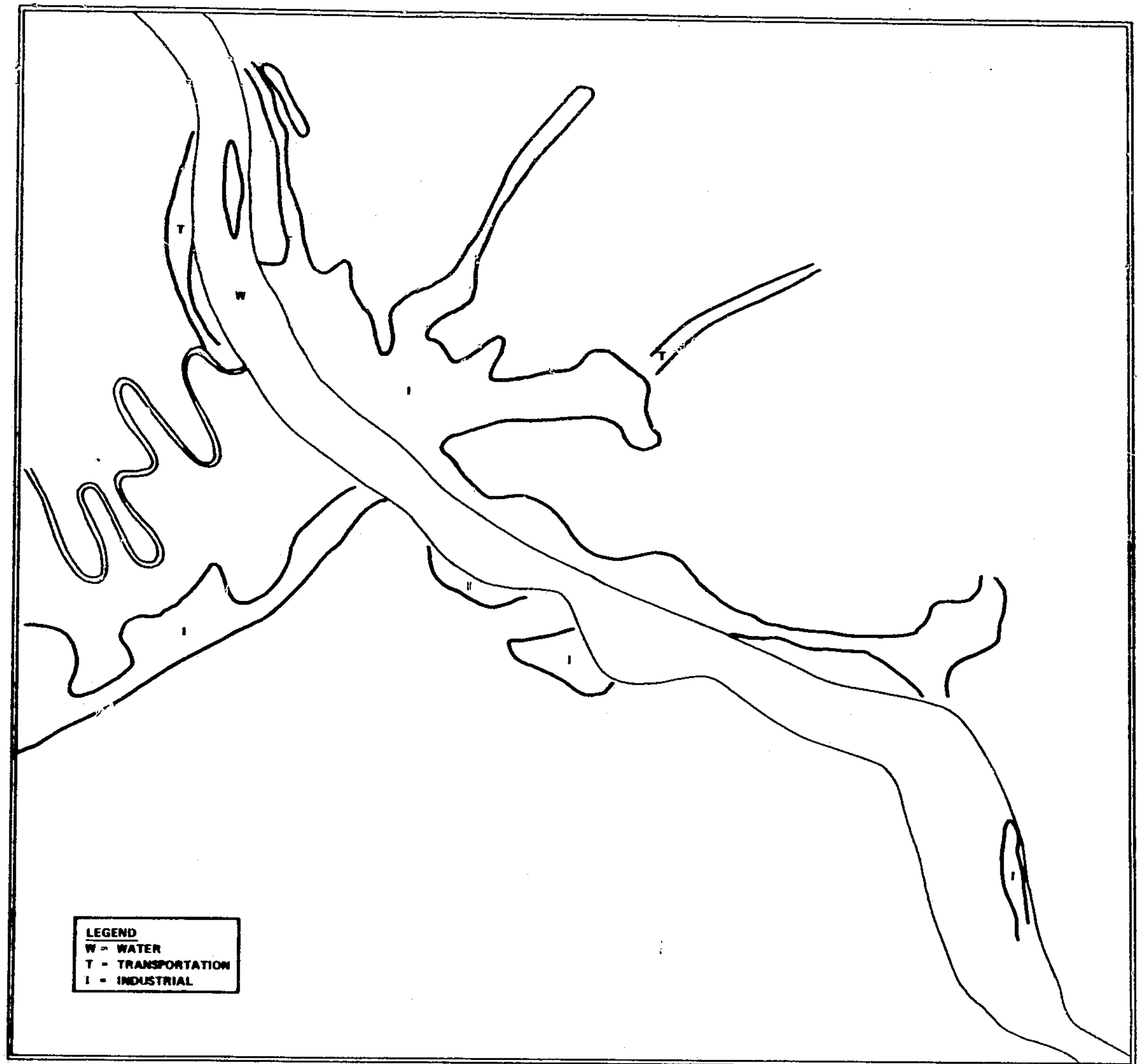


FIGURE 2-35
OCTOBER vs. JULY—HARRISBURG
MAP COMPARISON FOR INDUSTRIAL

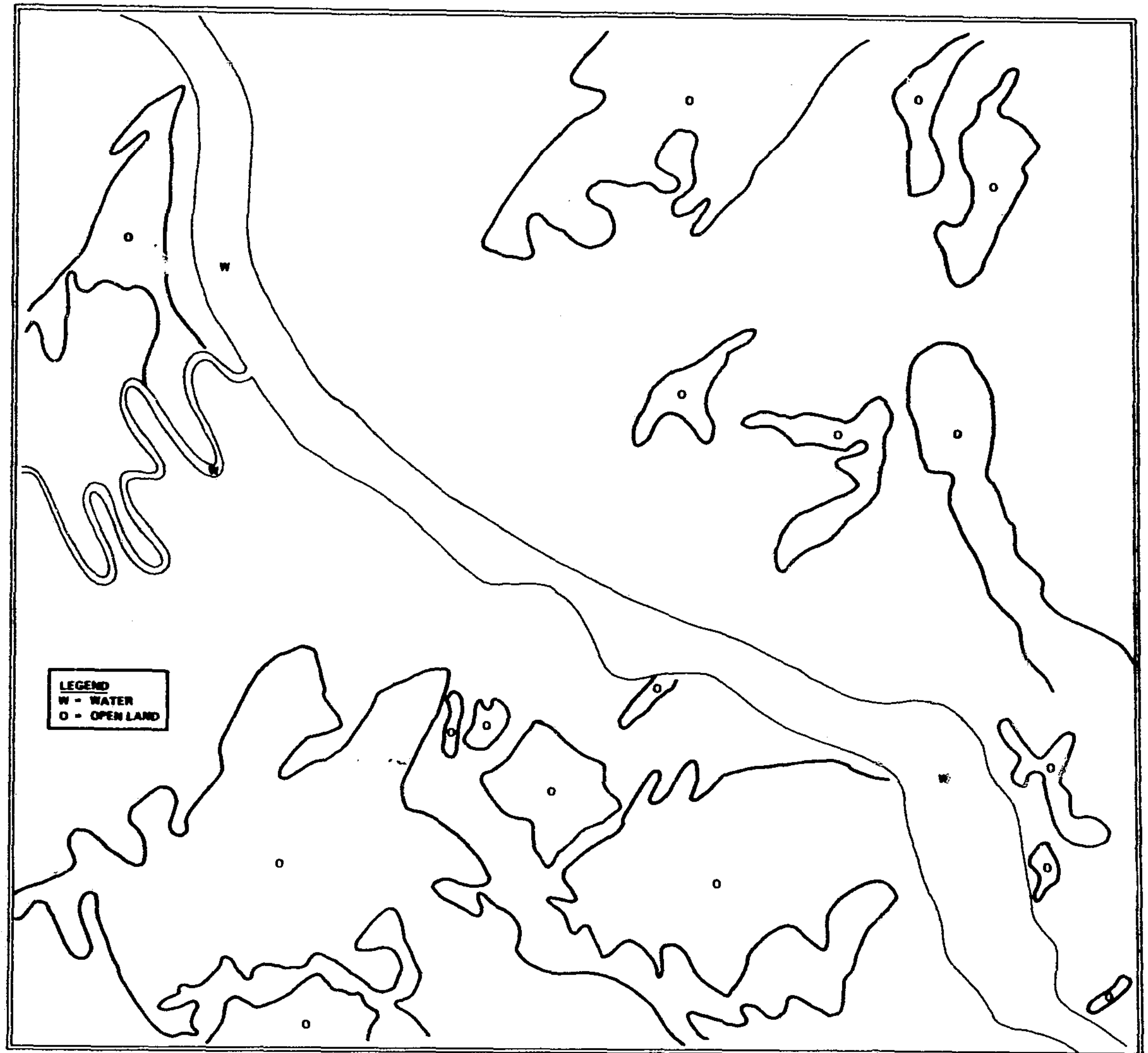


FIGURE 2-36
OCTOBER vs. JULY—HARRISBURG
MAP COMPARISON FOR OPEN LAND

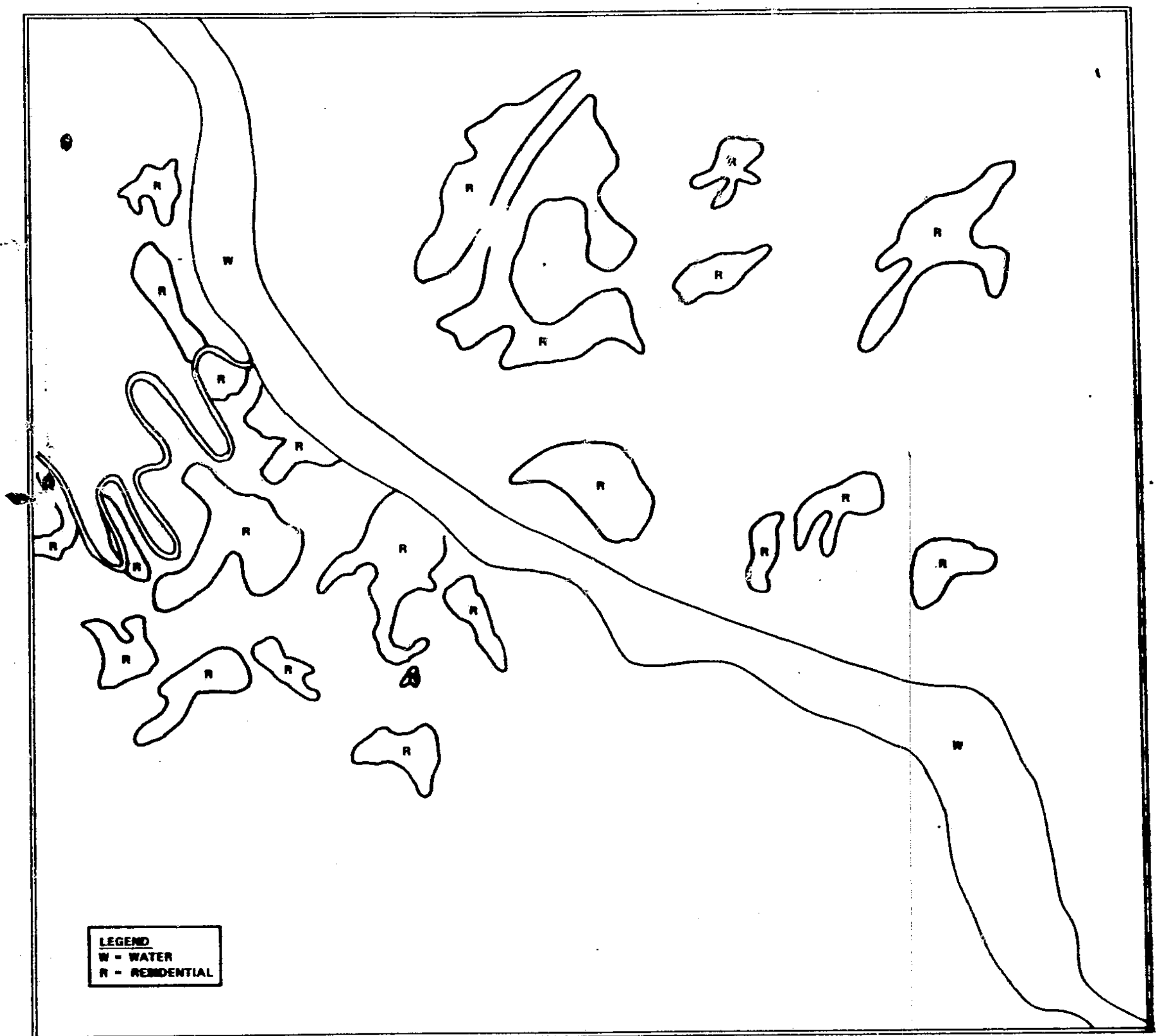


FIGURE 2-37
OCTOBER vs. JULY—HARRISBURG
MAP COMPARISON FOR RESIDENTIAL

Since Table 2-25, like Table 2-23, represents the percent of the total area classified, the two can be directly compared. Specifically using category 1 of Table 2-25, there is close agreement for the categories of water, industrial, forest and transportation; residential and open land contain some confusion. Each category classifies as follows:

WATER - the category is correctly delineated; there is additional classification of the rail yards.

TRANSPORTATION - classifies the three rail yards and the Harrisburg State Airport; it does not classify the runways of Olmstead AFB. There is some additional classification of the industrial area around Harrisburg.

FOREST - this category is classified correctly with no superfluous classification.

INDUSTRIAL - classifies industrial areas correctly, with some additional classification of transportation.

OPEN LAND - there was quite a bit of confusion in this category with forest; this is due, as previously mentioned, to only having one set of signatures used. In order to show the boundaries of the category, open land, the map of the category forest was overlaid onto open land and the open land map includes the outline of all areas other than forest.

RESIDENTIAL - there was some confusion in this category with industrial areas. The final map was evolved using the same method that was used for open land.

In conclusion, it has been shown that land use classification to the level of detail discussed above can be achieved using CCT's and aircraft underflight photographs quickly and accurately. The signatures, although not transferable from date to date, can be easily developed with the presence of accurate ground information for a few training areas (5 to 10 pixels each) of a larger test site (containing 7 million pixels). ERTS coverage will not replace conventional land use mapping techniques where the ultimate in geometric registration is required. However, as a complementary tool, it is very useful in updating existing geometric presentations. It will allow the planners to add information such as land use change on a systematic and cost effective basis.

2.3.1.7 Land Use - Algorithms. In an effort to determine the possibility of more rapid classification techniques, an investigation began concerning the development of land use signature variation algorithms. The changes in the signatures from month to month are due to (1) the change in the intrinsic reflectance of the target, (2) the solar elevation angle, and (3) the change in atmospheric backscatter.

All signatures were grouped by categories and plotted. Four categories will be discussed, two inorganic targets (buildings, Figure 2-38, and railyards, Figure 2-39) and 2 organic targets (forest, Figure 2-40 and agriculture, Figure 2-41). For the organic targets there is a distinct rise in the graph in channel 6 for all months but January, the middle of the dormant season. For the railyards there is slight rise in channel 6; this could be the result of

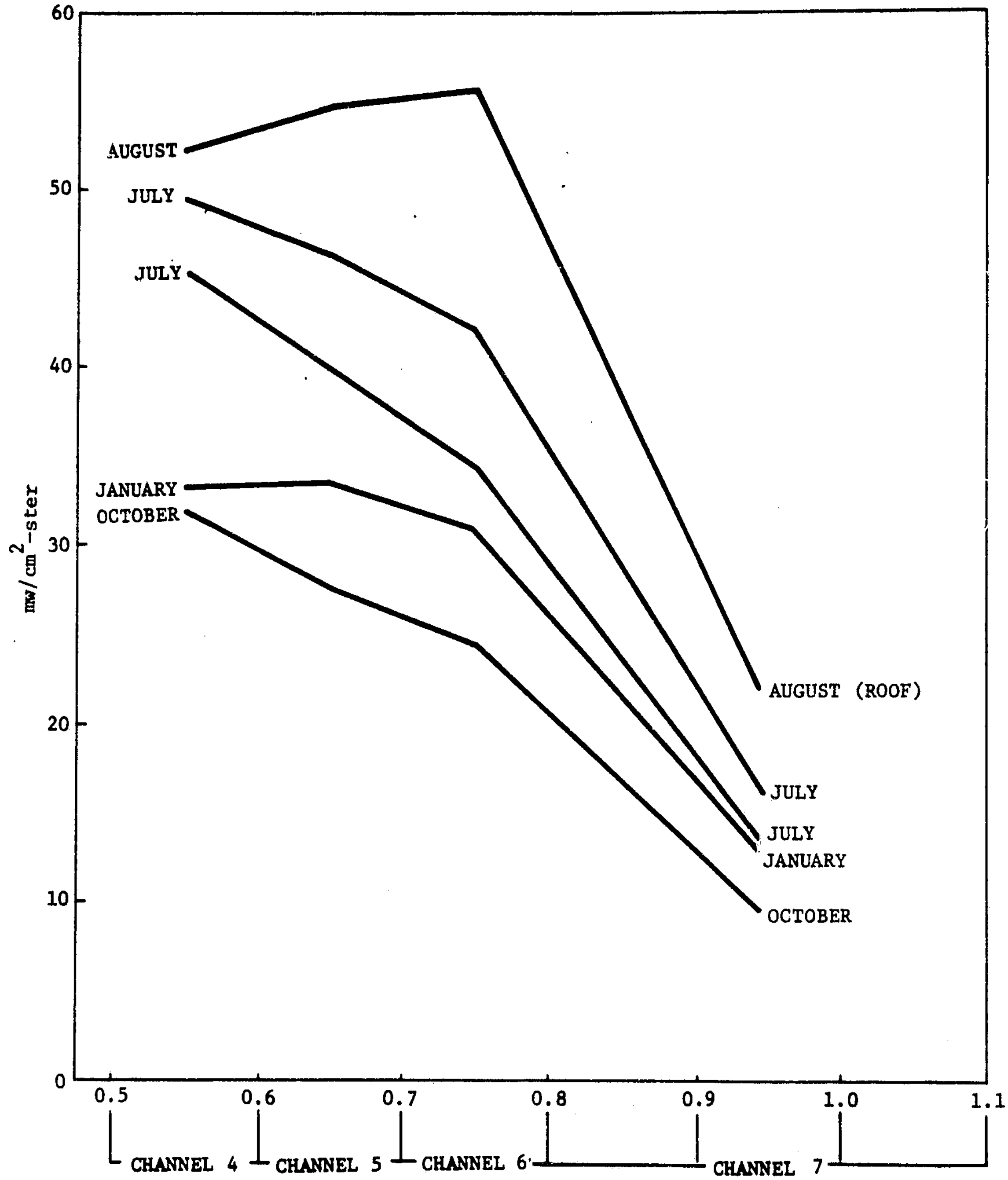


FIGURE 2-38
SIGNATURE PLOT FOR INORGANIC CLASS
BUILDING

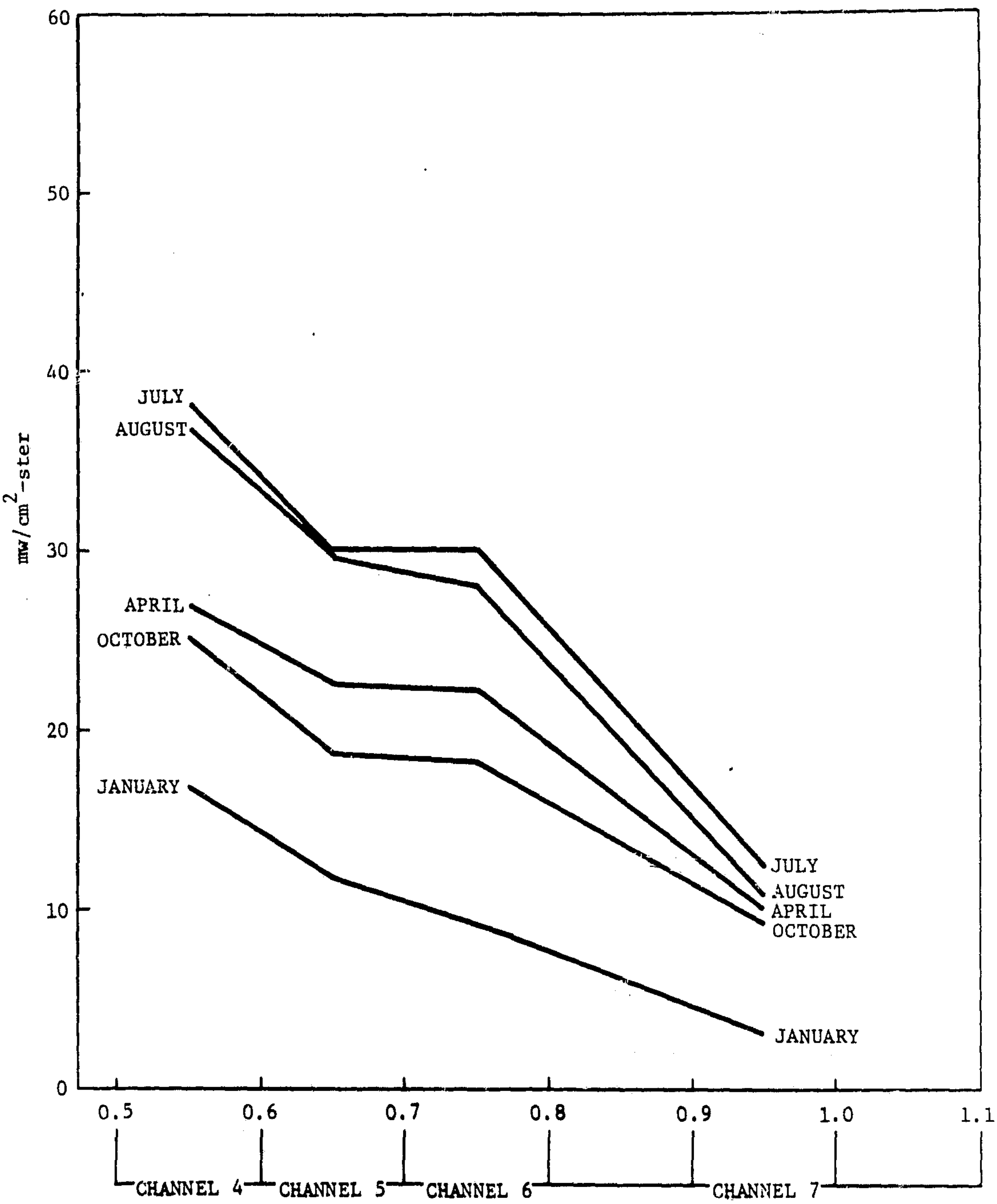


FIGURE 2-39
SIGNATURE PLOT FOR INORGANIC CLASS
RAILYARDS

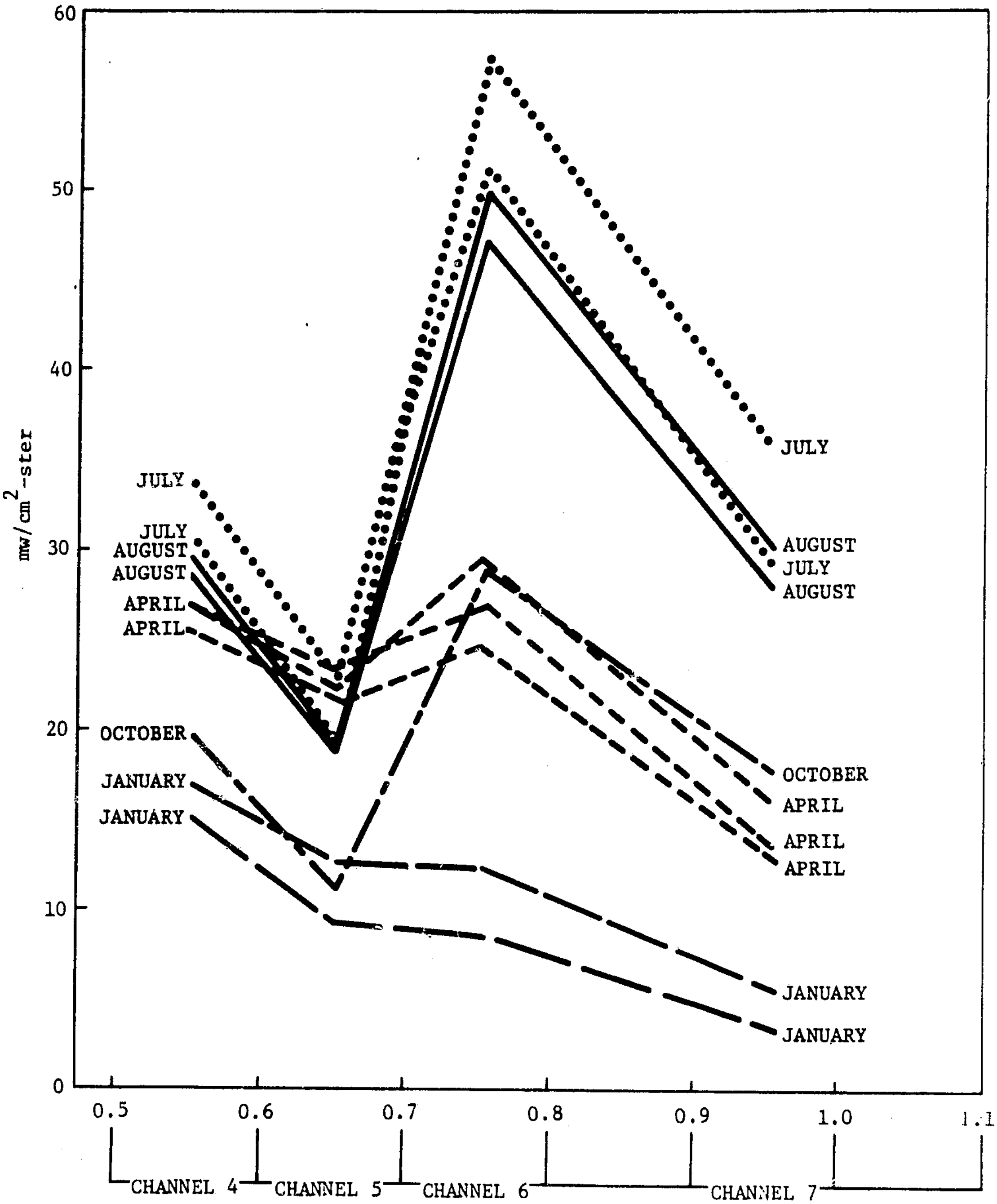


FIGURE 2-40
SIGNATURE PLOT FOR ORGANIC CLASS
FOREST

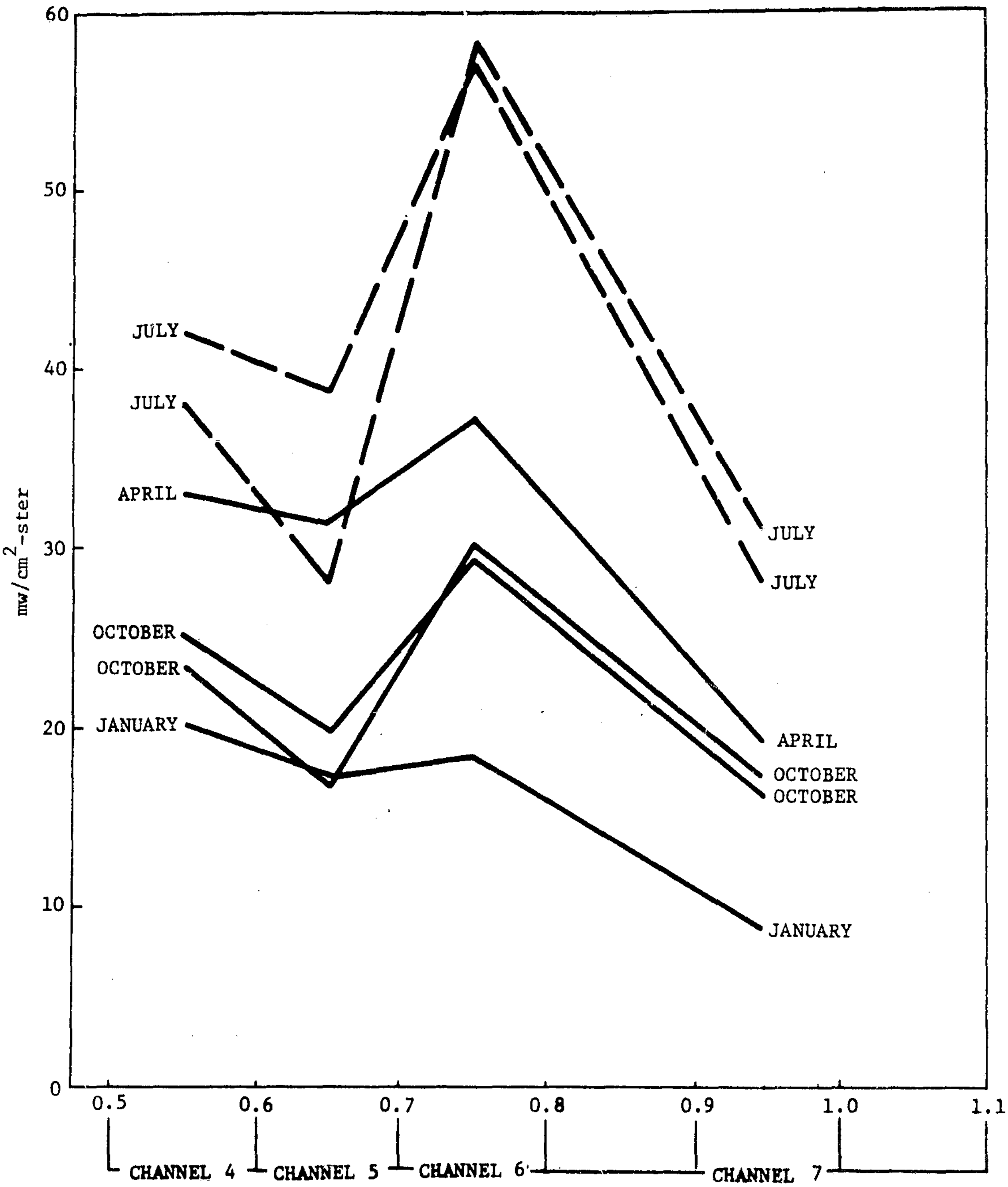


FIGURE 2-41
SIGNATURE PLOT FOR ORGANIC CLASS
AGRICULTURE

low vegetation growing around the area (also explaining the confusion with creek as stated in the land use discussion). For the category building, there is no evidence of organic growth.

The effect of sun angle can be seen in Figures 2-42 and 2-43, for forest and railyards respectively. For the inorganic target the signatures, with the sun angle effect removed, tend to cluster together, and in some cases overlap. The reason they do not totally overlap is probably due to the atmospheric backscatter and computation round-off effects. The inorganic targets themselves do not intrinsically change with the season and therefore season cannot be a large factor in the difference.

The organic target forest, however, does not have this clustering characteristic. There is still the atmospheric backscatter and computation round-off effects that are causing the difference in signatures, but here the nature of the target has a gross effect. It is this unknown factor of an organic target which contributes to the larger differences between signatures.

These three factors that cause the differences in signatures are important for any algorithm that might be developed. The solar elevation angle effect can be removed with no difficulty. However, at this point the atmospheric effect has not been conclusively defined. Once contributing factors such as recent rain, settled dust and turbidity are quantitatively measured then an algorithm for inorganic targets seems possible. For the organic targets more work will be required in studying the changes in the targets for each season. In both cases additional work is needed before an algorithm can be realized.

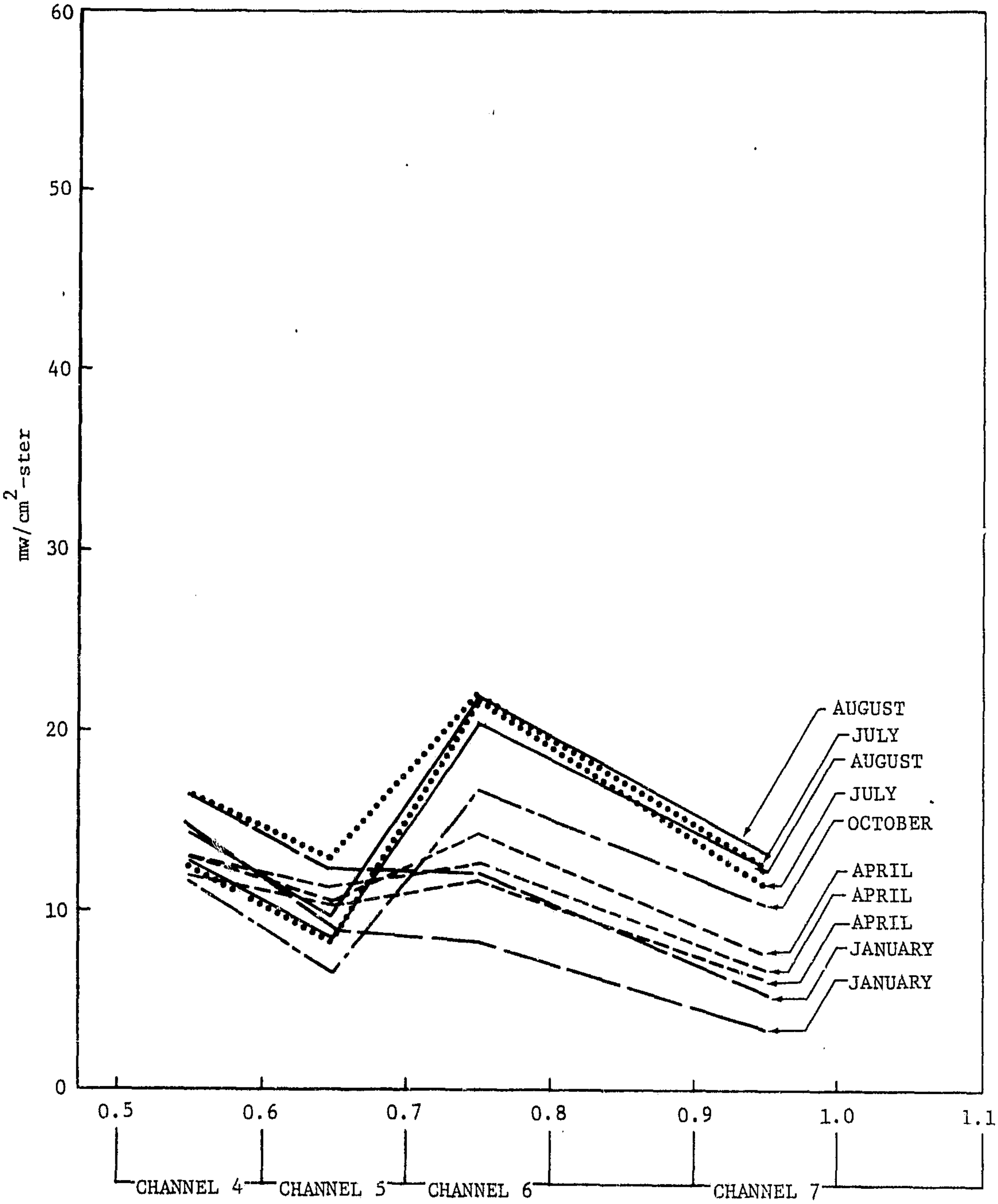


FIGURE 2-42
SIGNATURE PLOT - FOREST
WITH SUN ANGLE EFFECT REMOVED

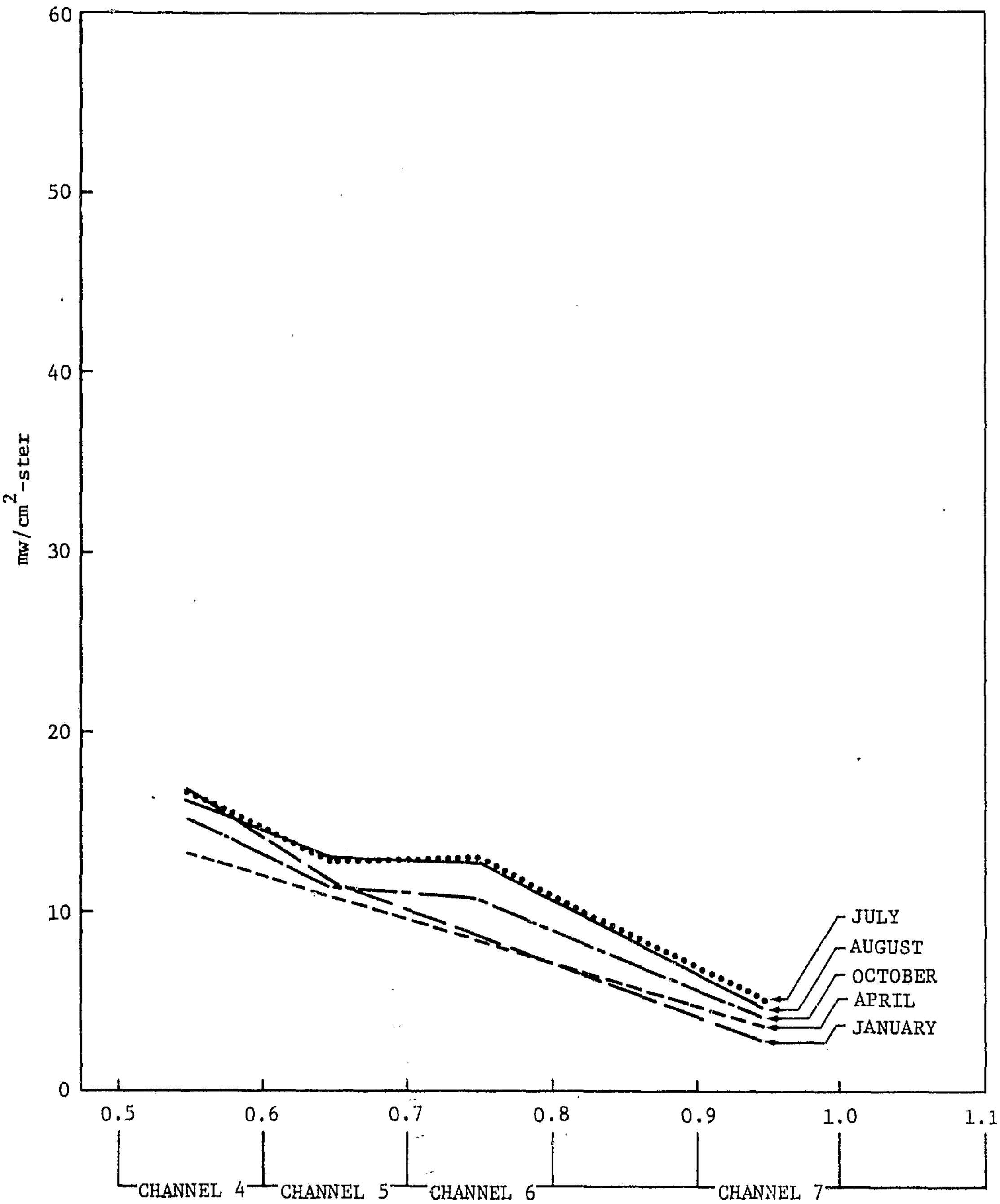


FIGURE 2-43
SIGNATURE PLOT - RAILYARDS
WITH SUN ANGLE EFFECT REMOVED

2.3.1.8 Land Use Analysis in Test Site 2. The continuing data analysis phase of land use analysis in Test Site 2 began as an extension of the techniques developed in Test Site 1, and included a test of the transferability of signatures from one test site to another and a special strip mine analysis. Using the procedures described in the Test Site 1 work, signatures were developed for the land use categories and a classification map of the Wilkes-Barre/ Scranton area at approximately 1:48,000 scale was produced. Major classification groups for 11 October 1972 and 9 July 1973 were outlined (see Figures 2-44 and 2-45) and then the analysts carefully compared the results to recent U-2 photography and somewhat older local and regional land use color-coded maps (Figure 2-46). Agreement in all categories was judged excellent, and it was felt that repeating the time-consuming township-by-township quantification of acreage agreement that had been performed for Test Site 1 would be less beneficial than new analysis which would add to the knowledge of general land use analysis techniques developed around metropolitan Harrisburg. Consequently, the main Phase III land use effort in Test Site 2 was on expansion of what had been learned in Test Site 1, rather than repetition and further confirmation of previous results.

2.3.1.8.1 Signature Transfer. One new technique tested in Test Site 2 was signature transfer. The signatures which had been developed for land use classification in Harrisburg were run for the Wilkes-Barre Scranton area and a classification map was generated. A comparison of

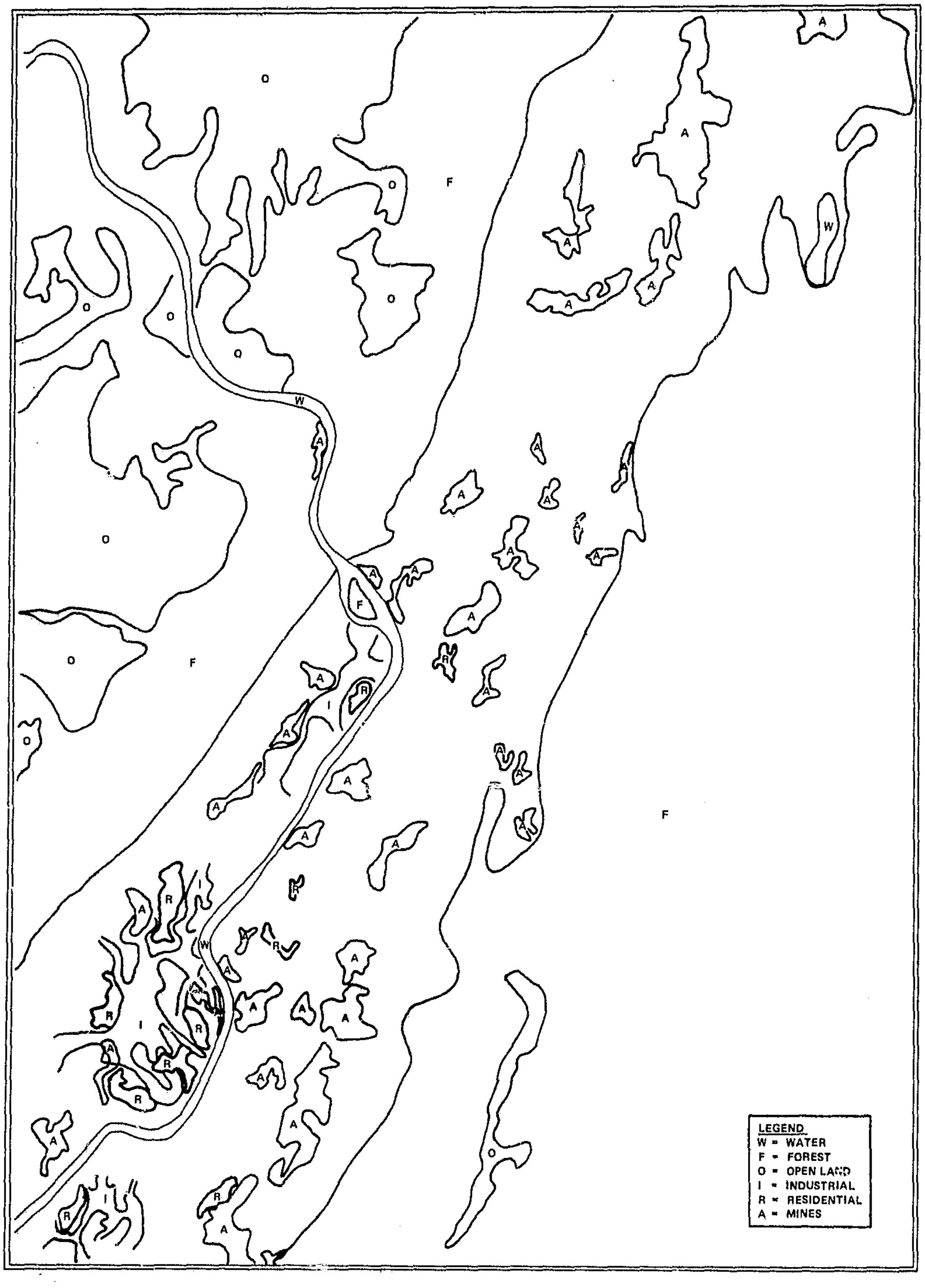


FIGURE 2-44
LAND USE CLASSIFICATION—WILKES-BARRE/SCRANTON
11 OCTOBER 1972

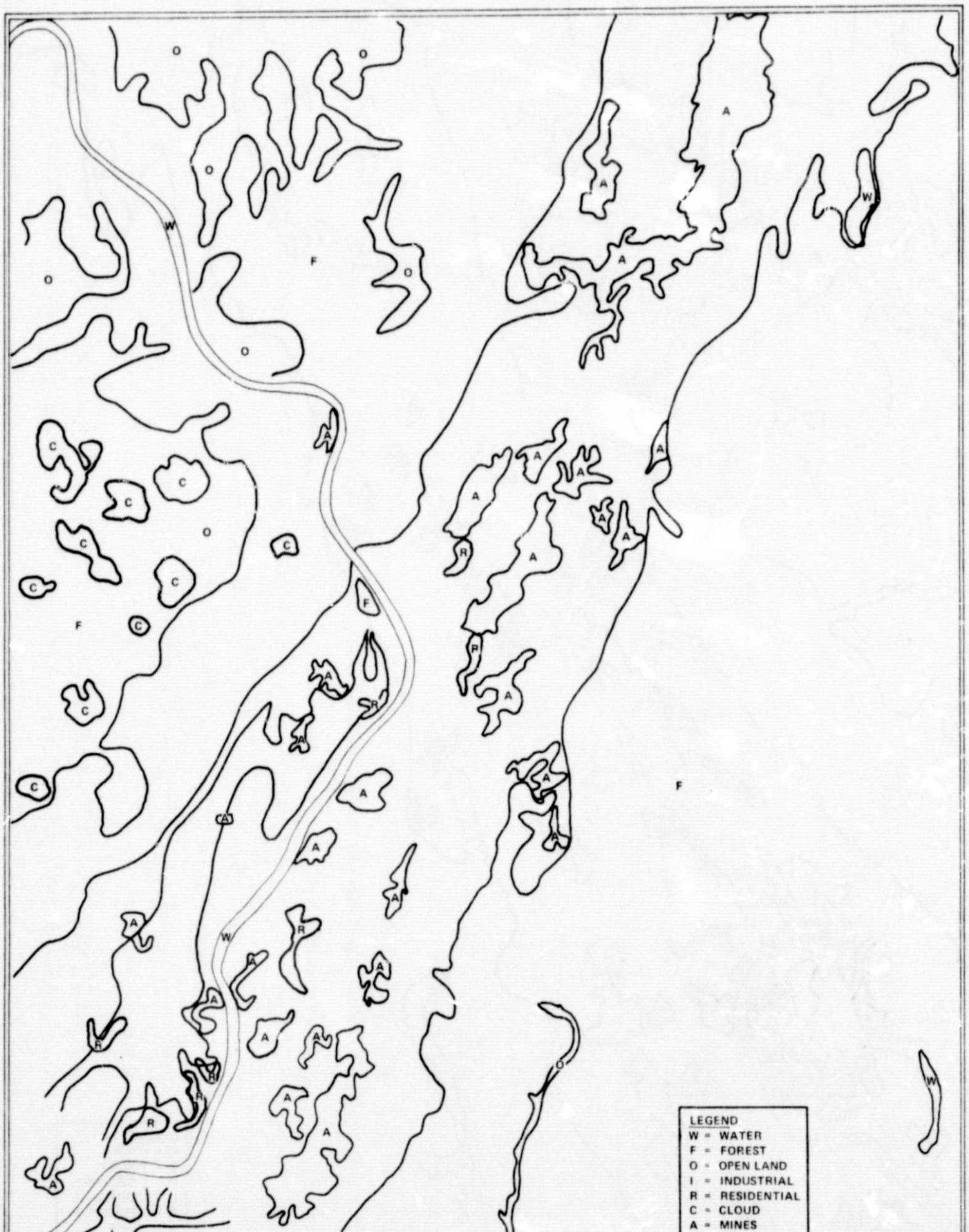


FIGURE 2-45
LAND USE CLASSIFICATION—WILKES-BARRE/SCRANTON
8 JULY 1973

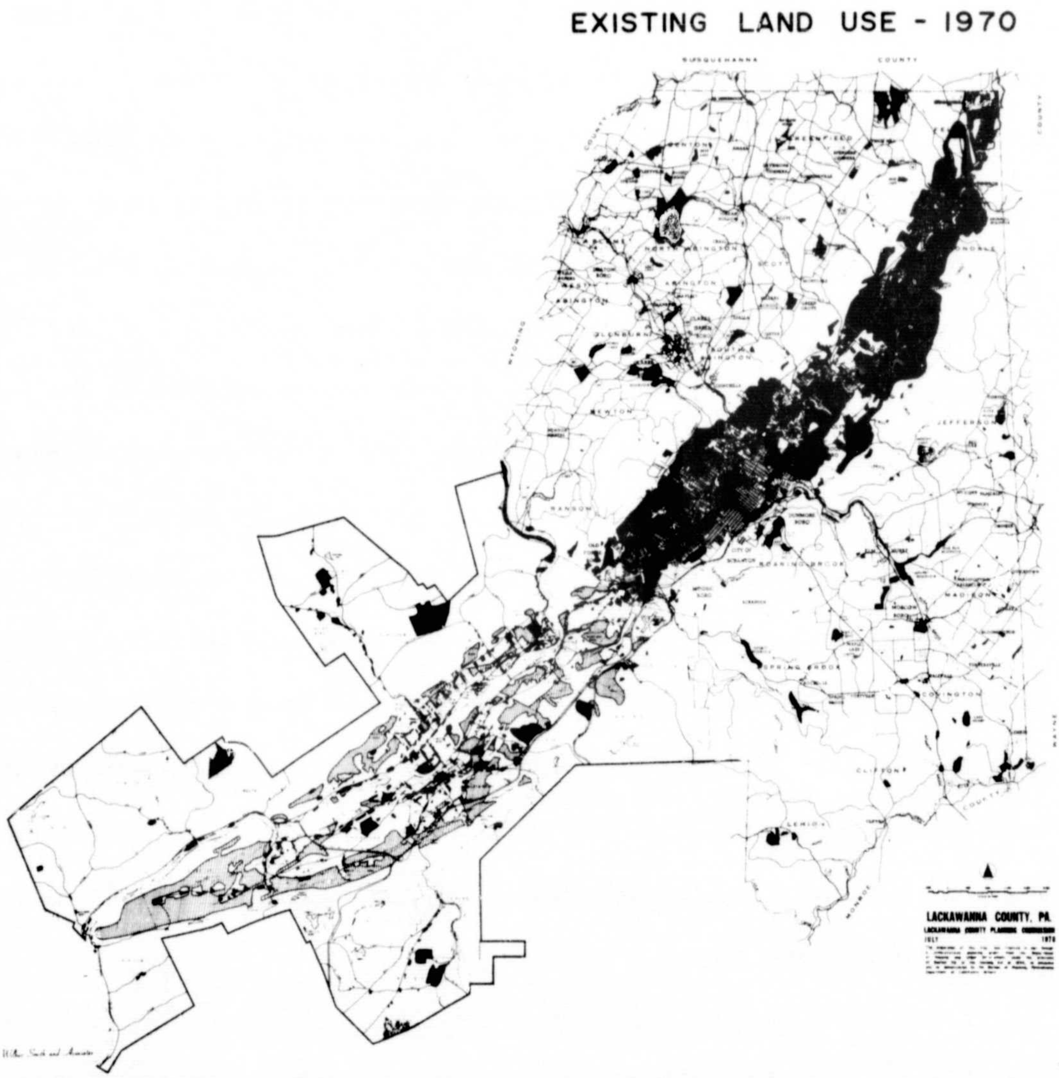


FIGURE 2-46
COMPOSITE OF LAND USE MAPS
FOR LUZERNE AND LACKAWANNA

this map and the one produced from signatures developed independently showed nearly perfect agreement, with one exception. A prevalent physical feature of Test Site 2, accounting for approximately seven percent of the total area, is surface mining activity and refuse banks (Figure 2-47 illustrates the extent of mining activity in Test Site 2). Since surface mining is virtually non-existent in the Harrisburg area, there were simply no mining area signatures to transfer. When the mining area signatures developed for Test Site 2 were added to the Test Site 1 signatures, however, the unclassified areas were filled in and overall classification agreement was on the order of 90 percent. This same transfer test was performed using data from two additional coverages, and in each case similar success was achieved in transferring land use classification signatures between the two test sites. In no case, however, has there been success in applying a signature developed in one test site for one coverage to either test site on a subsequent coverage, ie., 18 days or greater. The analysis indicates that there is a requirement to develop signature variation algorithms before temporal signature transfer will be successful.

2.3.1.8.2 Special Mining Area Analysis. A second expansion of the land use analysis effort for Test Site 2 was to look more specifically at strip mining, the major land use problem in the region. As noted, mining areas and refuse banks are prominent features throughout Test Site 2. The Northern Anthracite Field, in which the site is located, has been mined extensively for over 50 years. During most of

FIGURE 2-47
CLASSIFICATION MAP FOR SCRANTON
WILKES-BARRE SHOWING WATER
AND MINES

this period there was no effective mining permit or reclamation legislation, so that strip and open pit mining was carried out virtually anywhere that it was profitable. As a result, scarring and despoilation of the land is evident throughout Test Site 2. More recent state and federal legislation has sought to control surface mining and to insist on reclamation of land where mining is permitted. While the remedial legislation has clearly been needed, it has also added tremendously to the surveillance burden of the officials charged with enforcement. The land use classification capability of ERTS can be a useful tool in detection of strip mining activity (past and present) and the reclamation progress. The remainder of MITRE's Phase III land use analysis in Test Site 2 was directed toward testing the feasibility of using ERTS as a source of information for monitoring strip mine activity.

The first task in testing the strip mine monitoring capability of ERTS was to select a test area within Test Site 2 which had the various mining area levels of activity within its boundaries. These levels, or categories, of mining activity of interest were the following:

- active mining areas
- old unreclaimed mining areas
- refuse banks
- revegetated mining areas

From ground truth data collected during Phase I of the investigation, notably the USGS maps and the study by Peters, et al.[1], old mining areas and refuse banks were identified throughout Test Site 2; (See Figure 2-48). Current information on active mining and reclamation, however, was more difficult to obtain. The individual coal company permit application files at the State Department of Environmental Resources in Harrisburg did yield information on areas within the test site where strip mining had been approved, but no record was available of current or recent actual mining activity or reclamation. Consequently a meeting was held in Wilkes-Barre at the U.S. Bureau of Mines Field Office with officials of the Mine Safety Office and Environmental Affairs Office. From their personal knowledge of the current situation in the area, these officials were able to provide information on the location of active mines and areas where natural revegetation was in progress, and also to provide valuable information on the coal companies active in Test Site 2 which greatly facilitated subsequent searches of commonwealth permit files. Although the information the Bureau of Mines officials provided was the best available to any government agency, and it was sufficient to select a test area for ERTS analysis, it was significant that it consisted chiefly of sketching general areas of mining activity on USGS 7.5 minute quadrangle maps. No more detailed information, such as present acreage and precise boundaries of disturbed land, was available. The officials indicated that surveys

[1] Peters, Spicer, and Lovell, A Survey of the Location Magnitude, Characteristics, and Potential Uses of Pennsylvania Refuse, Coal Research Board SR-67, January 1968.

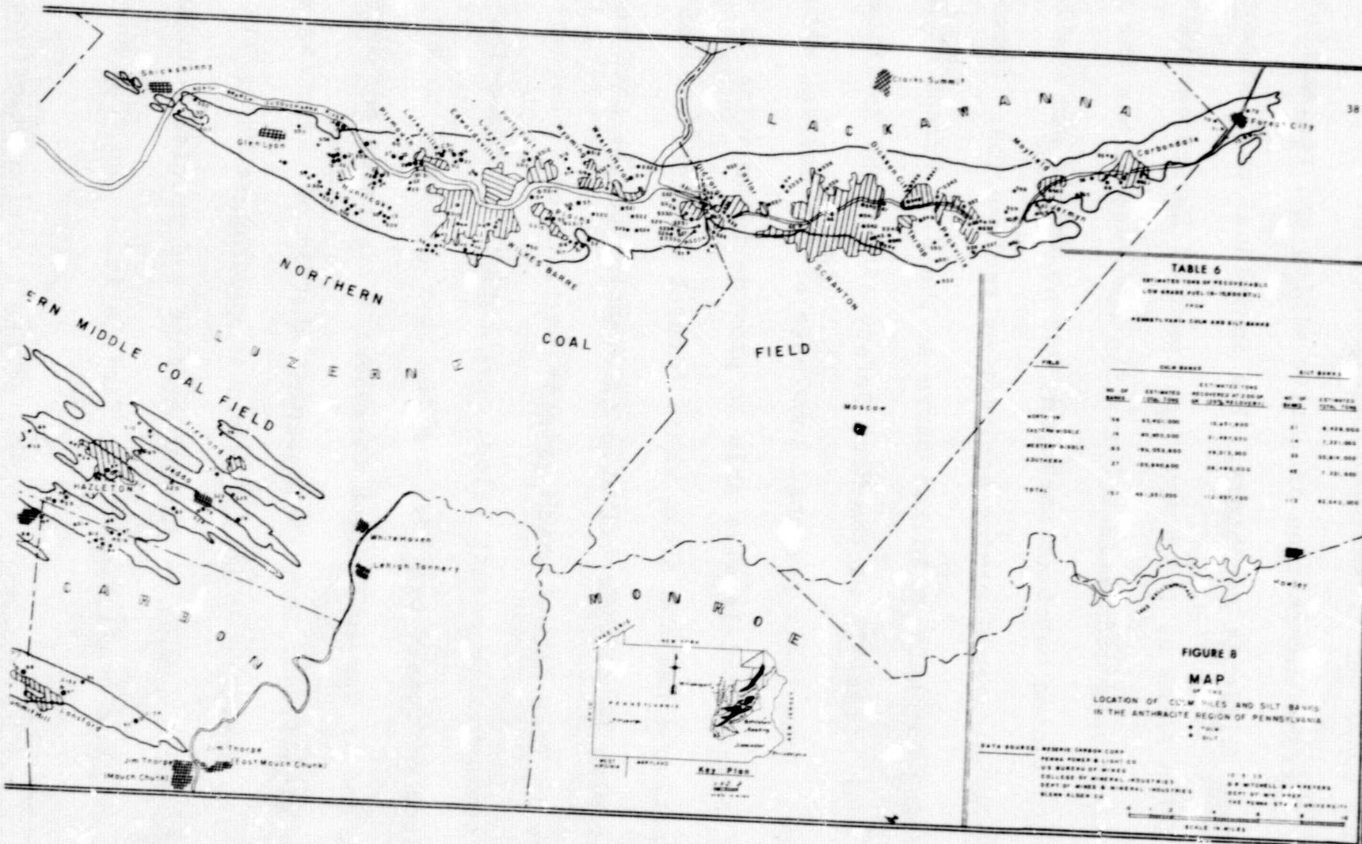
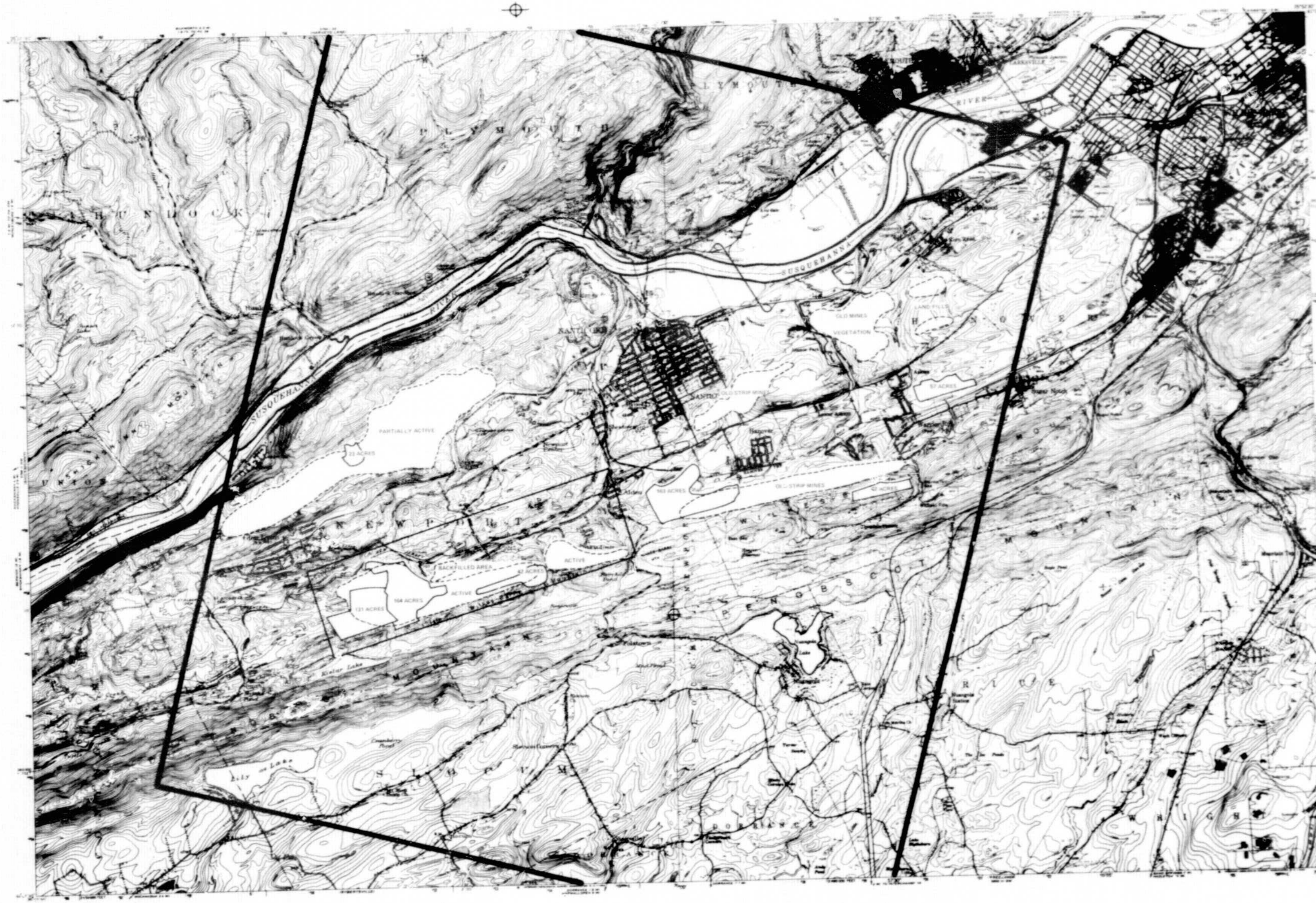


FIGURE 2-48
MAP SHOWING MINING ACTIVITY IN THE SCRANTON/WILKES-BARRE AREA

required to keep abreast of current status of mining and reclamation on anything but a spot check basis would be economically impossible. They felt that if ERTS could provide the information sought, it would be a most valuable source of updating information to allow timely and accurate assessment of mining and reclamation compliance.

From the information obtained in Wilkes-Barre, it was clear that the area which contained the best mix of the four mining categories of interest was one located to the south and west of Nanticoke, Pennsylvania. Figure 2-49 is a composite of parts of the Wilkes-Barre West and Nanticoke 7.5 minute quadrangle maps with the approximate boundary of the test area superimposed. The additional notation shows the mining area information which was obtained from the Bureau of Mines Field Office and from the State Department of Environmental Resources permit application files.

Once the test area had been selected, signature development proceeded through cluster analysis in the mining areas according to the procedures described previously for land use classification. The one exception was that analysis was full scale, every pixel for the maximum specific definition of the area, rather than the every-other-pixel analysis that had been considered adequate for general metropolitan area land use classification. This was necessary since the average active area was of the order of five to ten acres (approximately 4 to 8 pixels). As a result, the computer map of the test area was approximately the same 1:24,000 scale as the 7.5 minute quadrangle maps, allowing for direct comparison of results.



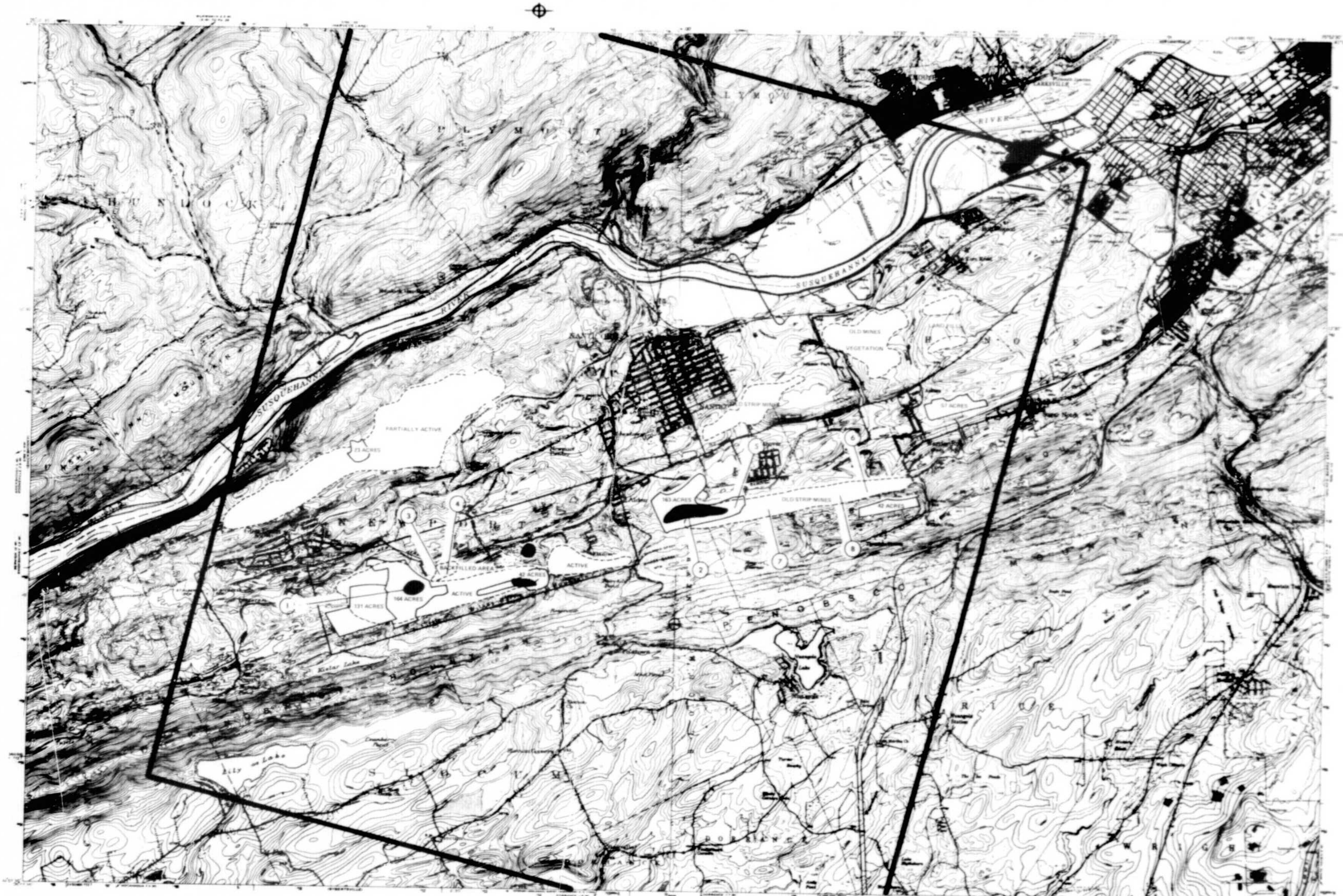
(- - -) - MINING AREAS IDENTIFIED
BY THE BUREAU OF MINES

FIGURE 2-49
NANTICOKE AND WILKES-BARRE WEST
MAPS WITH MINE INFORMATION OVERLAND

The first ERTS data analyzed specifically for the mine categories was the 11 October 1972 coverage. As expected, some difficulty was encountered in distinguishing between the spectrally close water and mining area signatures, but several iterations of the analysis procedures resulted in signature information for each of the mining categories of interest which appeared to classify the mining areas correctly according to the ground truth information on hand. There remained, however, one major problem. The ground truth was too generalized for pinpointing active mining areas since the information provided only an estimated area within which there was some active stripping. The ERTS analysis was showing trees, water, probable active mining, probable revegetated mining area, probable refuse bank, and probable old mining areas mixed through the area designated as active mining in the ground truth. The problem, in short, was how to determine which spectral response in the active areas should be associated with which mining area category, and to verify that in fact there is a mixture of the categories in the areas designated active by the Bureau of Mines officials.

The Bureau of Mines Field Office was contacted again, and it was confirmed that in MITRE'S test area many of the currently active sites were reworkings of smaller portions of areas where strip mining had been carried on as long ago as the 1930's. Consequently ERTS could be expected to detect a mix of different reflectivity for older mining areas, refuse banks with varying degrees of natural revegetation from none for the newer areas to heavy for the oldest, and the completely denuded land in an active area. However, lacking a complete current survey of the test area or review of complete recent aircraft photography, the Bureau of Mines officials could not identify exactly which pixel size areas were active and which were another category within the general area where they knew active mining was underway. The only possible source for that information, they felt, would be the surveyors of the coal companies active in the test area.

Fortunately, it was learned that only the Blue Coal Company is currently active in the test area, and they were willing to provide complete cooperation with the MITRE investigation. A remaining difficulty was that their records and maps, like those of the Bureau of Mines and Department of Environmental Resources, showed only the large tracts where they had permission to mine, rather than the extent of actual mining for any particular date. Nonetheless, the Chief Surveyor of Blue Coal was able to accompany MITRE investigators to the locations of active stripping in the test area and to sketch the boundaries of the specific active areas, vegetated areas, and refuse banks onto the 7.5 minute quadrangle map. While he was not able to estimate the acreage involved for any given date, his information was sufficient to positively differentiate the mining area signatures and properly assign the categories. Figure 2-50 shows the test area with the Blue Coal Company information added. Figures 2-51 through 2-54 are ground photographs taken in the test area in November 1973 to illustrate the mining area categories detected by ERTS. Numbers on the map, Figure



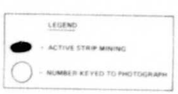
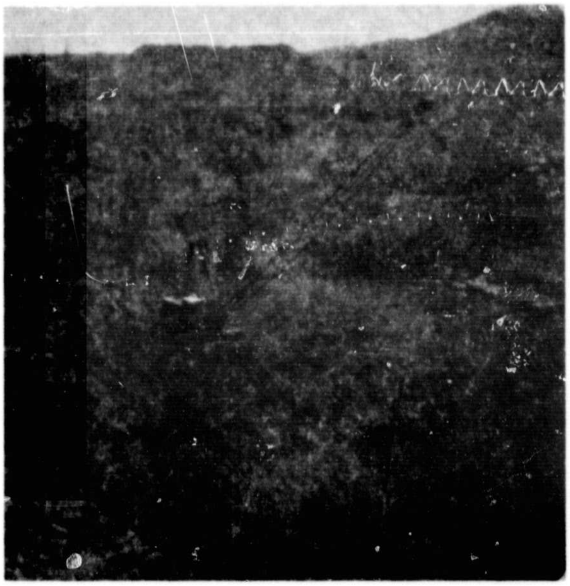


FIGURE 2-50
NANTICOKE AND WILKES-BARRE WEST
MAPS WITH BLUE COAL CO ACTIVE
MINES INDICATED



1.* OPEN PIT NEAR WANAMIE

2.* PIT AND STRIP NEAR HANOVER

*Numbers keyed to map, Figure 2-50.

FIGURE 2-51

ACTIVE SURFACE MINING AREAS

3.* GRADING IN PROGRESS

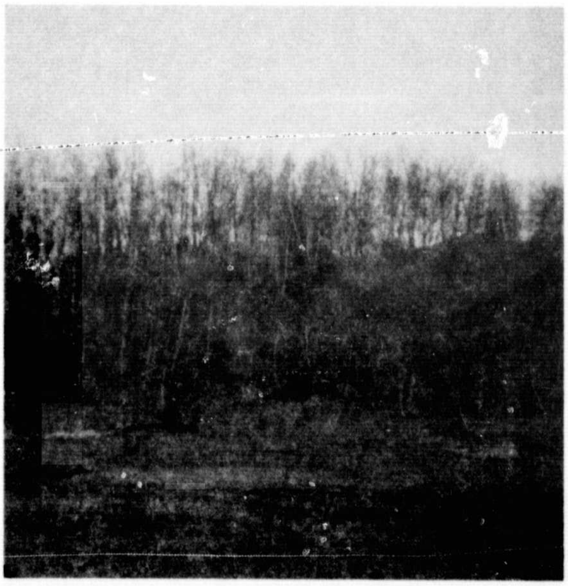
4.* AREA NOT YET GRADED

*Numbers keyed to map, Figure 2-50.

FIGURE 2-52

BACKFILLED MINING AREA

5.* PARTIAL REVEGETATION
STRIPPED AREA

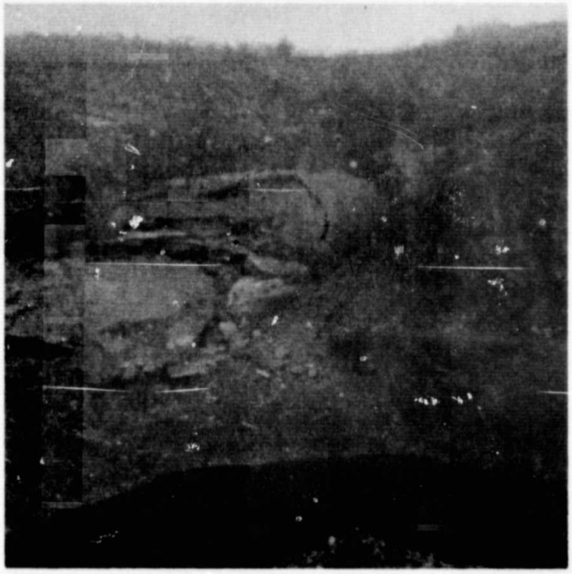


6.* PARTIALLY REVEGETATED
CULM BANK

*Numbers keyed to map, Figure 2-50.

FIGURE 2-53

RECLAMATION IN MINING AREAS



7.* UNRECLAIMED OPEN PIT

8.* INACTIVE STRIPPED AREA

*Numbers keyed to map, Figure 2-50.

FIGURE 2-54

OLD INACTIVE MINING AREAS

2-50, are keyed to the numbers on the photographs to show where the photographs were taken.

With this more definitive ground truth it was possible to classify the mining areas properly and continue the analysis throughout the test area. When over 99 percent of the test area had been classified and spot-verified by reference to the U-2 photography and 7.5 minute quadrangle maps, a map was produced with all signatures blank except those for the mining areas and the river and urban/residential. In this way the mining areas are highlighted for comparison with information on the 7.5 minute quadrangle maps, and the water and urban/residential areas facilitate orientation of the computer map. Figures 2-55 and 2-56 show the computer maps for the October 11, 1972 and July 8, 1973 coverages, which may be compared to the ground truth shown on Figure 2-50. (April 9, 1973 was also attempted but discovery of bad CCT's too late for substitution by GSFC obviated land use mapping of this overflight date.)

Comparison data for the October 11, 1972 and July 9, 1973 overflights are shown in Table 2-25A for the four mining categories of interest. The average percentage of the total land in the test area which is made up of some type of mining activity is approximately 10 percent, or about 2715 acres. This is a higher percentage as compared to Test Site 2 as a whole (about seven percent) but that is to be expected since the test area was specifically selected as one in which there was considerable mining activity. The ERTS analysis of just the two overflight dates shows interesting trends which have been verified

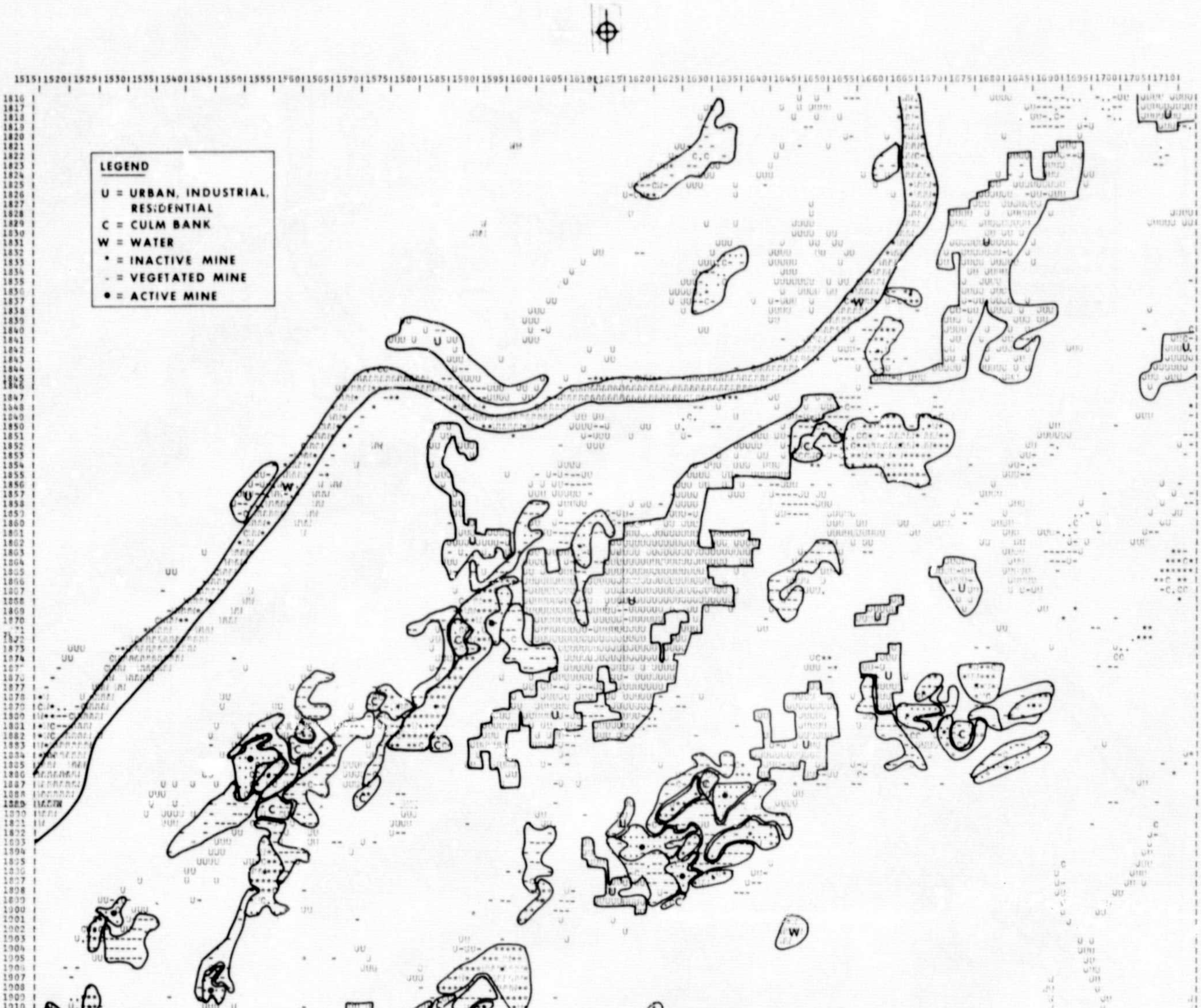


FIGURE 2-55
STRIP MINE CATEGORIES IN NANTICOKE TEST AREA
11 OCTOBER 1972

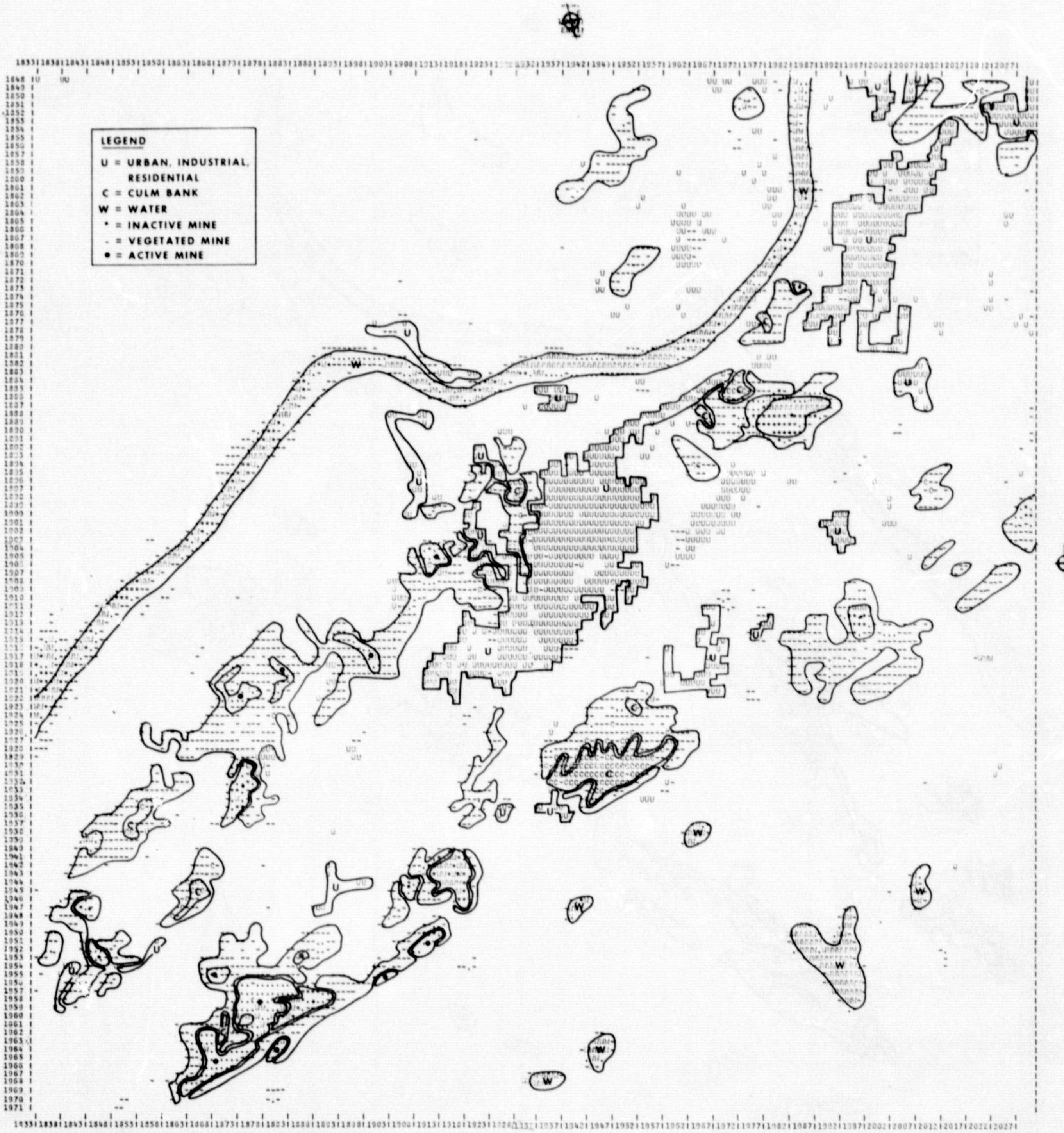


FIGURE 2-56
STRIP MINES CATEGORIES IN NANTICOKE
TEST AREA
8 JULY 1973

TABLE 2-25A

LAND USE TRENDS IN THE STRIP MINING TEST AREA

Land Use Category	Acres		Percent of Area	
	11 Oct. 72	8 July 73	11 Oct. 72	8 July 73
Active Mines	461.6	543.5	1.7	2.0
Inactive Mine Areas (Unreclaimed)	560.1	186.0	2.1	0.7
Refuse Banks	234.7	162.7	0.9	0.6
Revegetated Mine Areas	1113.6	2356.8	4.1	8.7
Other	24751.5	23950.1	91.2	88.0
Total Test Area*	27121.5	27199.1	100	100

* Acreages for total test area do not agree exactly because of slightly different line and element boundaries for the two overflight dates.

by the available ground truth data for the area. From October to July, for example, the category "active mines" increased by about 82 acres, or about 18 percent. This is consistent with the Blue Coal Company information which shows increasing strip mine activity at several sites in the test area during that time period. The inactive mining area category showed a marked decrease of 374 acres from October to July. This, according to the ground truth, is attributable to two factors. First, nearly all the active mining done during that time period consisted of reworkings of older mining areas. As a result, the active mining category increased in acreage at the expense of the inactive mine area category. The second factor reducing inactive mine area acreage was the natural growing season increase in vegetation in July over October. As Table 2-25A shows, the revegetated mine area category increased by over 100 percent in July. The revegetation occurred, as the data indicate, in the inactive mine areas and refuse banks categories, accounting for the reduction in acreage allotted to those categories in July.

Although no ground truth data exist on acreages for the individual mining categories of interest, the acreage of an overall mining area can be calculated from ERTS data and compared with planimetered acreage from the total mining areas estimated by the Bureau of Mines and derived from the permit files. For the mining area boxed off in Figure 2-50, the results are as follows:

ERTS Mining Acreage:	573
Ground Truth Mining Acreage:	604
Percent Agreement:	95

Given the inability to determine exact boundaries and acreages of mining area categories from existing ground truth, and the very dynamic land use change nature of strip mining, this 95 percent agreement is an exceptionally good indicator of the value of ERTS information. Although it was not possible to test during the time remaining for this investigation, a superior verification method would be to obtain aircraft coverage coincident with ERTS coverage for a training area portion of the test area which includes all mining area categories for signature development, then apply the resultant classification throughout the test area. Verification could then be accomplished by comparison with aircraft photography from one or more small randomly selected portions of the test area outside of the training area. In this way current, repetitive, accurate monitoring of strip mine and reclamation activity could be accomplished.

2.3.1.8.3 Conclusions: Land Use Analysis In Test Site 2.

- The procedures developed for Test Site 1 for general metropolitan area land use analysis can be applied successfully to land use analysis in Test Site 2. The only change was that signature information to classify mining areas had to be developed for Test Site 2.
- Signatures developed to classify land use in either of the test sites can be applied successfully to classify other test

sites, an areal transfer of approximately 100 miles, for the same coverage date.

- By application of the appropriate algorithm it may be possible to transfer signatures from one coverage date to another, but such an algorithm has not been developed.
- It is possible to classify and monitor strip mining and reclamation on a rapid and repetitive basis with ERTS data and some aircraft photography or ground survey of a small representative area for signature development and verification. While other investigators[1] have reported similar success, their analysis has been on a much smaller scale (1:250,000) using active mining targets on the order of thousands of acres. MITRE's analysis has been at a scale of 1:24,000 and current active mining targets have been detected in the size range of 5-10 acres. The skill score of 95 percent agreement for one training area, plus the demonstrated ability to discriminate accurately four categories of mining activity, indicate the potential for an immediate application of ERTS-1 information. This level of analysis demonstrates to Federal, state, and local authorities the capability for the timely, repetitive monitoring of mining and reclamation which they require and which to date they have been unable to obtain from other sources.

---

[1]Rogers, Reed and Pettyjohn "Automated Strip Mines and Reclamation Mapping from ERTS" Unpublished paper for NASA's Symposium on Significant Results Obtained from the ERTS-1, December 1973.

2.3.2 Phase III - Water Quality Continuing Data Analysis

MITRE's water quality analysis effort was shifted back to the Susquehanna River by MITRE and the NASA/ERTS Technical Monitor after it had been determined that the Potomac River data was not usable due to striping (See Appendix B). The test areas that were chosen along the Susquehanna River are the following:

TABLE 2-26

SUSQUEHANNA RIVER WATER QUALITY TEST AREAS

Test Area		River Mile
1	River Mouth at Chesapeake Bay	0
2	Conowingo Dam	10.1
3	Above Holtwood Dam	26.6
4	Safe Harbor Dam, Conestoga Creek Mouth	32.6
5	Marietta	45.2
6	Above Swatara Creek Mouth	57.2
7	Harrisburg, Conodoguinet Creek Mouth	67.6
8	Juniata River Mouth	81.5
9	Fishers Ferry	109.0
10	Sunbury	121.5

Signatures were developed for each test area using cluster analysis (DCLUS). (See Appendix A for a description of this subroutine). The signatures were then inserted into the classification program (D-CLAS). A distance of separation table, which identified categories similar enough to be represented by one mean signature, was generated. If the distance of separation between two categories was less than 1.0 quanta, then the signatures for those categories were combined by taking a weighted mean. The procedure resulted in five signatures being developed. These signatures range from most turbid water, category 1 to cleanest water, category 5. (See Table 2-27). Only MSS channels 4, 5 and 6 were used since channel 7 had no water quality variation information of value.

TABLE 2-27

WATER SIGNATURES

CATEGORY	CHANNEL 4	CHANNEL 5	CHANNEL 6
1	20.97	13.18	8.54
2	19.49	11.62	6.65
3	18.57	9.99	4.93
4	17.79	10.00	8.32
5	17.58	9.46	6.23

Each of the test areas was then classified with the above signatures, thus mapping out water quality along the Susquehanna River. Figure 2-57, 2-58, 2-59 and 2-60 are test areas 1, 4, 5 and 9 respectively. For all water quality maps only the River is shown; all land is blanked out.

At the River mouth (Figure 2-59) there is generally clean water throughout (category 3 with some category 5 showing up). Along the river bank we detect more turbid water. The areas indicating most turbid water

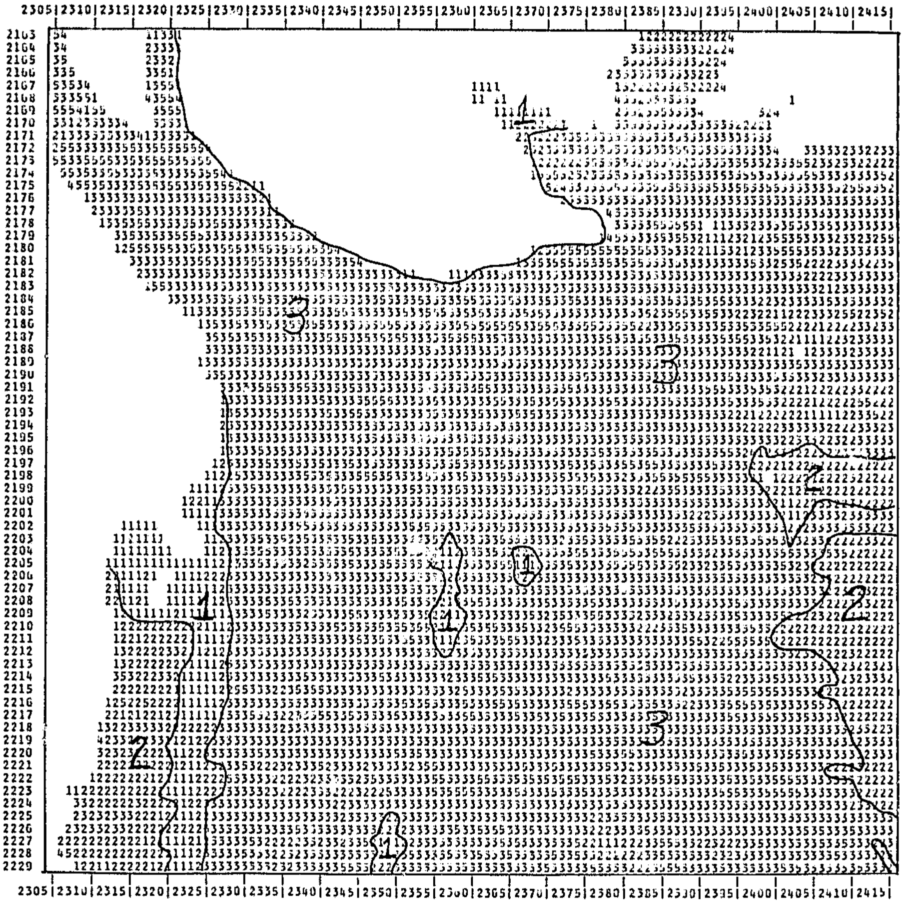


FIGURE 2-57
WATER QUALITY TURBIDITY AT
SUSQUEHANNA RIVER MOUTH
11 OCTOBER 1972

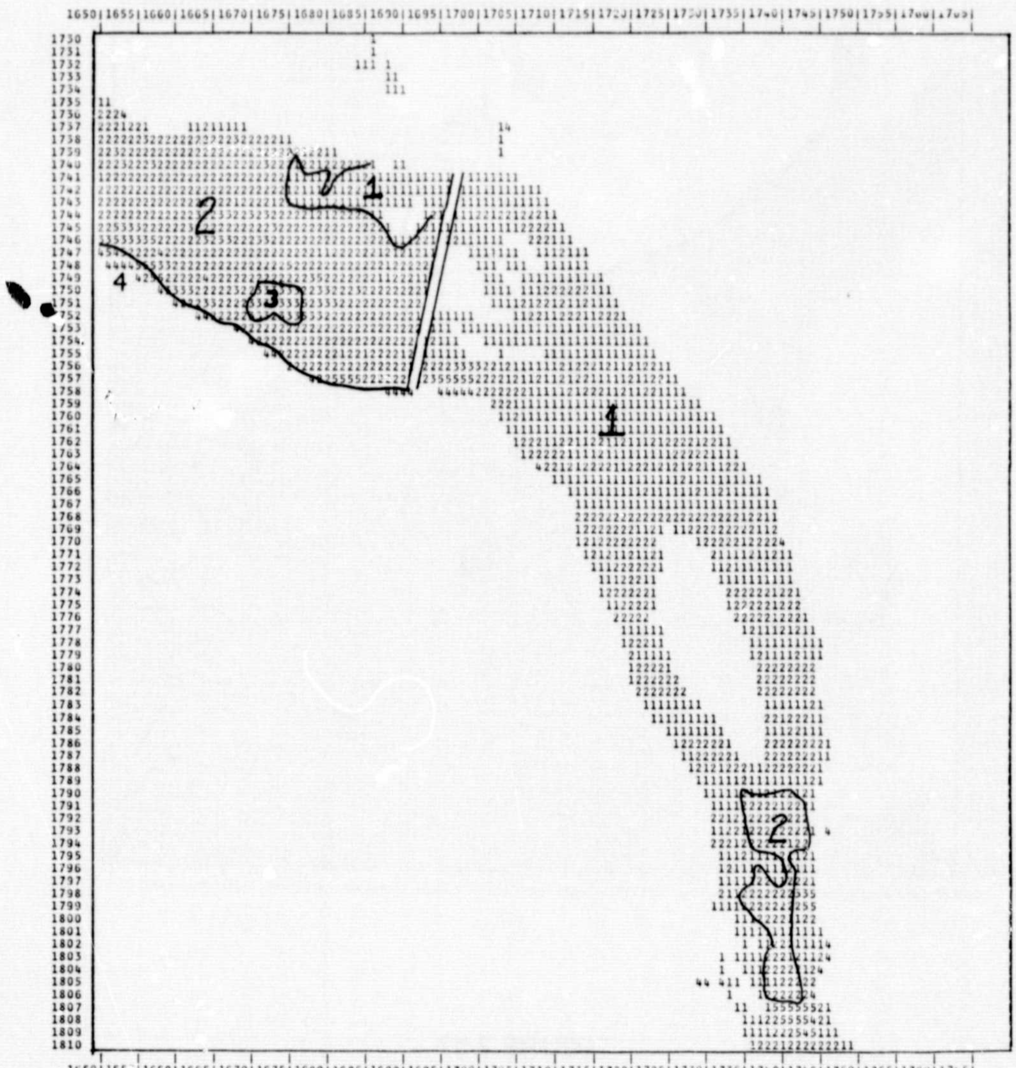


FIGURE 2-58
WATER QUALITY TURBIDITY AT
SAFE HARBOR DAM
11 OCTOBER 1972

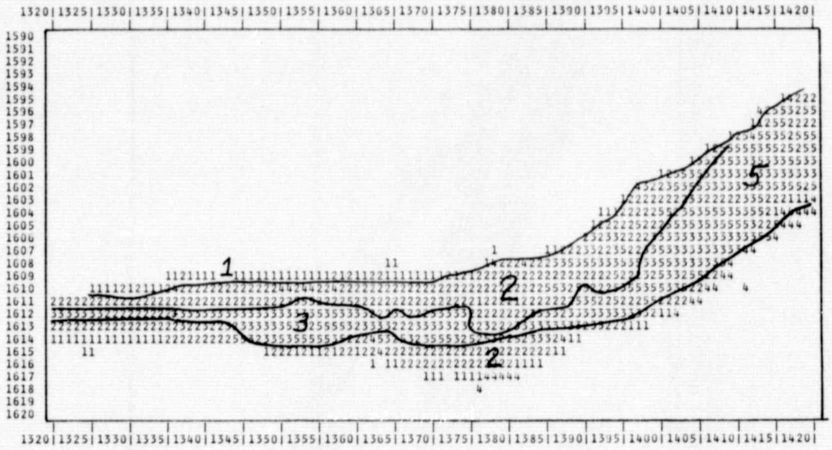


FIGURE 2-59
WATER QUALITY TURBIDITY
AT MARIETTA
11 OCTOBER 1972

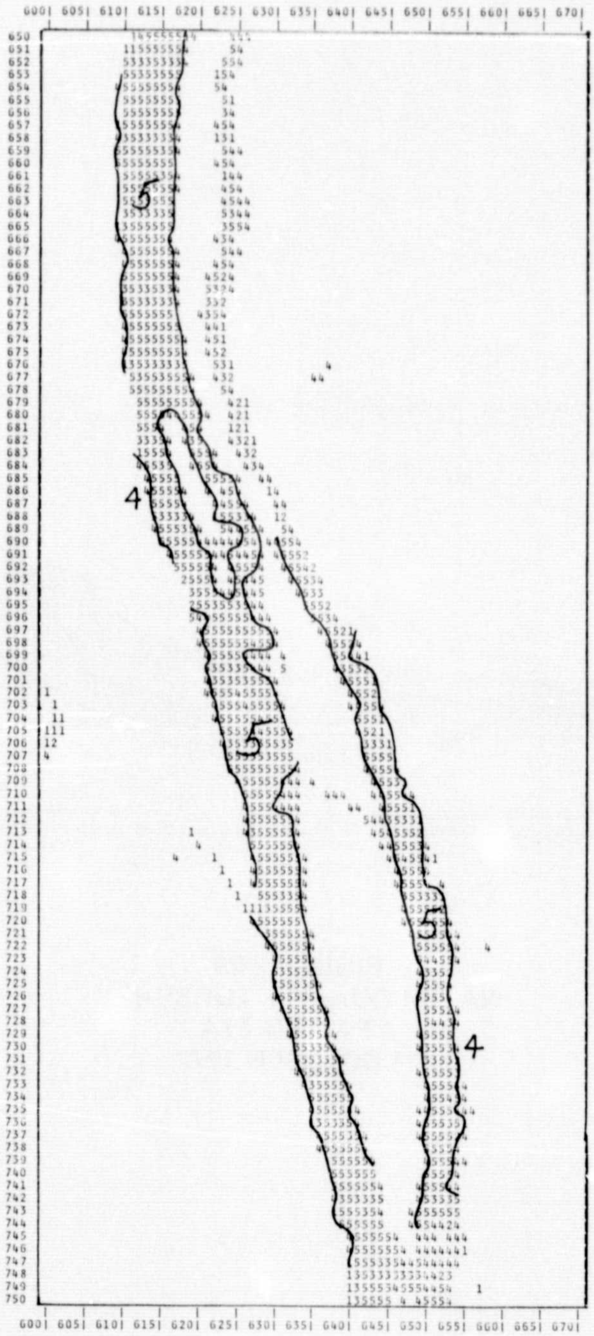


FIGURE 2-60
WATER QUALITY TURBIDITY AT
FISHERS FERRY
11 OCTOBER 1972

in the middle of the map are probably sandbars.

The Safe Harbor Dam Area (Figure 2-58) is the most turbid as shown by the predominant mapping of categories 1 and 2. Marietta (Figure 2-59) has clearer water with a stretch of categories 2 and 5 in the center. Fishers Ferry (Figure 2-60) shows a large amount of category 5 implying a lower level of turbidity in this area. Category 4 has been showing up along the shoreline in several of the test sites implying surface water drainoff probably with some silt loading.

An index of water quality was then computed for each test area as follows:

$R_{i,j,k}$ = Reflectance in (mw/cm^2-ster) from Channel (k) of Water Type (i) in Test Area (j)

$a_{i,j}$ = Percent Area of Water Type (i) in Test Area (j)

$A_j = \sum_{i=1}^{n} a_{i,j}$ = Percent Area of All Water in Test Area (j)

$\alpha_{i,j} = \frac{a_{i,j}}{A_j}$ = Percent Area of Water Type (i) in All Water in Test Area (j)

$\rho_{i,j} = \frac{1}{m} \sum_{k=1}^{m} (R_{i,j,k}) \cdot (\alpha_{i,j})$ = Average Reflectance of Test Area (j) for Water Type (i) in (mw/cm^2-ster)

$P_j = \sum_{i=1}^{r} \rho_{i,j}$ = Water Quality Index for Test Area (j)

Figure 2-61 shows the water quality indices for the 11 October 1972 study; note that Safe Harbor which has the highest index of turbidity also shows up most turbid on the Channel 4 image, Figure 2-62.

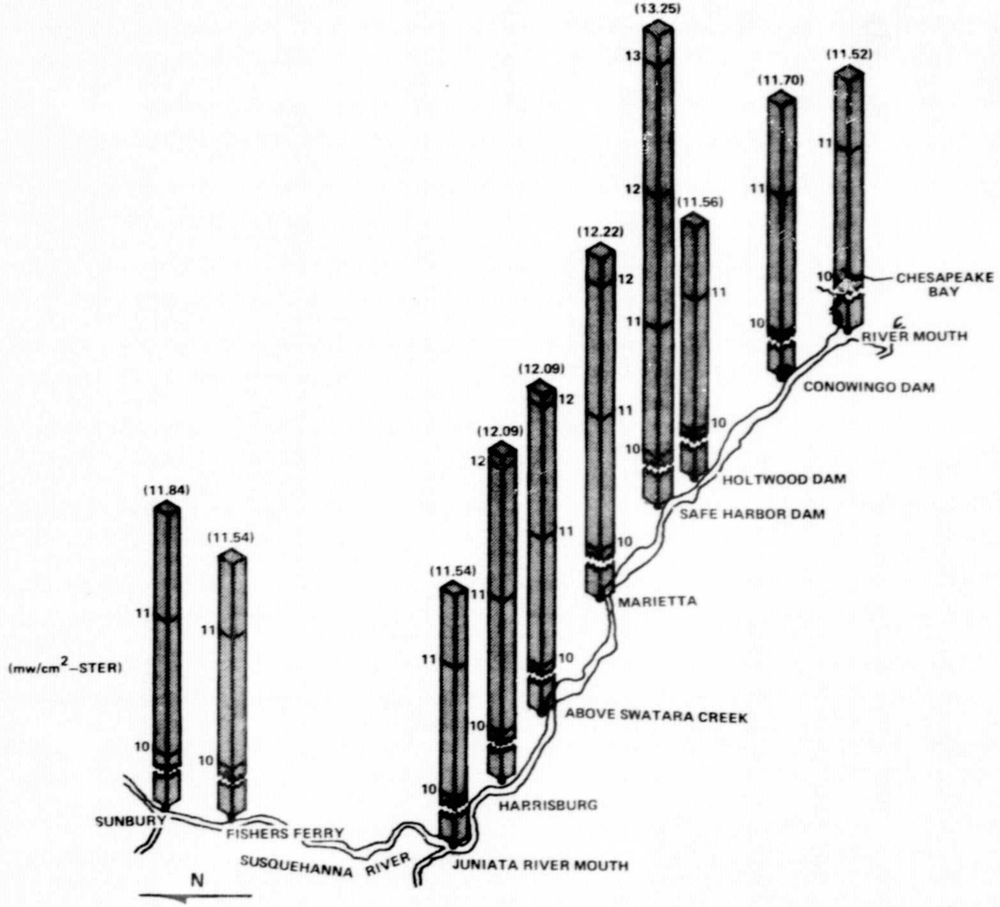


FIGURE 2-61
WATER QUALITY INDICES ALONG SUSQUEHANNA RIVER, 11 OCTOBER 1972

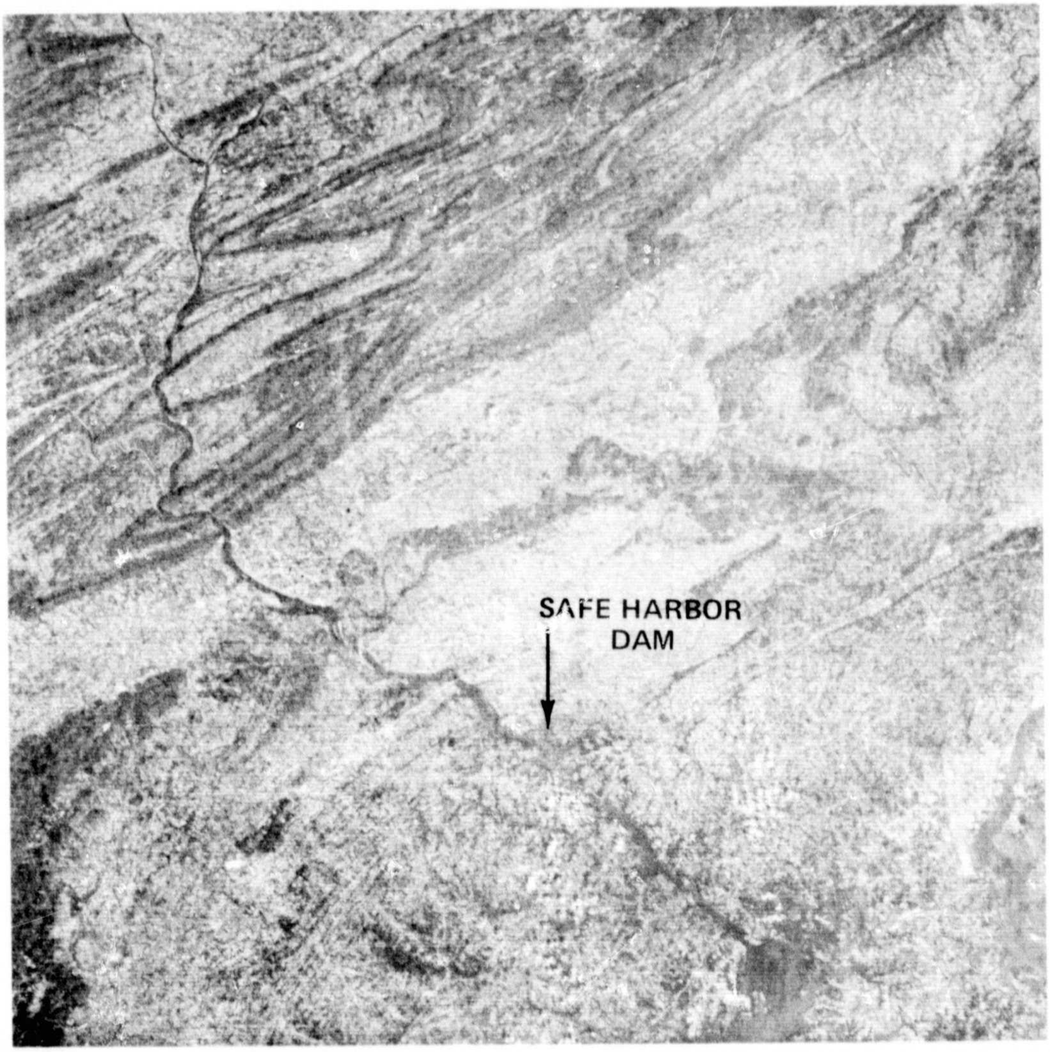


FIGURE 2-62
ERTS-1 IMAGE CHANNEL 4
11 OCTOBER 1972

Figure 2-63 shows the percent of each water type present in each test area. A look at Safe Harbor reveals that there is no clear water (i.e., type 4 or 5) in this area. Another interesting area is Sunbury. Although there is a large percentage of type 5 and 4 water there, the water quality index is higher than that computed for the Juniata River Mouth. This is due to the equal percentages of types 1, 2, and 3 percent (33% total) in the water which contribute to raising the index. Each of the remaining test areas can be analyzed in the same manner. We believe, however, that the water quality index, rather than the percent of water type, gives a total description of the water and can be used more directly to describe water quality along the Susquehanna River.

With ERTS-1 MITRE has been able to determine a range of turbidity, but is is only with in-situ water information that these levels can be quantified into physical units. In order to acquire this water information, Mr. Reed at USGS/Harrisburg was contacted. The only water quality station which USGS maintains along the Susquehanna River from the mouth to Sunbury is at Harrisburg. At that station they had turbidity readings for 1 October 1972 and 31 October 1972. In order to reach a reading for 11 October 1972 interpolation of available data was made by USGS. At Harrisburg the east side of the river was estimated to have a sediment level of 12-15 micrograms/litre and the west side 9-11 micrograms/litre. These readings imply that the east side of the river is more turbid. This conclusion conflicted with our results from Harrisburg, Figure 2-64, which shows the dirtier water to be along the west

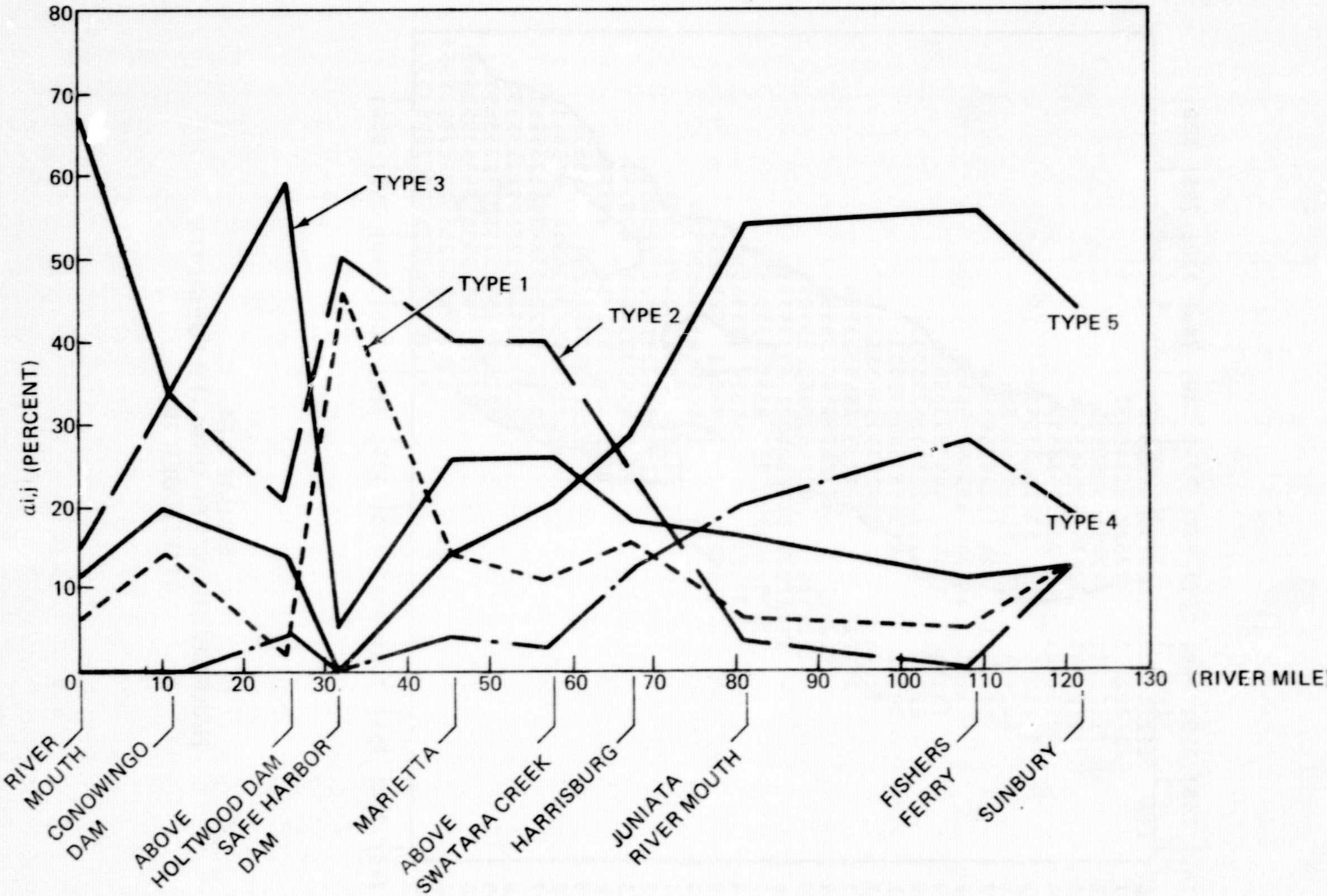


FIGURE 2-63
TYPES OF WATER QUALITY ALONG SUSQUEHANNA RIVER, 11 OCTOBER 1972

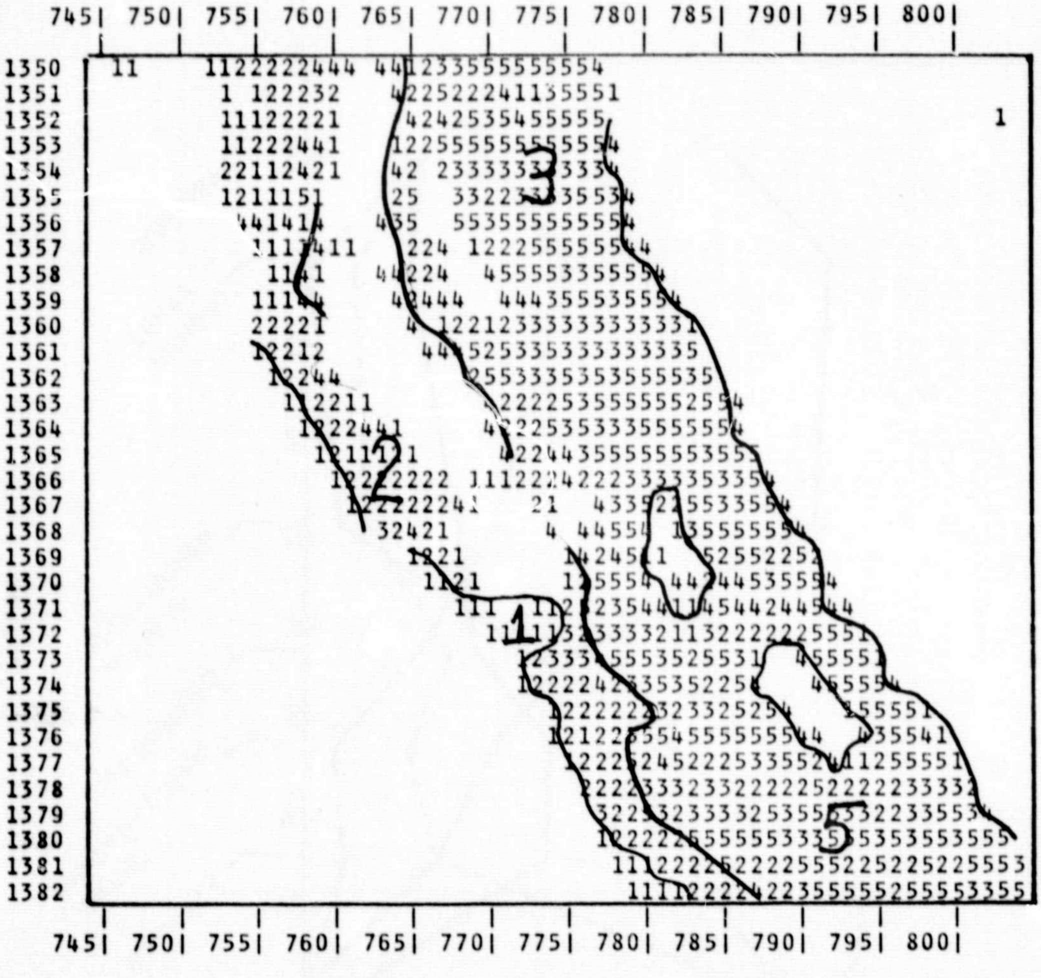


FIGURE 2-64
HARRISBURG WATER QUALITY TURBIDITY
11 OCTOBER 1972

bank. At this point Mr. Reed was again contacted. He stressed that they (USGS) did not have data close enough to 11 October 1972 to give us very substantial help. Therefore, Mr. Reed stated that we should not over-value his figures; rather we should give preference to our own findings.

The other source for water information which MITRE hoped would assist in quantifying the water quality indices was from the Philadelphia Electric Co. The data that were received covered sporadic dates from 31 October 1972 through 24 March 1972 (See Appendix C). Since the MITRE water quality analysis was done on 11 October,1972, these data were not helpful in quantifying our indices.

2.3.2.1 <u>Water Quality Temporal Variation Algorithm at Harrisburg</u>. The water quality turbidity index based on sufficient water quality information is a useful tool to describe the overall dynamics of a body of water. The main problem in using this index immediately is the lack of reliable water quality ground truth information. In order to calibrate the ERTS data a DCP network that contains at least five sampling points across the river for every river mile under consideration is necessary. This way quantitative indices of the quality could be given accurately.

During the investigation total five dates were classified; these were only five out of a year's coverage. The ERTS coverage for the year has very few other cloud free days over MITRE's test sites to allow for more frequent classification. Thus for a target such as water, which is constantly changing, more frequent coverage is necessary.

In regard to a water signature variation algorithm, the water signatures from the land use classification were grouped by date and plotted (Figure 2-65 through 2-69). The signatures from these five overflights, along with the Susquehanna River classification signatures of 11 October 1972 (Figure 2-70), were then evaluated.

The first thing to note is the increasing in reflectivity in channel 6 for all creek signatures. This is because this signature not only includes the water of the creek but also the vegetation which lines its banks. Another point of interest is that six signatures are needed to

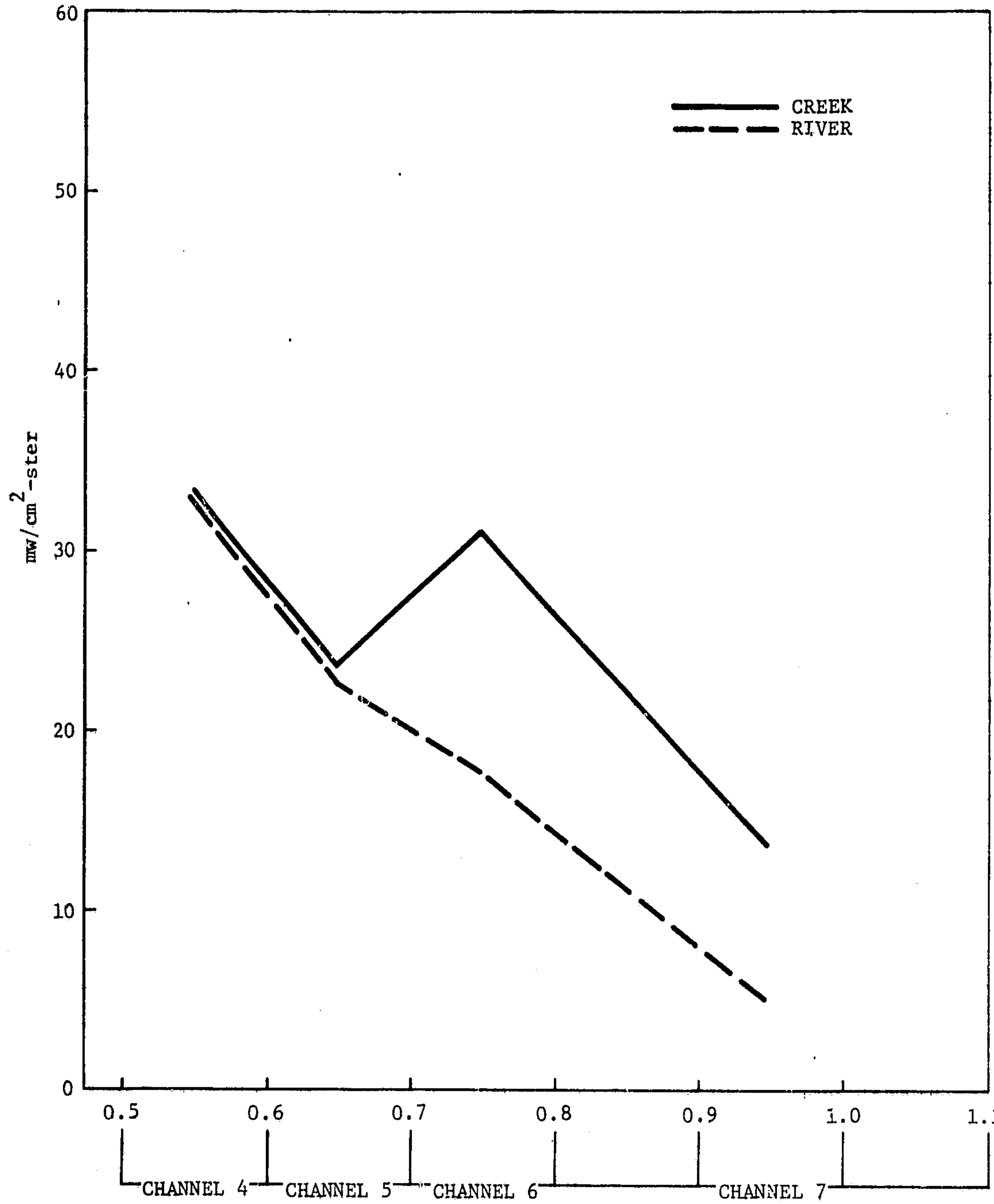


FIGURE 2-65
WATER QUALITY SIGNATURES
1 AUGUST 1972

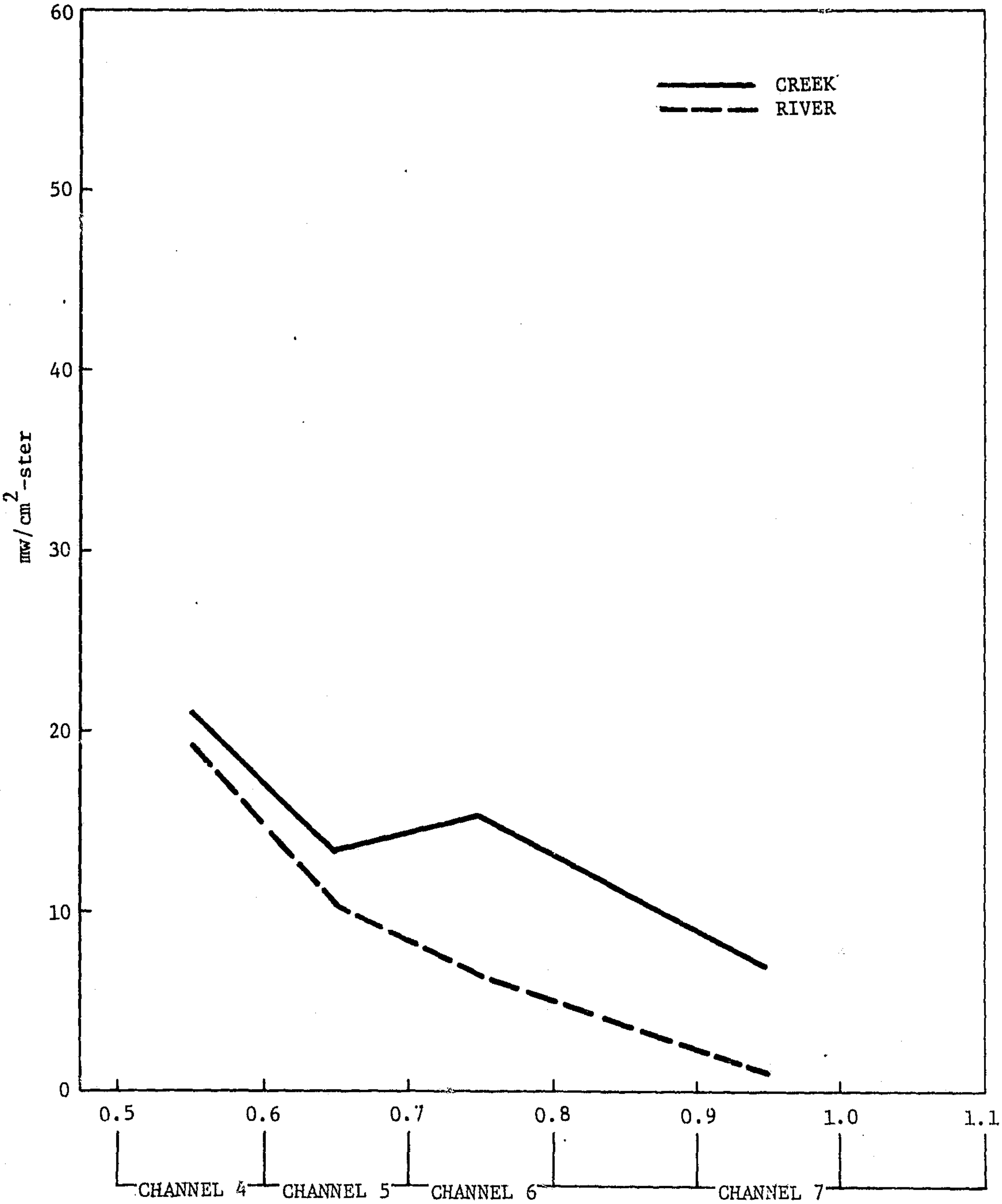


FIGURE 2-66
WATER QUALITY SIGNATURES
11 OCTOBER 1972

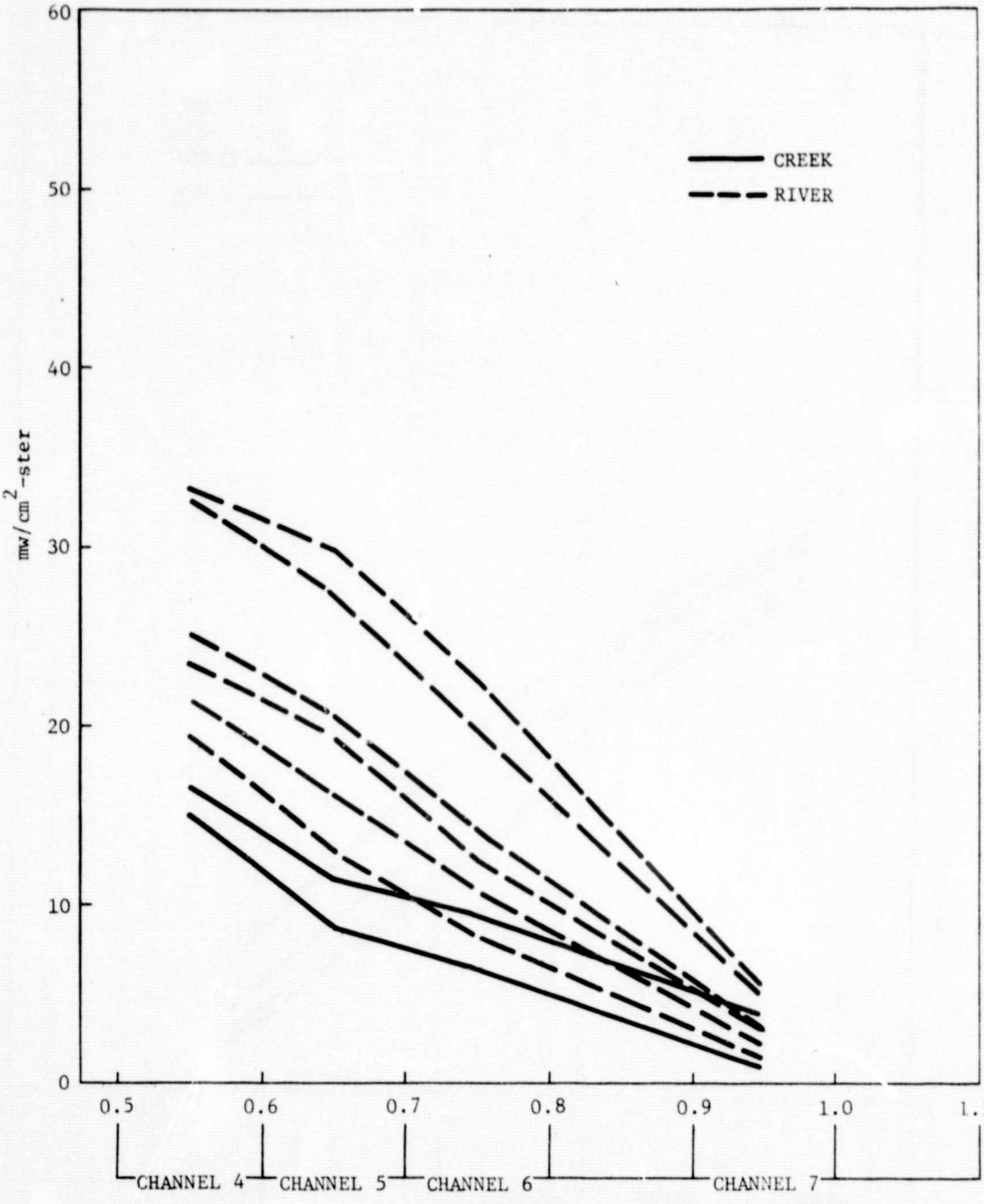


FIGURE 2-67
WATER QUALITY SIGNATURES
9 JANUARY 1973

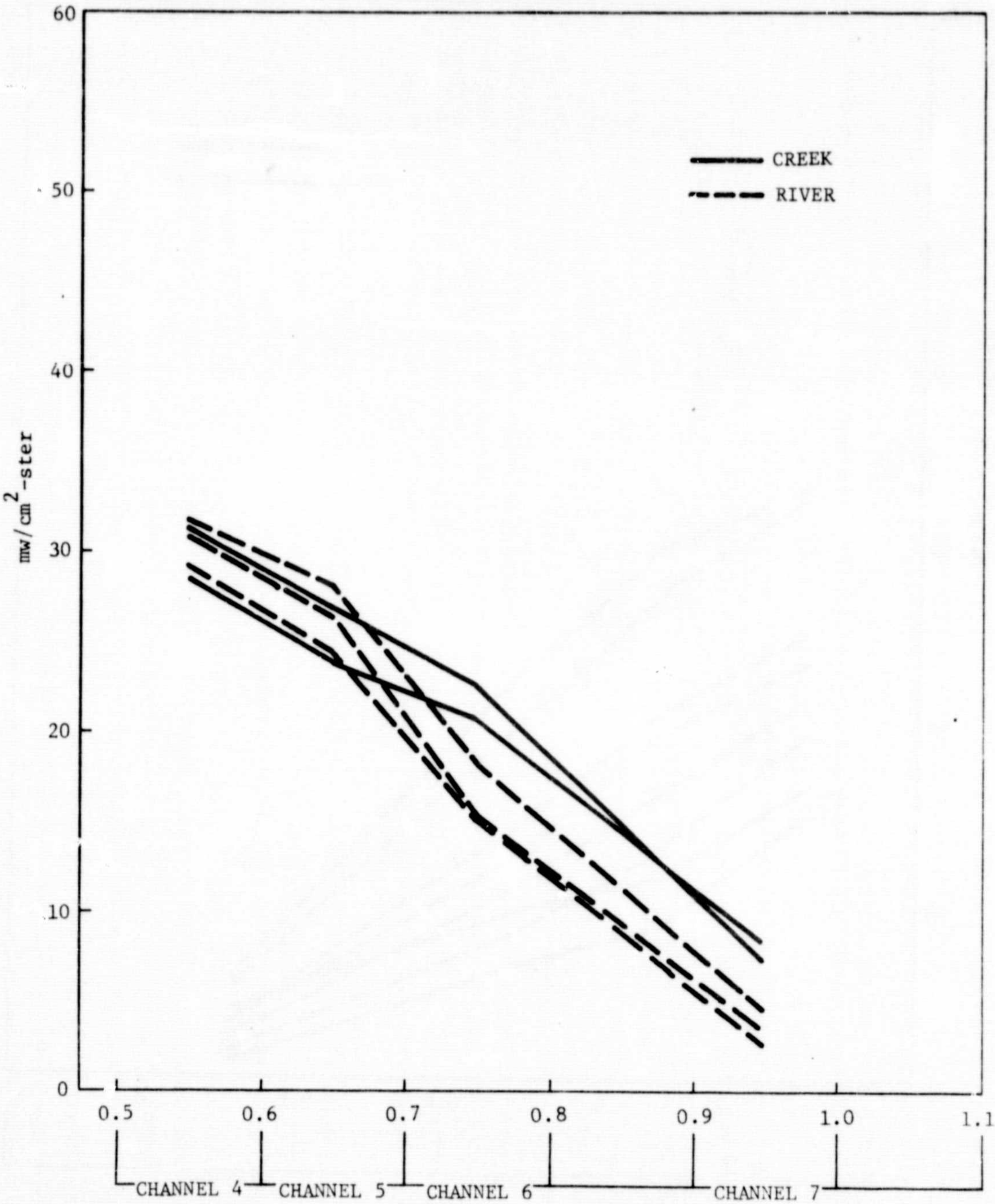


FIGURE 2-68
WATER QUALITY SIGNATURES
9 APRIL 1973

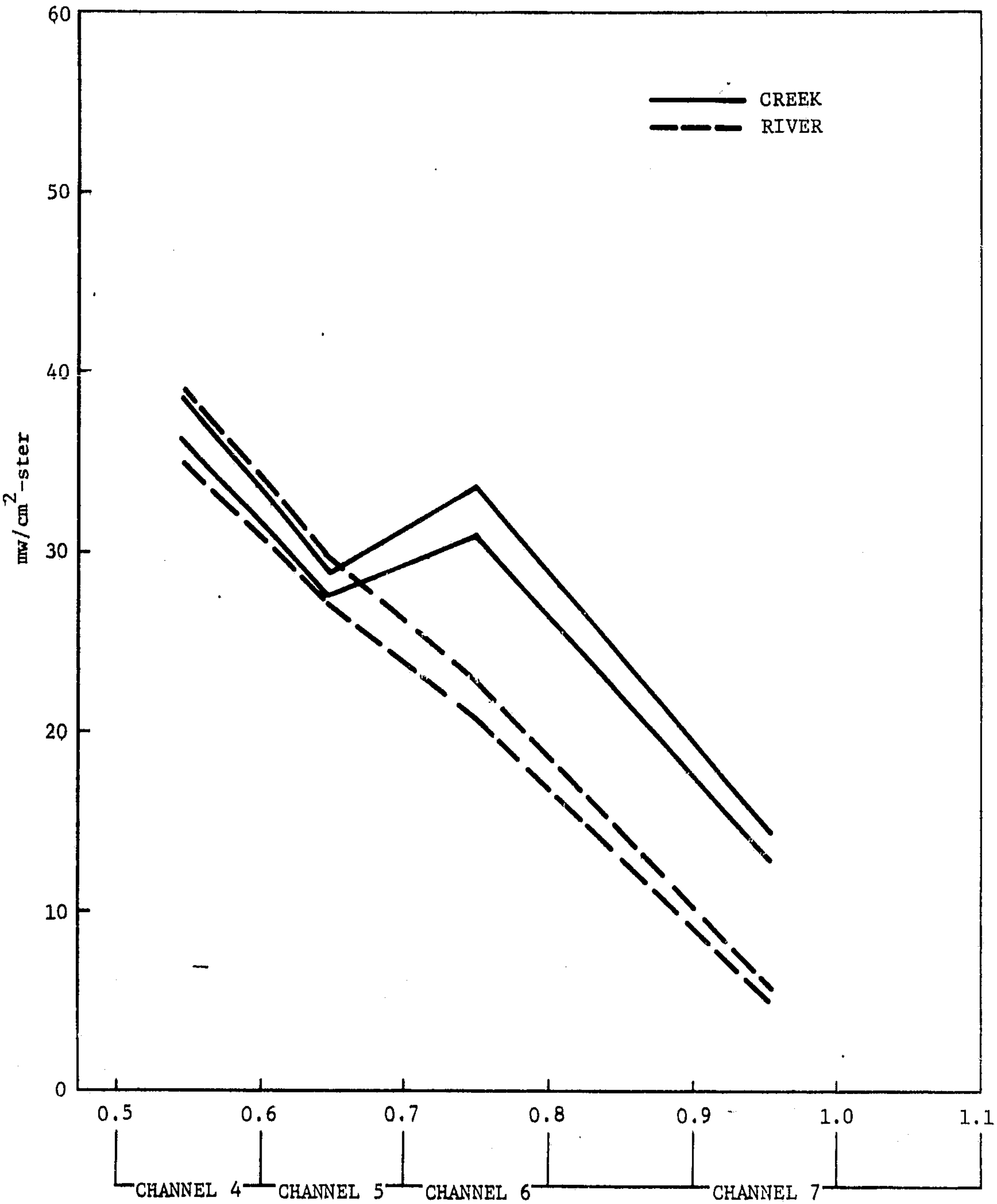


FIGURE 2-69
WATER QUALITY SIGNATURES
8 JULY 1973

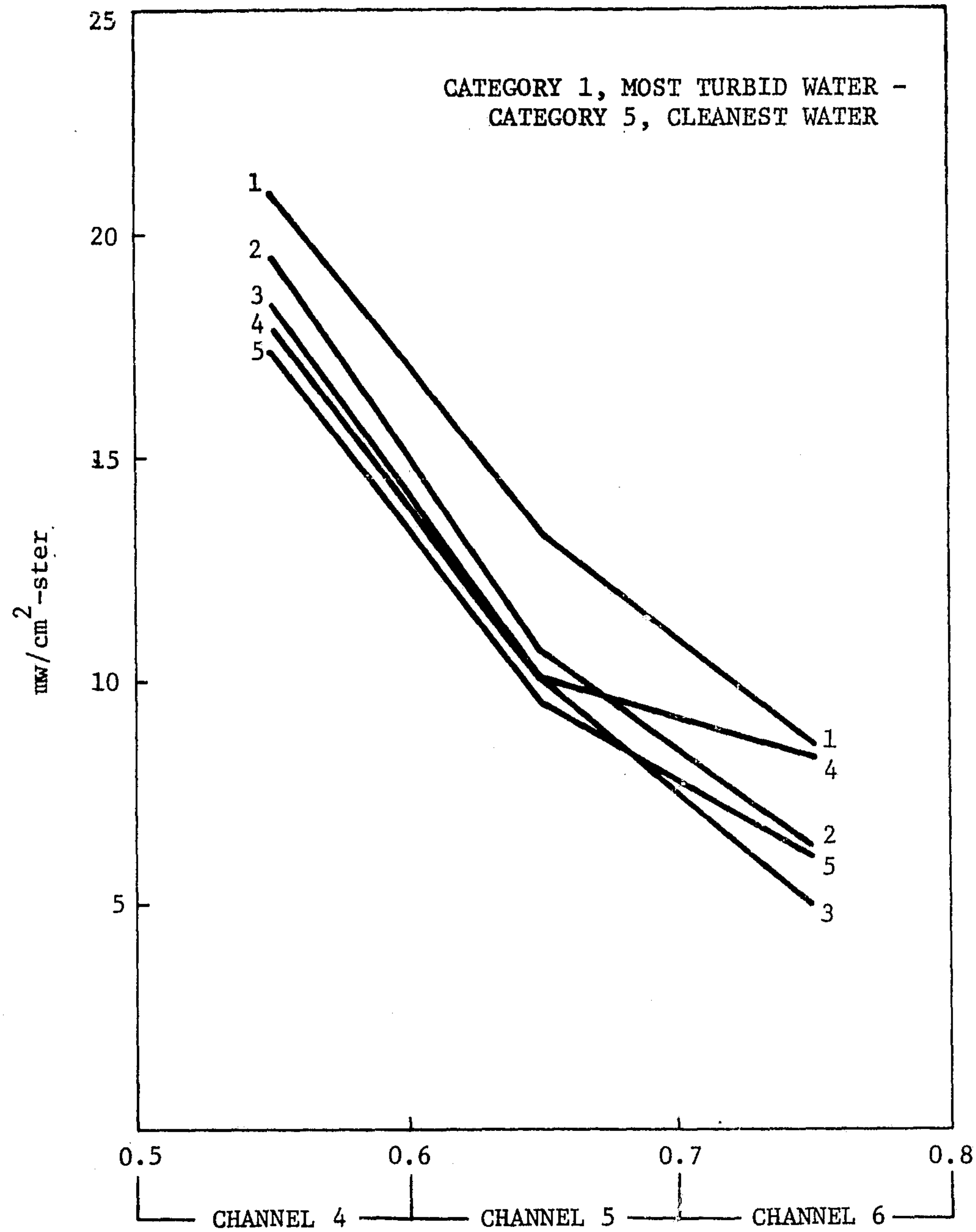


FIGURE 2-70
WATER SIGNATURES FROM SUSQUEHANNA RIVER CLASSIFICATION
11 OCTOBER 1972

classify the Susquehanna in January. This was probably the result of ice chunks floating in the river. For the other months the water signatures show a monotonic decreasing in brightness with increasing wavelength.

An algorithm of water quality turbidity versus time, presently, does not seem possible. First the time lag between acceptable dates of ERTS coverage is too gross. Then, too, factors that affect a body of water, such as organic load, ice, etc. must be measured and taken into account. Until all the above mentioned factors can be considered the development of a variation algorithm is unlikely. The method that was used to develop the signatures for MITRE's test sites, that is redeveloping signatures for specific test areas for each overflight and applying them throughout the test sites, is preferred at this time.

2.3.2.2 Pennsylvania Flood Quick Response Task. During this reporting period, a special ERTS analysis request was received from Mr. Norman Melvin of EPA's Region III Headquarters in Philadelphia, Mr. Melvin was aware of MITRE's ERTS work on land use and water quality along the Susquehanna River, and when a special situation arose in west-central Pennsylvania requiring flood aftermath assessment, he asked MITRE to see if information was available from ERTS which would assist in the overall assessment.

Heavy rains (nine inches in 24 hours) has caused severe flooding on September 11, 1972, affecting the following rivers and creeks in Armstrong and Indiana counties:

Cush Cush

Rayne Run

Pine Run

Crooked Creek

Little Mahoning Creek

Plum Creek

A Federal Disaster Area was declared on September 25 for the following communities:

Marion Center

Rochester

Cherry Tree

Mather

Clymer

Stafford

Dickensonville

Home

Shillocketa

Plumville

Although the area was not in either of MITRE's test sites, MITRE agreed to examine ERTS coverage to determine if any coverage about the time of the flood would provide useful data for analysis of the area. The following are the results of the checks on all coverages of the area from September 1972 to January 1973.

1. September 7: Coverage was four days prior to the flood. Cloud cover acceptable.

2. September 25: Imagery showed excessive cloud cover over the area. Fourteen days after flood.

3. October 13: Over 50 percent cloud cover over area of interest. Thirty-two days after flood.

4. October 31: Imagery showed excessive cloud cover over the area. Fifty days after flood.

5. November 18: Imagery showed excessive cloud cover over the area. Sixty-eight days after flood.

6. December 6: Imagery showed excessive cloud cover over the area. Eighty-six days after flood.

7. December 24: Imagery showed excessive cloud cover over the area. One hundred and ten days after flood.

8. January 11: Cloud cover acceptable over test area. One hundred twenty-nine days after flood.

Unfortunately, none of the coverages of flooded area could be considered useful for further analysis, primarily because of excessive cloud cover. The January coverage was acceptable on the basis of cloud cover, but was eliminated because of the length of time which transpired since the flood. Reports of investigations of flood inundation assessment indicate that about seven to ten days after flood crest is near the maximum elapsed time for identifying the high water mark, and after about 30-45 days indicators of plant stress caused by flooding have begun to fade.[1,2] It was concluded that although ERTS had a demonstrated capability for providing useful flood damage assessment information, the capability is dependent upon good cloud-free coverage within a reasonable time after flood crest. It this particular situation the required coverage was not available.

2.3.3 Phase III - Mesoscale Air Quality Continuing Data Analysis

The initial effort at mesoscale air quality analysis during Phase III was a continuation of the processes described in Section 2.2.3. By the end of Phase II, data for three ERTS coverages and corresponding NOAA Turbidity Network data had been calculated and plotted for comparison. During Phase III data from four additional coverages of the Harrisburg area became available. These data were calculated and plotted with the turbidity data for the same dates. As Figure 2-71 shows, there appears to be a striking correlation between the intensity variation over time recorded by ERTS and the turbidity variation as measured by Volz sunphotometers. The initial objective of showing at least a gross quantitative correlation between ERTS intensity and mesoscale air quality was considered achieved.

---

[1] Hallberg, et al. "Application of ERTS-1 Imagery to Flood Inundation Mapping", Symposium of Significant Results Obtained from ERTS-1 vol. 1, Section A., Washington, D.C.: NASA 1973 pp. 745-753.

[2] Morrison, R. and Cooley, M. "Assessment of Flood Damage in Arizona by Means of ERTS-1 Imagery", ibid, pp. 755-760.

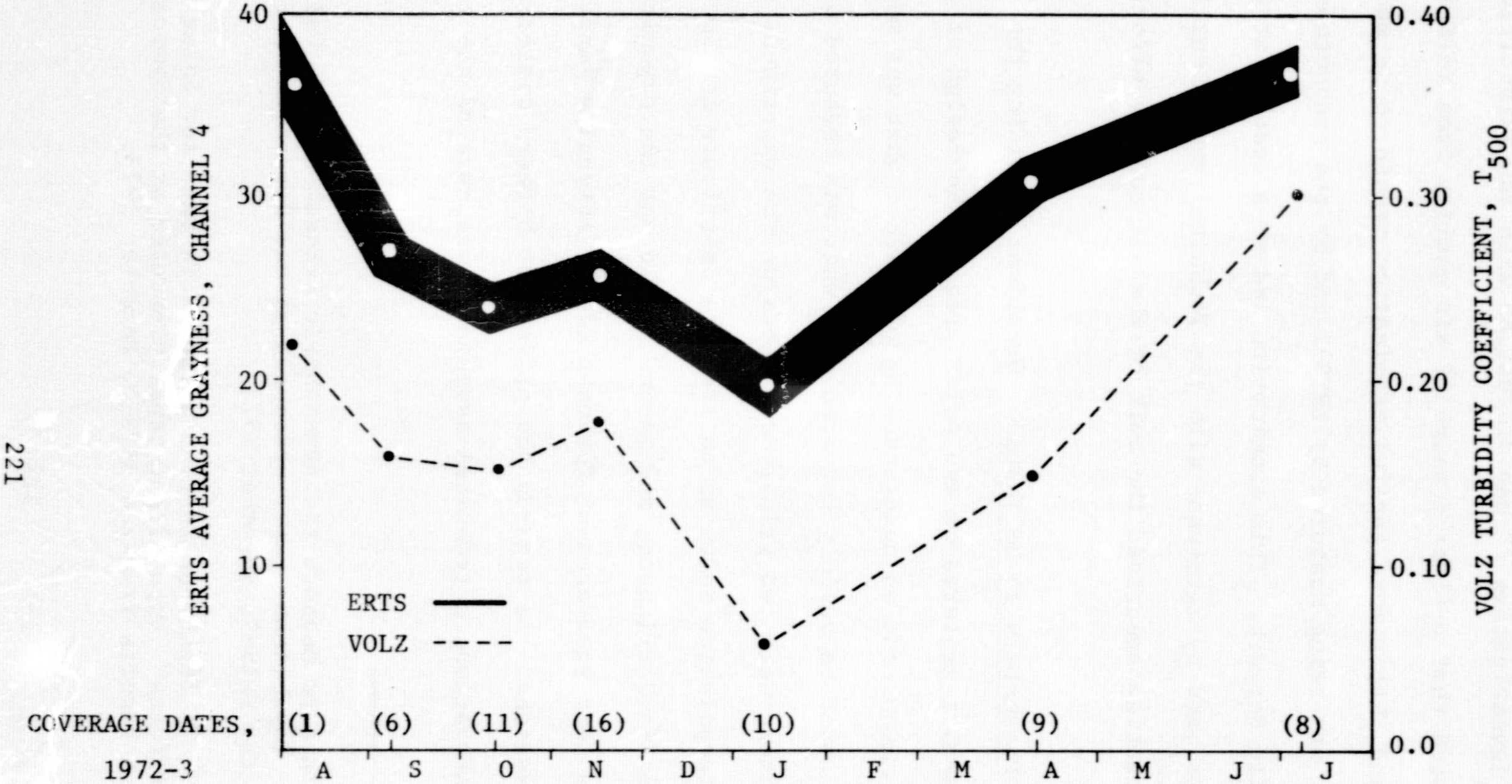


FIGURE 2-71

COMPARISON OF ERTS AVERAGE INTENSITY VARIATION WITH CALCULATED TURBIDITY VARIATION OVER THE HARRISBURG TEST AREA

Beyond the initial objective, however, work in atmospheric effects by other ERTS investigators[1,2] and discussion with the Scientific Monitor suggested that a finer measure of air quality from ERTS might be possible, and that a more careful examination needed to be made of precisely what was being measured by ERTS-1 and by the sunphotometers of the Turbidity Network. This examination led to a testing of the initial results, and by agreement with the Technical and Scientific Monitors the testing comprised the bulk of the air quality effort in Phase III.

2.3.3.1 Parameters to be Tested. Questions regarding the mesoscale air quality results centered on two major areas: the design of the original experiment and an understanding of whether what was measured on the ground could be validly compared with what was measured at the spacecraft. There were two primary questions on the experiment design. First, did interpolation serve as an adequate substitute for not having a sunphotometer in Harrisburg; and second, would not the organic components of the test area account for most of the intensity variation over growing seasons? As regards the difference between spacecraft and ground observation, a technical assessment was made of the two

---

[1]Griggs "A Method to Measure the Atmospheric Aerosol Content Using ERTS-1 Data" Unpublished paper presented at the Symposium on Significant Results from the ERTS-1, December 1973.

[2]Rogers et al. "A Technique for Correcting ERTS Data for Solar and Atmospheric Effects" Unpublished paper presented at the Symposium on Significant Results from the ERTS-1, December 1973.

measurement techniques to ensure that proper consideration was taken of such critical parameters as solar elevation angle, reflectance of radiation back through the atmosphere for ERTS versus direct radiation from sun to earth in the sunphotometer measurement, effect of skylight on the sunphotometer measurement, etc. To correct for possible error introduced by growing season effect, a new experiment was conducted over smaller inorganic land and water test sites. To check the accuracy and validity of interpolating turbidity at Harrisburg, an experiment was also run at inorganic land and water targets in Baltimore at the location of a sunphotometer station. To insure that all atmospheric and radiation effects were accounted for, a simple model of the atmosphere was constructed which did include all effects on the spacecraft and sunphotometer calculations. The final step was to apply the data from the new experiments in the context of the atmospheric model to determine the true relationship between ERTS reflectance data and ground calculated turbidity.

2.3.3.2 Design of the New Experiments. Basically, two new mesoscale air quality experiments were conducted: one in the Harrisburg test area to eliminate the growing season interference, and one in Baltimore to eliminate questions of interpolation as well as growing seasons. For the Harrisburg experiment, an inorganic target area of about 30 pixels in the Susquehanna River was selected, and ERTS Channel 4 intensity for the area was calculated as described in Section 2.2.3 for the five coverage dates for which tapes were readily available. The interpolated turbidity used previously for these dates was checked and found to be correctly calculated. (These data are shown later when comparison with the Baltimore data is made).

In Baltimore, the sunphotometer observations are made near City Hall*. Since City Hall is just off the harbor (less than 1 mile) it is relatively easy to locate on the ERTS intensity maps. For the Baltimore part of the experiment, an approximately 85 pixel area was taken as an urban inorganic target. Since a water target was also available, an approximately 85 pixel area of the harbor was also selected. Tapes for five coverages were readily available, and the Channel 4 intensity was calculated for each date for both the land and water inorganic Baltimore targets. Turbidity measurements were also available for the five dates, and these were obtained. All data were then prepared for inclusion in the model of the atmosphere which was being developed.

2.3.3.3 Atmospheric Model. The first step in developing a simple model of the atmosphere to establish the validity of using ERTS observed reflectance as a measure of air quality was to understand the constituents of the ERTS data and turbidity data.

ERTS data are provided by the four band Multispectral Scanner (MSS) on board the spacecraft. Channel 4 (0.5-0.6μ) data are used. The radiance at the down-looking spacecraft is quantized in 64 levels in each region of smallest view of the instrument (pixel). The MSS data

---

*Southwest Corner of Baltimore and South Streets, on the roof of the sixth floor.

are relayed to the ground where they can be used for construction of images and CCT's. At this point, according to a prescribed technique, the 64 gray levels are converted for Channel 4, in a non-linear operation, to 128 levels. MITRE developed an intensity map from the CCT indicating the gray level as a quantum level of a total count of 128 for each pixel. A gray scale count of 127 in band 4 represents a radiance of 2.48 mw/cm^2-sr.

Ground level measurements of atmospheric attenuation coefficients have been provided by the NOAA Turbidity Network. These NOAA ground stations make measurements of the radiance of the solar disk and a small region of the sky surrounding the sun, since the instrument has a 2° field of view while the sun appears as a disk of 0.5° angular size. In addition, the solar elevation, time of measurement, horizontal visibility, visual obstructions, temperature, dew point, wind and sky cover were noted. A mean solar distance correction factor is used in conjunction with the zenith angle and meter deflection of the instrument to compute the atmospheric turbidity averaged over a 0.01μ band at 0.5μ. The attenuation is described by the following equation[1]

$$S \cdot I = I_o \cdot 10^{-(B_{500} + \tau_r + \tau_z)\, m}$$

---

[1]Flowers, E., "NOAA Atmospheric Turbidity Program," Unpublished paper received in October 1972 from Division of Meteorology, NOAA/EPA, Raleigh, N. C.

Where I is the radiance at λ=500nm at the observation point

I_o is the extraterrestial radiance for mean sun-earth distance

S is the correction factor for mean sun-earth distance

τ_r is the scattering coefficient for air

τ_z is the absorption coefficient for ozone

B_{500} is the turbidity coefficient

m is the absolute air mass

The turbidity coefficient was noted and corrected for the influence of ozone absorption and Raleigh scattering, and represents the attenuation of light at 0.5μ over a path of one air mass. For convenience of interpretation, the B_{500} turbidity data is converted to the transmittance, τ, of one air mass by the formula

$$\tau = 10^{-\left[B_{500} + \tau_r + \tau_z\right]}$$

With these basic definitions of the ERTS data and NOAA turbidity data, a simple model of the atmosphere was developed along the lines of that described by Rogers[1] to test the validity of the data developed at Harrisburg and Baltimore as described above. The model is defined as follows.

The up-welling diffuse radiation from the surface is

$$L_T = \frac{\rho H}{\pi}$$

where ρ is the reflectivity and H is the irradiance in the target region.

---

[1]Rogers, et al. op cit.

When measuring total radiance from a satellite, two terms contribute. The reflected radiation is attenuated and reaches the satellite with an amplitude of $L_T \tau$ and a second contribution from atmospheric scatter (L_A) also adds to the result. Thus, the total radiance at the satellite is:

$$L = L_T \tau + L_A$$

$$= \frac{\rho \tau}{\pi} H + L_A.$$

H is also the sum of two components, skylight and sunlight. The skylight component is defined to be H_{sky} while the contribution of the sunlight is

$$H_{sun} \sin \Theta$$

where Θ is the solar elevation angle. H_{sun} is described by

$$H_{sun} = H_o \tau^m$$

where H_o is the solar irradiance outside the atmosphere and m is the air mass ($\approx \frac{1}{\sin\Theta}$ for $\Theta \gtrsim 10^o$).

Thus the total detected signal is

$$L = \frac{\rho \tau}{\pi} \left[H_o \tau^m \sin \Theta + H_{sky}\right] + L_A$$

Since the radiance seen by the satellite, L, is known, knowledge of the Θ, ρ, H_{sky} and L_A allow computation of τ.

In most cases ρ can be well estimated, and Θ is known as is H_o. Thus τ becomes a function of H_{sky} and L_A. An instrument developed by Rogers[1] measures the parameters needed to complete the analysis in the following manner:

H - 2π field of view (FOV) observation of downwelling radiation

H_{sky} - 2π FOV observation of downwelling radiation minus solar disk radiation

Θ - measured by the instrument also

L_{meas} - radiance from a narrow solid angle measured at various positions in the sky

Once having made these measurements on the ground below the spacecraft, at the time the satellite sensors are recording data, only a value for L_A need be provided to allow complete computation of τ. The technique used is to measure the sky radiance, L_{meas}, scattered through an angle equal to that through which light is scattered to the spacecraft. This value is then corrected for the difference in air mass between the direction of observation and the direction of the spacecraft. If $\theta<45^o$ the measurement procedure is straight forward. If $\Theta>45^o$ modeling is necessary to extrapolate to the desired scattering angle. If L_{meas} is determined at an angle equal to the scattering angle to ERTS then[2]:

$$L_A = L_{meas}\left[\frac{1-\tau}{1-\tau^m}\right].$$

---

[1]Rogers, et al. op. cit.

[2]Rogers, et al. ibid.

Here it is assumed that the ground measurement and ERTS overflight occur at the same time. If they do not a correction factor for the time difference is required.

Finally, τ is expressed as a function of the other system variables by:

$$L = \frac{\rho\tau}{\pi}\left[H_o\tau^m \sin\theta + H_{sky}\right] + L_{meas}\left[\frac{1-\tau}{1-\tau^m}\right].$$

Data, however, provided by the NOAA Turbidity Network ground station only include θ and

$$H_{sun}\sin\theta = H_o\tau^m \sin\theta$$

while the satellite provides L. Therefore, determination of τ requires some estimates with respect to the values of L_{meas}, H_{sky} and ρ. Incomplete knowledge of these values prevents unambiguous comparison of ground-based and satellite-born results.

However, H_{sky} may be estimated.[1] The steps in the estimation are:

(1) Establish the extra-terrestial radiation in the band of the instrument at various times of the year; $H_o\sin\theta$

(2) Reduce this value by 9% to account for water vapor and ozone absorption; $0.91\ H_o\sin\theta$

(3) Subtract the solar beam irradiance, which is in effect measured by the ground stations so

---

[1]List, "Smithsonian Meteorological Tables", Smithsonian Institution Washington, D.C. 1968 p. 420.

$$0.91\ H_o \sin\theta - H_o \tau^m \sin\theta$$

(4) Take ½ of the result

$$H_{sky} = H_o \sin\theta \left[.91 - \tau^m\right] \times ½$$

A check of this formula can be made using data provided by Rogers.[1] For March 27, 1973 in the lower Michigan area he quotes

$$H_o : 18.62 \frac{mw}{cm^2}$$

$$\tau : 0.752$$

$$\theta : 42^o$$

Using these values and the previously quoted formulas

$$H_{sky} = 1.6 \frac{mw}{cm^2}$$

compared with his measured value of $H_{sky} = 1.9 \frac{mw}{cm^2}$.

Using this approximation one obtains:

$$L = \frac{\rho\tau}{\pi}\left[H_o \tau^m \sin\theta + ½ \times 0.91\ H_o \sin\theta - ½\ H_o \tau^m \sin\theta\right] + L_A$$

$$= \frac{\rho\tau}{\pi}\left[0.455\ H_o \sin\theta + 0.5\ H_o \tau \sin\theta\right] + L_A.$$

As noted, $L_A = \left[\frac{1-\tau}{1-\tau^m}\right] L_{meas}$.

---

[1]Rogers, et al. op. cit.

A rough approximation for L_{meas} would be that it is

$$\frac{1}{2\pi} H_{sky}$$

if L_{meas} is distributed uniformly over the hemisphere of sky above a point on the ground. For one set of conditions this is confirmed by Rogers[1] data where

$$L_{meas} = 0.268 \frac{mw}{cm^2\text{-sr}}.$$

Thus $2\ L_A = 1.68 \frac{mw}{cm^2}$ equals H_{sky} which is in good agreement with the measured value of $1.9 \frac{mw}{cm^2}$.

Therefore,

$$L = \frac{\rho\tau}{\pi}\left[0.455\ H_o\ \sin\theta + \tfrac{1}{2}\ H_o\tau^m \sin\theta\right]$$

$$+ \frac{1-\tau}{1-\tau^m}\ \frac{1}{2\pi}\ \tfrac{1}{2}\ H_o\ \sin\theta\ (.91 - \tau^m).$$

This equation must be solved for a value of τ such that the predicted radiance equals the observed radiance, L.

Before applying the model's final equation to the available data, it may be useful here to list the data for review. Table 2-28 shows all data used in this portion of the investigation for all available ERTS

---

[1]Rogers, et al. op. cit.

TABLE 2-28

LISTING OF ERTS AND TURBIDITY NETWORK DATA

Date	Solar Elevation	BALTIMORE B_{500}	BALTIMORE R_L	BALTIMORE R_W	HARRISBURG B_{500}	HARRISBURG R_L	HARRISBURG R_W
1 Aug '72	56°	-	-	-	0.22	0.691	0.639
6 Sept '72	48	-	-	-	0.16	0.541	-
23 Sept '72	44.7	0.375	0.541	0.353	-	-	-
11 Oct '72	37	0.223	0.541	0.419	0.15	0.463	0.368
16 Nov '72	27	-	-	-	0.18	0.504	-
9 Jan '73	23.5	0.081	0.360	0.338	-	-	-
10 Jan '73	22	-	-	-	0.06	0.375	0.475
9 April '73	49	0.144	0.603	0.606	0.15	0.609	0.601
2 June '73	61.9	0.249	0.798	0.734	-	-	-
8 July '73	60	-	-	-	0.30	0.719	0.707

R_L - ERTS Radiance detected over a land target, $\frac{mw}{cm^2\text{-}sr}$

R_W - ERTS Radiance detected over a water target, $\frac{mw}{cm^2\text{-}sr}$

B_{500} - Turbidity coefficient from Turbidity Network coverages of Baltimore for water and land inorganic targets, and for a water target and the previously analyzed total test area target for Harrisburg. Additionally, the B_{500} values are shown. Those for Baltimore are calculated from the values observed near City Hall, and for Harrisburg they are interpolated from surrounding stations.

The first application of the last equation was with the Susquehanna River target at Harrisburg. The radiance values were obtained from the ERTS tape and a value of reflectivity (ρ=0.02) was chosen for the water. The equation was then used to solve for an appropriate value of τ. Conversion of τ to B_{500} was then performed and the following results were obtained.

TABLE 2-29

COMPARISON OF ERTS AND GROUND DATA
FOR HARRISBURG WATER TARGET

Date	B_{500} (ERTS)	B_{500} (Ground Data)
1 August 1972	0.38	0.22
11 October 1972	0.26	0.15
10 January 1973	1.22	0.06
9 April 1973	0.39	0.15
8 July 1973	0.41	0.30

For all dates except January, the trend in the data suggests that reasonable results have been obtained. It is not suprising, however, that the January date not agree since inspection of the computer produced ERTS maps indicates that patches of ice existed in the river which would have produced a significantly higher albedo than suggested by the two percent reflectivity used for the calculations.

The conclusion that the mid-winter data is unuseable is suggested by two other presentations. A figure follows (2-72) which illustrates, with data points and error bars, the radiance seen by ERTS at various times of the year. A line has also been drawn showing the yearly variation in solar radiation reaching the Earth in Channel 4, the data having been normalized to agree with the ERTS data on August 1, 1972. Note that four of the five data points lie close to the line. The only exeption is the January data, which in addition to showing a higher than expected response, also show a large variation for various adjacent points in the river, presumably due to the presence of ice in the river.

The second point is that if it is assumed that the ground data for B_{500} is accurate, use of the last equation again can then be made to determine ρ such that the ground and satellite data agree exactly. The results are shown in the following table.

TABLE 2-30

RESULTS OF MODEL FOR HARRISBURG WATER TARGET

Date	ρ
1 August 1972	0.11
11 October 1972	0.08
10 January 1973	0.28
9 April 1973	0.15
8 July 1973	0.10

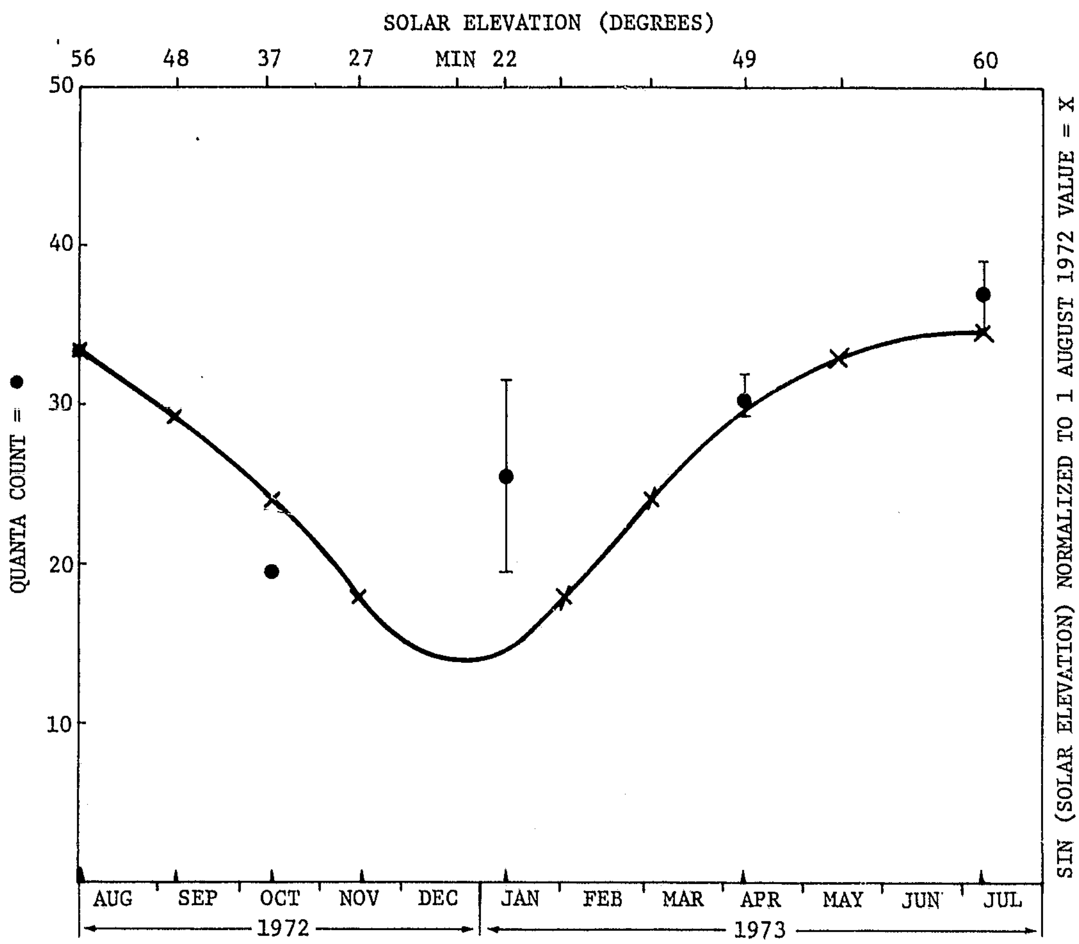


FIGURE 2-72

ERTS RADIANCE OBSERVED OVER SUSQUEHANNA RIVER TARGET NEAR HARRISBURG

These results also show that the winter date would have to have a rather high reflectivity for the data to agree. This is consistent with the previous conclusions.

The original air quality effort had been made to study the ability of ERTS to detect pollution over large areas containing a variety of geographical features, rather than a small water target. An approximately 325 square kilometer area containing Harrisburg was chosen. The geographical distribution during the time of study in percent is shown in Table 2-23.

Comparison of the ERTS turbidity data and the ground data shows the following agreement (assuming $\rho = 0.14$)

TABLE 2-31
COMPARISON OF ERTS AND GROUND DATA
FOR HARRISBURG TEST AREA - LAND

	B_{500}(ERTS)	B_{500}(Ground Data)
1 Aug 72	0.22	0.22
6 Sept 72	0.08	0.16
11 Oct 72	0.14	0.15
16 Nov 72	0.59	0.06
10 Jan 73	0.47	0.15
9 April 73	0.16	0.15
8 July 73	0.21	0.30

Again the agreement in amplitude and trend is quite good except in the winter data of November and January. Determination of the reflectivity required for good agreement produces

DATE	ρ
1 August 1972	0.14
6 September 1972	0.12
11 October 1972	0.14
16 November 1972	0.27
10 January 1973	0.21
9 April 1973	0.15
8 July 1973	0.11

which again suggests the existence of higher reflectivity during the winter months.

The results obtained for the Baltimore area are not so easy to interpret. The results are shown below.

TABLE 2-32

COMPARISON OF ERTS & GROUND DATA FOR BALTIMORE

	GROUND DATA	ERTS DATA	
		LAND (0.14)*	WATER(0.02)*
23 Sept 72	0.375	0.137	0.066
11 Oct 72	0.223	0.252	0.149
9 Jan 73	0.0813	0.319	0.377
9 April 73	0.144	0.155	0.071
2 June 73	0.249	0.301	0.134

*Reflectivity coefficients are shown in parenthesis, same as Harrisburg.

Here the ground measurements reflect the expected trend of increased air clarity in the winter (lower values for B_{500}). The values computed from the satellite data do not agree well with the measured data. At this time no clear reasons exist which explain this discrepancy.

2.3.3.4 <u>Conclusions on Tests of the Mesoscale Air Quality Analysis</u>. The data developed through the model tend to be rather reliable over both land and water in the Harrisburg area except during the winter months. The influence of color changes in vegetation with the season is not clear although independent measurements of ρ over water and appropriate satellite coverage would tend to minimize the problem. Further, Volz photometer data do not provide all of the information necessary for an accurate and complete analysis. Application of the Bendix photometer described by Rogers[1] would provide the information required for a more complete analysis. Another influential factor is the non-linearity in the satellite data conversion already mentioned. While a detailed investigation of this factor has not been made, the change in the significant results is expected to be small. Overall, it appears that a measure of mesoscale air quality is forthcoming from analysis of ERTS and turbidity data. However, especially with regard to the unclear results for Baltimore, insufficient time and resources remain in the present investigation to develop a more refined quantification.

[1]Rogers, et al. op. cit.

2.3.4 Microscale Targets - Land, Air and Water

The microscale target areas selected for MITRE's ERTS-1 investigation are the following:

Holtwood Dam Lake

Conowingo Dam

Safe Harbor Lake

*Codorus Creek Lake

Brunner Island

Conewago Creek Mouth

Lime Kiln at Annville

*Harrisburg

*Susquehanna River - Sunbury to Maryland

Lancaster

York

*Swatara Creek Mouth

Conestoga Creek Mouth

*Juniata River Mouth

*Three Mile Island

A study was undertaken of these areas in order to determine targets for possible further identification.

Images were available for 1 August 1972 (1009-15241), 6 September 1972 (1045-15243), 11 October 1972 (1080-15185), 16 November 1972 (1116-15192), 9 January 1973 (1170-15191), 10 January 1973 (1171-15245), and 9 April 1973 (1260-15195). However, only the October, November, January (1170-15191) and April images included all the target areas; the remaining dates cover those areas designated by asterisks, (*).

The dates that proved least helpful for our analysis were 16 November 1972, 9 January 1973, and 10 January 1973. The November 16th images were very hazy in the Channel 4 and 5 images. For both January 9th and 10th the Susquehanna River is dotted with patches of ice, making it hard to identify turbidity caused by merging streams.

For the other images and dates the most detailed was 11 October 1972. All along the river on this date water gradations are very evident especially in the Channel 4 images. This scene and date was chosen for MITRE's water quality analysis (Section 2.3.2). Also on this day apparent point source smoke plumes were detected, (Figure 2-73). In accordance with a redirection of the air quality effort which included analyzing point source targets of opportunity, the plumes were to be investigated on a non-interference basis with land use analysis. The plumes that were detected included the following:

- Brunner Island Power Plant
- Annville Lime Kiln
- Delmarva Power Plant

The other targets of interest were (1) a small plume of turbid water flowing into the Susquehanna River from Swatara Creek in August and (2) a plume from the Conodoguinet Creek in September.

Since the major emphasis of the last part of the investigation was on land use, time did not permit any additional investigation of these targets.

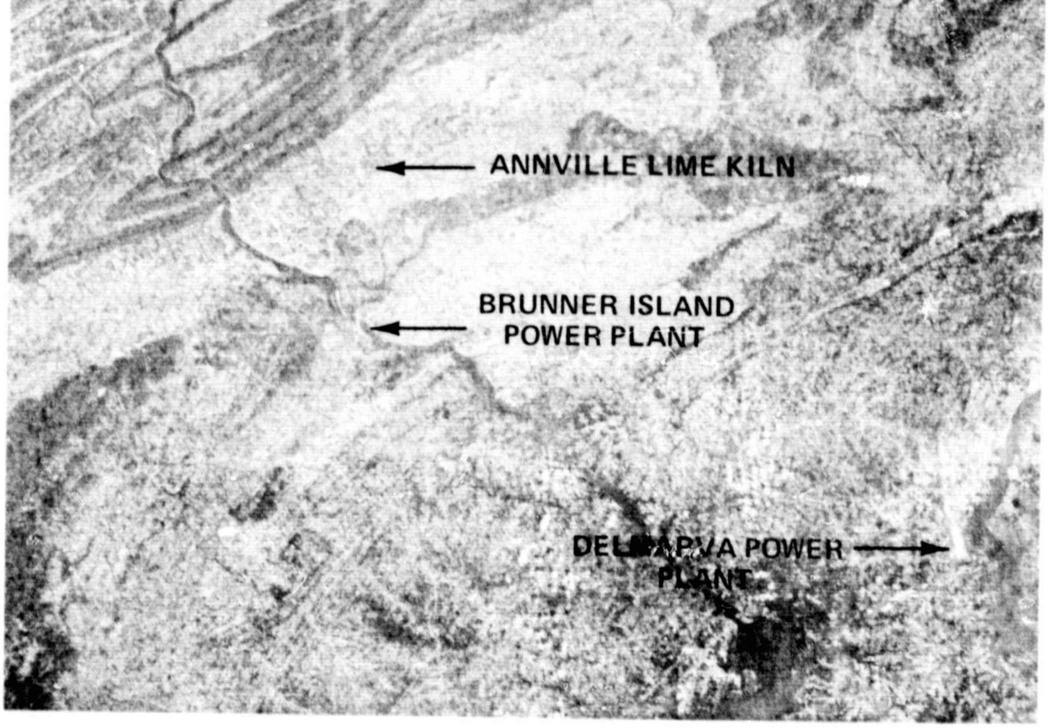


FIGURE 2-73
MICROSCALE AIR QUALITY TARGETS
11 OCTOBER 1972

3.0 ERTS ENVIRONMENTAL DATA SYSTEM SPECIFICATIONS

From the inception of the first ERTS-A proposal in April, 1971, the dual objectives of the MITRE investigation have been (1) define indices of change in land use, water quality, and air quality; and (2) describe specifications for an ERTS environmental data system. The eventual goal is defined in the original proposal: "The ultimate result...could be a coordinated set of requirement specifications for routine environmental monitoring by spacecraft."[1] Clearly, the two investigation objectives and the ultimate goal are related and interdependent. Requirement specifications for routine environmental monitoring depend on what has been found to be both feasible and useful in the description of an ERTS system for monitoring land use change, water quality, and air quality. The latter, in turn, is dependent upon the investigation experience in developing aggregate change indices of land use, water quality, and air quality in the investigation test sites. To complete the circle, the manner in which the investigation of indices is carried out and the level of detail sought will depend upon the ultimate goal of the investigation as defined by needs of ultimate users of the information generated.

In consonance with NASA's emphasis on demonstrating the immediate real-world application of ERTS to major resources problems, rather than detailed scientific research and development experimentation, MITRE's

---

[1]MITRE, Nationwide Environmental Indices from ERTS, M71-16, April 1971.

investigation has concentrated on what is possible now in environmental monitoring with ERTS on a broad scale. The original objective was to define aggregate, nationwide indices of land use change, water quality, and air quality which would provide useful inputs to state, regional, and national strategies and policies. The goal was a system for providing general information for overall environmental policy decisions, not specific data on environmental change in a small area requiring local action. While it was recognized that both large-scale and small-scale information would be required jointly by environmental decision makers, it was felt that ERTS-1's synoptic, repetitive, nationwide coverage ideally suited it to provide the information required by such users as the Council on Environmental Quality and the Environmental Protection Agency as an aid in determining the overall status of elements of the nation's environment. The original proposal by MITRE was, as a result, aimed toward broad national environmental indices and an ERTS system which would provide overall, aggregated environmental information.

As the proposal process evolved, it was agreed between NASA and MITRE that at least for the initial effort, the scope (and accordingly, the cost) of the investigation would be narrowed to a specific geographical region in Pennsylvania, and that use would be made of photogrammetric equipment and digital analysis techniques being developed at Pennsylvania State University. In this way a pilot investigation would be conducted on a smaller scale than the originally proposed nationwide coverage. Environmental indices would still be calculated for land use change, water quality, and air quality, but they would be for a specific sub-state size area, rather than the nation. Similarly, the monitoring system which would be described would apply to the specific test site, although appropriate extrapolations for a nationwide system could be made. However, even in the context of a more focused, smaller-scale investigation, the kind of information sought was still that which would be useful to the general environmental manager, rather than to an expert in a specific research discipline. The utility of a generalized index over detailed specific data for the environmental manager was best described in the Third Annual Report of the Council on Environmental Quality, which was published in August, 1972, the same date that MITRE's ERTS investigation began. To quote briefly from that report:

> "Accurate and timely information on status and trends in the environment is necessary to shape sound public policy and to implement environmental quality programs efficiently. . . One of the most effective ways to communicate information on environmental trends to policymakers and the general public is with indices. . . The raw data . . . is the most precise in the sense of providing the details of a particular environmental condition - but the least meaningful to policymakers and the general public. . . On the other hand, the use of a limited number of environmental indices, by aggregating and summarizing available data, could illustrate major trends and highlights the existence of significant environmental conditions. It al could provide the Congress and the American people measures of the success of Federal, State, local, and private environmental protection activities."[1]

MITRE's interrelated objectives were to produce these aggregate indices of land use change, water quality, and air quality, and to

---

[1] Council on Environmental Quality, Environmental Quality - 1972, Washington 1972, pp. 3-4.

describe an ERTS system for continuing environmental monitoring. The previous sections dealt primarily with the details of the investigation experience leading to the development of indices. This section describes the development of specifications for an ERTS environmental data system based on the results of the work described in the previous sections. The system specifications will be discussed in terms of system requirements, system analysis, system description, and system cost.

3.1 System Requirements

The basic requirements considerations for an environmental system are identification of the primary users that the system is intended to serve, and the real information needs of those users. As the introduction to this section noted, the primary user MITRE has identified for the environmental indices and the monitoring system are the Federal, State, and regional environmental managers. More specifically, these potential users identified in the course of the MITRE investigation include the following:

- Federal: Environmental Protection Agency (EPA)
  Council on Environmental Quality (CEQ)
  National Oceanic and Atmospheric Administration (NOAA)
  Department of Interior (DOI)
  Department of Housing and Urban Department (HUD)
  Department of Transportation (DOT)
- State: Pennsylvania Department of Environmental Resources (Geological Survey, Bureau of Mines), Air and Water Pollution Control Boards, Office of State Planning
- Regional/Local: Tri-County Regional Planning Commission, Economic Development Council of Northeastern Pennsylvania, county and city planning commissions, local air and water pollution control boards

If the Pennsylvania investigation experience is extrapolated to a national information user identification, finding users is clearly not a problem in itself. The problem, rather, is defining the system requirements so that the information produced fits the needs of the identified users. The informational needs have been assessed by MITRE in essentially two groupings: needs identified through ERTS investigations, and needs identified through other than ERTS experience. While the needs thus determined are not meant to form an all-encompassing list, they are felt to be sufficiently representative to be used in the aggregate for defining the general user requirements for an ERTS environmental monitoring system.

For over five years The MITRE Corporation has been involved in a range of environmental investigations for such agencies as E.P.A., C.E.Q., N.O.A.A., A.E.C., the Army Corps of Engineers, D.O.T., H.U.D., H.E.W., N.A.S.A., and the Department of the Interior (U.S.G.S. and Bureau of Mines); as well as providing environmental planning assistance to a number of state, regional, and local governments. It is this background combined with the experience of the MITRE and other related ERTS investigations that have resulted in a development of user requirements for environmental information from ERTS.

3.1.1 Land Use Analysis Requirements

3.1.1.1 Land Use Requirements from Sources Other than ERTS. It would probably be an understatement to say that land use planning has undergone a period of very rapid evolution over the past decade. The frequently conflicting goals of conservation, environmental protection, economic development, and growth have forced attention of environmental managers at all levels to planning for the best use of available land. The most recent manifestation of increased attention is the pending Federal legislation[1] which designates the states as the chief resources and land use planning authorities, and charges them among other responsibilities with establishing and maintaining an inventory of resources and land use within the state. In support of the USGS, MITRE assisted in the development of the Resources and Land Information (RALI) program which will form the backbone of Federal information assistance in complying with the anticipated legislation. Through this experience MITRE was able to arrive at an appreciation of the information needs of the various Federal, state, and regional resources and land use planners and relate them to what ERTS could provide.

Probably the simplest conclusion would be that even within the category of environmental managers there is a diversity of opinion as to how much information is needed, at what scale, and how often. Local planning officials may well need map or photographic products at a scale of 1:24,000 or larger, and to monitor land use change adequately in their jurisdictions they may require updating information on a seasonal or biannual basis. Federal and state planners, however, require more aggregated, summarized views of much larger areas; and because they are more interested in major changes, they need information

---

[1] Land Use Policy and Planning Assistance Act, S. 268, passed by the Senate June 21, 1973.

updates less frequently. In most cases, scales ranging from 1:1,000,000 to 1:250,000 would be sufficient, with updates occurring biennially or annually. Table 3-1, reproduced from MITRE's RALI report, illustrates Federal needs for different levels of planning.

3.1.1.2 Land Use Analysis Requirements From ERTS Investigations. As noted in previous sections of this report, there are a number of on-going ERTS-1 investigations which deal with various aspects of land use. Throughout the course of the MITRE investigation the National Technical Information Service has been utilized to keep abreast of developments in related investigations. One important piece of information gleaned from the review was identification of users and user requirements. The following notes, while not meant to include all related land use investigations, summarize user requirements and other pertinent information from investigation progress reports and technical papers.

1. E. L. Thomas (Maryland Department of State Planning), Investigation of the Application of ERTS-A Data to Integrated State Planning in Maryland, May 1973. Photo interpretive techniques used for land use mapping at 1:125,000 scale. Sixteen categories (some in USGS Level II) classified. ERTS imagery found to be very good for state resource and land use planning.

2. John L. Place (USGS), Change in Land Use in the Phoenix Quadrangle Arizona, Between 1970 and 1972: Successful Use of a Proposed Land Use Classification System, March 1973. Photo interpretive techniques (density slicing, color adding) used at 1:250,000 scale to

TABLE 3-1

FEATURES OF SYSTEM ALTERNATIVES

FEATURE	SYSTEM IMPLEMENTATION LEVEL		
	URBAN PLANNING SUPPORT	STATE & REGIONAL PLANNING SUPPORT	NATIONAL PLANNING SUPPORT
AREAL COVERAGE	SMSA'S ONLY	ENTIRE COUNTRY	ENTIRE COUNTRY
GRID CELL SIZE	20 ACRES	40 ACRES	640 ACRES
MAP SCALE	1:24,000	1:62,500	1:250,000
DATA ATTRIBUTES PER CELL	1000	500	500
PORTION OF DATA BASE ACCESSIBLE IMMEDIATELY	20%	0	0
PORTION OF DATA BASE ACCESSIBLE IN ONE DAY	100%	100%	100%
INTERACTIVE DISPLAY CAPABILITY	EXTENSIVE	LIMITED	NONE
OUTPUT CAPABILITY	ON-LINE AND REMOTE BATCH	REMOTE BATCH ONLY	REMOTE BATCH ONLY
DATA SELECTION CRITERIA	USER SPECIFIED	USER SPECIFIED	USER SPECIFIED

Source: C. Bisselle, et al. Resource and Land Information Program: System Concept, Implications and Development Plan, MTR 6275, The MITRE Corporation, October 1972.

detect land use changes. Considered valuable technique for resource managers at all levels for initial planning phase, and to update maps based on air photos.

3. Robert H. Alexander (USGS), ERTS Regional-Scale Overview Linking Land Use and Environmental Processes in CARETS; and Land Use Classification and Change Analysis Using ERTS-1 Imagery in CARETS, March 1973. Photo interpretive land use mapping at several scales from 1:100,000 to 1:1,000,000. ERTS found to be useful in detecting land uses in USGS Levels I, some II, even some III. Land use appears to be best way for resource managers to assess overall environmental change in an area, and ERTS can provide the information. Alexander expects that digital data analysis will yield even better results.

4. R. Simpson and D. Lindgren (Dartmouth), Land Use of Northern Megolopolis, March 1973. The fairly well quoted photo interpretation mapping of Rhode Island in 40 man hours. The scale was 1:250,000 and eight categories were classified.

5. R. Breckenridge, et al. (U. of Wyoming), Remote Sensing Applied to Land - Use Studies in Wyoming, March 1973. Photo interpretive techniques applied to land use mapping in Wyoming at full scale (1:24,000) demonstrates that ERTS can supply basic, broad-scale land use data continually, faster, and more efficiently than conventional techniques.

6. B. Sellman (ERIM), Land Resources Survey for the State of Michigan, March 1973. At time of report, ERIM was preparing land use photomosaic of Michigan at 1:250,000 and a procedure for including

ERTS data tapes in the transportation models of the Michigan Department of Highways. Plans are for ERIM to make ERTS data available to all appropriate agencies in the state government.

7. G. Simonson (Oregon State U.), Comparative Evaluation of ERTS-A Imagery for Resource Inventory in Land Use Planning, November 1972. Land use map overlays of the State of Oregon produced through photo interpretation of ERTS imagery at 1:1,000,000 scale. Estimate about 40 man hours per 100 square miles. Simonson had begun mapping at 1:250,000 at time of report.

8. C. Welby, et al. (N.C. State U.), Utilization of ERTS-1 Data in North Carolina, December 1972. Color additive photo interpretation at 1:125,000 shows roads, quarries, degree of urbanization. Found very useful for synoptic planning. Would prefer larger scale and may have to use digital analysis beyond 1:125,000.

9. E. Thomas (Md. Dept. of State Planning), Investigation of the Application of ERTS-A Data to Integrated State Planning in Maryland, May 1973. Photo interpretive land use mapping at 1:125,000. Sixteen categories (USGS Levels I and II) were classified. Department of Planning finds the ERTS product very useful.

10. E. Hardy (Cornell U.), ERTS Evaluation for Land Use Inventory, July 1973. Enhanced photo interpretive mapping of land use in New York at 1:125,000 using 25 hectare (62 acre) interpretation areas in a 6300 square kilometer test site. Compares favorably with conventional Land Use and Natural Resources (LUNR) inventory of the state. Report included

a section on users and their data requirements.

One important part of this work with regard to system requirements was a survey conducted to identify land use mapping needs of various potential users. Groups surveyed included state university county agents, state environmental managers, city and county planners, and Cornell academic counterparts of the first three groups. General findings were (1) most popular scale was 1:25,000; next was 1:125,000; (2) having current maps was important to all; most users wanted updating annually; (3) ERTS can be beneficial to a wide range of users when combined with information from other sources.

11. D. Sweet (Ohio Dept. of Economic and Community Development), Relevance of ERTS-1 to the State of Ohio, July 1973. Photo interpretation of imagery and comparison to air photos for land use and resource inventory statewide at scales ranging from 1:1,000,000 to 1:24,000. Land use very useful for state planning at 1:250,000 scale, it costs less, and can be done more rapidly than by conventional means. Strip mining and reclamation can be monitored by ERTS.

12. O. Malan (National Physical Research Laboratories, South Africa), To Access the Value of Satellite Imagery on a National Scale, February 1973. Photo interpretation at the 1:1,000,000 scale found very useful in nationwide resource and land use analysis in South Africa. Even at this small scale, some highways, railroads, different levels of urban density, and mining activity were observed. ERTS considered excellent for synoptic land use analysis.

13. R. Rogers and L. Reed (Bendix), Automated Strip Mine and Reclamation Mapping from ERTS, December 1973. Digital interpretation of ERTS CCT's demonstrates that mining and reclamation can be monitored in Ohio. Scale used was 1:250,000, but a range of scales is possible.

14. R. Ellefsen (California State U.), ADP Pattern Recognition of Urban Land Use from Satellite-Borne Multispectral Scanner, November 1973. Using essentially the digital cluster analysis techniques developed at LARS, Purdue, a San Francisco urban area was mapped with eight functional land use categories at 1:24,000. The goal is a system to provide land use map update information and to detect change rapidly and automatically.

3.1.1.3 Land Use System Requirements-Conclusions. As is seen in the review of background MITRE work and review of results of other related ERTS investigations, ERTS appears to be ideally suited for providing information over much of the entire range of resolution, scales and frequencies required at different levels of resource and land use planning. Using analysis of every pixel (full scale), either through photo interpretation of the imagery or digital signature analysis of the MSS data tapes, land use maps can be constructed at a scale of about 1:24,000 (which corresponds to the scale of the USGS 7.5 minute quadrangle maps). At this scale the interpretation cell is on the order of several acres, and generally about 15 distinct land use categories can be classified, with even more sub-categories possible if desired. This would generally be the scale most useful for local metropolitan analysis, providing environmental planners and managers with a land use overview of their whole jurisdiction. While a larger scale, perhaps down to the level of 1" = 400', might be required to analyze specific small areas of concern in more detail, the ERTS derived land use map is useful complement in that it displays the overall metropolitan area. Additionally, ERTS has the capability to highlight areas of significant change on repetitive coverage (thematically if not geometrically). With the areas undergoing most change identified, the local and regional planner can then make the optimum allocation of his non-ERTS resources to analysis and action in those specific areas requiring geometrical update.

For larger state, regional, and national land use information needs, analysis can be done on scales ranging from 1:24,000 to 1:1,000,000 - or even smaller scale than that if required. In a presentation at the recent Symposium on Resources and Land Information, Dr. McKelvey of USGS stated the consensus on a priority scale for land use for Federal users was 1:250,000.[1] If the Federal environmental manager were the main user of an ERTS land use information system, and if it is agreed that 1:250,000 is the overall most useful scale, then it is already demonstrated that ERTS can be integrated into a system

---

[1] McKelvey, V., "The Scientist's Perspective", Unpublished paper presented at the National Symposium on Resource and Land Information, Reston, Va., November 1973.

which will meet user requirements. It has been additionally demonstrated that ERTS can be useful at the state and regional planning levels as well, with a wide range of scale flexibility.

3.1.2 Water Quality Analysis Requirements

3.1.2.1 Water Quality Requirements - Non-ERTS Sources. MITRE's chief background for identifying user requirements in water quality analysis evolves from experience with EPA in national river basin requirements analysis[1], water quality index development[2], and analysis of water quality remote sensing techniques for EPA[3]. From these experiences, two seemingly conflicting conclusions may be drawn. First, the water quality manager at any level needs an overview of the status of water quality throughout his area of responsibility and he needs it at fairly frequent intervals. Second, the state of the art in water quality monitoring, whether in-situ or remote, is in most cases inadequate to meet user requirements for complete accurate coverage. For in-situ monitoring, laboratory methods exist for sampling and analysis for most of the important water pollutants. The problem is maintaining adequate areal coverage continuously so that the environmental manager is immediately aware of changes and able to take

---

[1] Rowe, W. D., et al. National Plan and Strategy for Water Quality, MTR-1492, The MITRE Corporation, November 1970.

[2] Johnson, A. C., et al. Water Pollution Indices for Regional Program Planning, WP-7410, The MITRE Corporation, December 1970.

[3] Burton & Bhutani, op. cit.

appropriate action. As noted earlier in this report in the discussion of linking in-situ water quality stations to DCP's, automated continuous water quality sensors have not yet overcome problems of unattended reliability, and the schedules for maintenance result in a high cost operation if the sampling network is large enough to cover an area adequately.

One obvious answer would appear to be remote sensing by satellite or aircraft. Potentially an entire river basin, for example, could be monitored continuously. Unfortunatley, remote sensing is not without its drawbacks, as reported by NASA's Working Group on Remote Sensing of Pollution[1]:

> "Because of the particular spectral characteristics of water itself (it is reasonably transparent to electromagnetic radiation only in a rather narrow spectral region centered at 0.5μm) and the characteristics of the pollutants (most of them do not display the sharply defined spectral signatures that are characteristic of gases, for example), the number of pollutants that can be directly detected in water by remote means is rather limited."

Table 3-2 lists the water pollutants and remote sensing methods which are or may be applicable. Work recently completed by MITRE for EPA discusses in more detail these and a number of other sensors which are either available or under active development.[2] What is clear

---

[1] NASA Remote Measurement of Pollution, NASA SP-285, August 1971, p. 19.

[2] J. Burton and J. Bhutani. A Preliminary Review of Water Quality Remote Sensing Techniques, MTR-6480, The MITRE Corporation. January 1974.

TABLE 3-2

SENSOR/APPLICATION CORRESPONDENCE FOR REMOTE SENSING OF POLLUTION

1—PRESENTLY AVAILABLE
2—UNDER DEVELOPMENT
3—POTENTIAL APPLICATION

*—WITH INFRARED CHANNEL

		FILM CAMERAS													
		U/V	COLOR	COLOR I/R	MULTISPECTRAL	MULTICHANNEL SCANNING RADIOMETER	CORRELATION RADIOMETER	FRAUNHOFER LINE DISCRIMINATOR	PULSED LASER SYSTEM	LOW LIGHT LEVEL DEVICES	I/R IMAGER-SCANNER	MICROWAVE RADIOMETER	RADAR	SCINTILLATION DETECTOR	POLARIMETER
OIL		1	2	3	1	1	1	1	1		2	1	1		1
SUSPENDED SEDIMENT			1	1	1	1	2		2						2
CHEM. & TOXIC WASTES			2	3	2	2	2	3	2						
SOLID WASTES			1	1	1	1	2		2						2
THERMAL EFFLUENTS						1*					1	1			
RADIOACTIVE WASTES														1	
NUTRIENT WASTES			1		1	1	1		2						3
LIVING ORGANISMS	INTRO. OF SPECIES		2		2	2				3					
	BACTERIA								3						
	RED TIDE		1	1	1	1	1		1						
	HUMAN & CUL. EFF.		1	1	1	1				1	1		1		

Source: Remote Measurement of Pollution, NASA SP-285, August 1971.

in remote sensing of water quality is that the state of the art is very dynamic and a number of new methods are on the threshold. What is also clear, as was brought out at EPA's Second Conference on Environmental Quality Sensors[1] in October 1973, is that environmental managers can't wait for new developments. They are required to manage water resources using the best tools that are available now to measure the quality of water.

The next section discusses what has been learned in several ERTS investigations with regard to applying ERTS information to identified user requirements.

3.1.2.2 Water Quality Analysis System Requirements From ERTS Reports. As with land use, a second source of information on user requirements in water quality was a review of reports of other ERTS environmental investigators. Unfortunately there were far fewer investigators reporting on work related to water quality than was the case with land use, probably because few water quality parameters appear amenable to detection in ERTS data. Notes from those investigation reports which have been reviewed follow.

1. H. Yarger, et al. (U. of Kansas), Water Turbidity Detection Using ERTS-1 Imagery, March 1973. Photo interpretation and density slicing of ERTS imagery of reservoirs show high correlation of gray

---

[1]This Conference Report has not been published as of this date, February 1974.

levels and suspended load and Secchi disk measurements. ERTS may result in a reliable, low-cost system for predicting suspended load from ERTS imagery.

2. J. Schubert and N. MacLeod (American U.), Digital Analysis of Potomac River Basin ERTS Imagery: Sedimentation Levels at the Potomac-Anacostia Confuence and Strip Mining in Allegheny County, Maryland, March 1973. Digital investigation of the 10-11 October 1972 Potomac River plume shows various levels of reflectance which are probably sedimentation. Detection of organic effluents may be possible. No correlation with ground truth at time of report.

3. A. Falconer, et al. (Canada Centre for Inland Waters), Studies in the Lake Ontario Basin Using ERTS-1 and High Altitude Data, March 1973. ERTS data is expected to be very useful in analysis of micro and mesoscale dynamics including plumes and effluent upwellings.

4. T. Wagner and F. Polcyn (ERIM), Progress of an ERTS-1 Program for Lake Ontario and Its Basin, March 1973. Digital analysis was applied to developing a system for synoptic observation of such features as plumes into lakes. The system is expected to benefit state, regional, and in this case international environmental managers.

5. A. Coker, et al. (USGS), Detection of Turbidity Dynamics in Tampa Bay, Florida Using Multispectral Data from ERTS-1, March 1973. RBV imagery of turbidity from bay dredging combined with computerized ground truth. Possible basis for modeling three-dimensional turbidity dynamics. Information found very useful by Tampa Bay Port Authority.

6. R. Paulson (USGS), Preliminary Analysis of ERTS-Relayed Water Resources Data in the Delaware River Basin, March 1973. ERTS demonstrates viability as data relay station for DCP tied to river gaging stations in a river basin. Difficulties were encountered in tying DCP to water quality stations, however.

3.1.2.3 Water Quality Analysis Requirement - Conclusions. The major conclusion based on that experience was that the Federal, state, and regional water resources manager does require aggregate, synoptic information on entire river basins, reservoirs, etc., within his area of responsibility. For the national manager this would mean some index of water quality on a basin by basin basis. For the local level manager it may require data on a number of specific pollutants measured at least daily per river mile, as well as an aggregate index of water quality at least daily throughout his area of responsibility. As MITRE's ERTS experience and the review of other related investigations has shown, ERTS as presently configured can be expected to provide only a small portion of the total information required. The most useful information appears to be measurement and location of relative turbidity for specific dates, and calculation of change in relative turbidity levels over time. Since good coverage is not assured even once in 18 days, ERTS general water quality index would be most useful to a manager in measuring the longer term effects of resource management measures.

3.1.3 Air Quality Analysis Requirements

3.1.3.1 Air Quality Experience Other Than ERTS. Since 1969, MITRE has been involved in systems engineering work with environmental managers concerned with the measurement and control of air pollution. While the work has been funded primarily by EPA and its predecessor agencies in HEW, the specific projects have all involved close interaction with air pollution control officials at the Federal, state, regional, and local level. One of MITRE's earliest efforts was the establishment of a national data system[1] which would channel appropriate aerometric information between monitoring agencies at all levels and the Federal government. Obviously a key initial part of that effort involved defining the information requirements of the environmental managers who were the ultimate users of the system. Other projects have involved structuring national air quality monitoring strategies[2], specifying data systems for EPA's laboratories[3], defining monitoring requirements for EPA grant applications[4], and developing detailed system specifications for individual regional and state environmental monitoring systems[5]. Another area of related work was the development

---

[1]Stryker, S., et al. Establishing Continuing Data Flow to the National Aerometric Data Bank, MTR 6105, The MITRE Corporation, December 1971.

[2]Golden, J., et al. Initial Design of the National Aerometric Data Information Service, MTR-1651, The MITRE Corporation, June 1971.

[3]Burton, J. S. and Ricci F. J. Systems Engineering Study of the National Air Surveillance Networks/Laboratory System, WP-7294, The MITRE Corporation, October 1970.

[4]Keitz, E. L. and Mongan, T. R. Analysis of Requirements for Air Quality Monitoring Networks, M70-23, The MITRE Corporation, March 1970.

[5]Turner, S. J. and Golden, J. State of Kentucky Air Monitoring System Technical Specifications, MTR-6149, The MITRE Corporation, February 1972.

and calculation of national air quality indices for the CEQ which were published in their third annual report[1]. In regard to remote sensing of air quality, MITRE is currently working with NASA/Langley to define requirements and specifications for a range of instrumentation to be used in airborne and satellite monitoring of air pollution[2]. Table 3-3 is a reasonable listing of global air monitoring requirements for pollutants in addition to suspended particulates taken from a 1971 NASA study[3]. Thus the users of the required information have been identified through MITRE's work with Federal, state, regional and local air pollution control officials and the NASA global requirements estimates.

In summary, MITRE's other-than-ERTS experience in analysis of air quality monitoring systems requirements has resulted in an appreciation of the kind and amount of information that is required by environmental managers. One such void was the mesoscale air pollution between cities studied in the earlier sections of this report.

3.1.3.2 Air Quality Requirements - ERTS Experience. Of the three environmental media selected for the MITRE investigation, air quality had perhaps the least likeihood of receiving comprehensive quantification through analysis of ERTS data. Indeed, fewer ERTS environmental

---

[1]Council on Environmental Quality, op. cit.

[2]Duncan, L., et al. An Airborne Remote Sensing System for Urban Air Quality, MTR 6601, The MITRE Corporation, February 1974.

[3]NASA SP-285, op. cit.

TABLE 3-3

MONITORING REQUIREMENTS FOR AIR POLLUTANTS WITH RECOGNIZED ENVIRONMENTAL IMPACT

CONSTITUENT AND REGION OF THE ATMOSPHERE	GLOBAL	
	PROBLEM: Why are we concerned?	Accuracy
CO_2	Measure its increase, which is a factor in climate change	0.5 PPM
SO_2 - UPPER TROPOSPHERE AND STRATOSPHERE	Formation of particles in the stratosphere from SO_2 carried upward from the troposphere or injected by volcanos and SST's	0.5 PPB
O_3 STRATOSPHERE	What causes the long term changes in distribution of ozone? Is there a correlation with solar activity?	TOTAL CONTENT 1% DISTRIBUTION WITH HEIGHT 10%
H_2O STRATOSPHERE	(a) Determination of effect on ozone concentration (b) Determine effect on radiation balance of stratosphere (c) Determine influence on particle size distribution in the sulfate layer	TOTAL CONTENT 20% for (a) Much less accuracy for (b) DISTRIBUTION WITH HEIGHT 0.5 PPM for (c)
NO_x STRATOSPHERE	Determine effect on ozone concentration	NO_2 and NO 10 PPB
CONSTITUENT IN LOWER LAYERS	REGIONAL	
	PROBLEM: Why are we concerned?	Accuracy
SO_2	(a) Damage to plants (b) Particle formation which subsequently contributes to acid rain	10 PPB
H_2S	(a) Oxidizes to SO_2 (b) Its natural source is uncertain	0.1 PPB (?)
NO_x	(a) Damage to plants and toxicity at PPM concentrations (b) Photo-oxidation of hydrocarbons and particle formation (c) Precursor of PAN's	0.1 PPM for (a), 10 PPB for (b) and (c)
<HC>	(a) Lead to particle formation by photochemical processes (b) Lead to noxious and toxic products	<1 PPB (?) (necessary to distinguish species)
O_3	Irritant and destructive; a product of photochemical processes involving <HC> and NO_x	10 PPB
PAN'S	A class of toxic and irritant products of protochemical processes	1 - 10 PPB
Hg	Atmosphere transports Hg, which is toxic where it accumulates in the biosphere	10^{-2} PPB
HEAT RELEASED	A factor in regional climate change	——

Source: NASA, Remote Measurement of Pollution NASA SP-285, August 1971.

investigations were in the field of air quality than any other. The following are notes on those investigation reports which have been reviewed by MITRE for requirements analysis.

1. G. Copeland, et al. (Old Dominion U.), Correlation of Satellite and Ground Data in Air Pollution Studies, June 1973. Essentially, photo interpretation of point source plumes from ERTS imagery. Discussion of correlating results with ground measurements of various air pollutants, but no correlation accomplished at date of report.

2. E. Rogers (Aerospace Corporation), Remote Haze Monitoring By Satellite, March 1973. An attempt to correlate ERTS intensity measurements with measurements made with a solar aureole monitor in Los Angeles area. County air pollution data and airport visibility observations were also to be used. At date of report, no conclusive results on correlation.

3. R. Rogers (Bendix), A Technique for Correcting ERTS Data for Solar and Atmospheric Effects. Using ERTS reflectivity measurements and a radiant power measuring instrument, an atmospheric model was developed which allows correction of target reflectance for backscatter and attenuation. With modification, the method may be used to measure the attenuation and backscatter for correlation with air turbidity.

4. W. Lyons (Wisconsin U.), Use of ERTS-1 Satellite Data in Great Lakes Mesometeorological Studies, April 1973. Photo interpretation of

turbid air plumes from the Chicago - Gary area over Lake Michigan. Main concern was with weather modifying effects of man-made pollution.

5. M. Griggs (Science Applications, Inc.), A Method to Measure the Atmospheric Aerosol Content Using ERTS-1 Data, December 1973. Correlation of ERTS radiance data and Volz sunphotometer readings demonstrates a relationship of aerosol content and upwelling earth-atmosphere radiance.

3.1.3.3 Air Quality Analysis Requirements - Conclusions. The combination of experience in air quality monitoring systems and the shared experience of other ERTS investigators results in several conclusions regarding requirements for an ERTS information system. First, there is a need for regional synoptic air monitoring and analysis information by Federal, state, regional and local environmental officials. Legislation which establishes standards for Air Quality Control Regions, as well as the pervasive nature of air pollution, dictate that air quality be understood as a mesoscale as well as micro-scale phenomenon. While current MITRE efforts for NASA/Langley[1] indicate considerable promise for remote sensing of air pollution, ERTS data has been thus far limited to correlating total radiance and total atmospheric turbidity, rather than measuring specific pollutants of interest to environmental managers such as sulfur dioxide, carbon monoxide, etc. The optimum merger of complete user requirements with

---

[1] Duncan, et. al. Op. cit.

what is now possible with ERTS-1, would result in a requirement for ERTS measurement of radiance as an indicator of total air pollution burden over a mesoscale region.

3.1.4 Summary of Conclusions on System Requirements

Over five years of experience in nearly all aspects of the environmental field for sponsors ranging from CEQ and EPA, to the USGS and the Bureau of Mines, to state and local agencies, have provided MITRE with a unique appreciation of the information requirements of environmental resource managers at all levels. One conclusion that can be reached based on this experience is that there is a need at the Federal, state, regional, and local level to have available current, general indices of land use change, water quality, and air quality. While the requirement for precise quantitative measures of all environmental parameters is recognized, there is also a clear need for broader, aggregate indices of environmental quality on which to base decisions and evaluate programs. In water quality and air quality especially, state-of-the-art instrumentation does not in most cases provide the environmental manager with information on all pollutants of interest over his area of jurisdiction at the frequency desired. Similarly, synoptic land use change cannot be guaged with the currency required using conventional techniques, unless tremendous costs are found acceptable.

Part of MITRE's investigation has been aimed at finding a match between the requirements of identified users, and capabilities of ERTS to fill those requirements as determined by MITRE and other investigators of land use change, water quality, and air quality. In general, ERTS was found to be very beneficial in providing complementary information for land use mapping and change detection across a wide range of scales for an equally wide variety of users. Digital interpretation techniques aided by ground truth were found to be best for large scale work (e.g., 1:24,000), while either digital or photointerpretation of images was useful at smaller scales (e.g., 1:250,000). ERTS analysis has at this range of scales, demonstrated the capability for repetitive production of the 10-15 land use indices most frequently required by planners and managers.

For water quality and air quality, ERTS state-of-the-art has not yet been sufficiently developed to show much more than gross correlations with total turbidity. For water, several investigators, including MITRE, have been able to show several levels of turbidity which may be interpreted as an index of overall water quality. Since once per 18 days is the optimum ERTS coverage, however, a turbidity index would probably be more useful in monitoring gradual change in a lake or reservoir, rather than more rapid change as would occur in rivers with many effluent sources.

It seems from investigative experience that a useful index of overall air pollution burden is the most difficult to develop, although the work of several investigators[1,2] shows promise for the likelihood

[1]Griggs, op. cit.

[2]Rogers, op. cit.

of turbidity index development. While it seems unlikely that useful information or specific pollutants will be developed from ERTS data, an overall mesoscale turbidity index is feasible, and if developed will be useful to agencies such as NOAA, EPA, DOT, and state and regional air pollution control officials as well.

The following sections will describe the system and subsystems which can produce these environmental indices, and in general terms, the costs of such systems.

3.2 System Analysis, Description and Costs

3.2.1 Land Use Analysis System Description

Based upon the experience of the continuing data analysis phase and the analysis of the preceding section on system requirements, an ERTS environmental monitoring system for land use analysis can be generally described. While a number of alternative systems are possible for land use, the one described here is considered to have demonstrated its usefulness as it evolved through the course of the MITRE and other ERTS-1 investigations. The system will be described in terms of its two major components: ERTS data analysis procedures, and ground truth analysis procedures.

3.2.1.1 ERTS Land Use Digital Analysis Procedures. MITRE's total ERTS environmental monitoring system, as well as the sub-system for each of the three environmental parameters (land use change, water quality and air quality), is based primarily on digital analysis of the MSS CCT's. While other investigators have reported considerable success in land use analysis by photo interpretation of ERTS images at scales generally smaller than 1:125,000, the digital analysis approach to spectral data provides superior resolution at larger scale and also allows a more automated classification with less reliance on highly trained personnel. Only cost considerations cloud this conclusion. However, since the system would ultimately serve a variety of users at the Federal, state, regional, and perhaps even local level, the digital analysis approach was considered the preferable alternative in terms of range of scale, resolution, and speed and ease of analysis.

The basis of the digital analysis portion of the land use analysis system is a combination of unsupervised (cluster analysis) and supervised statistical analysis computer procedures on the spectral features in the data, several of which are described in Appendix A. Similar analysis programs have been developed by a number of investigators. Probably the best known and most widely used programs are those developed at the Laboratory for the Application of Remote Sensing (LARS) at Purdue. The programs used in the MITRE investigation are those developed at the Office of Remote Sensing of Earth Resources at Penn State, and they are essentially the same type of programs as those used at LARS but using more automatic interpretation of multi-band data. Such computer programs are available and operational and may be obtained by the environmental management agency at minimal cost (under $500).

A second type of software which was not employed in MITRE's investigation, but which would be valuable in land use analysis and mapping, is a set of programs to provide for more precise radiometric and geometric registration of bulk MSS data. An example of work in progress by a number of investigators is that by R. Bernstein of IBM, which has involved digital correction of tapes to result in products which correspond to UTM projections with no diminution of quality or resolution[1]. Another is the LARS[2,3] software reported on at the ERTS March and December 1973 Symposia. In the work reported by Bernstein, ERTS MSS CCT's are reformatted by spectral band demultiplexing and spatial data merging, and then radiometric and geometric corrections are made to the digital data. For the geometric corrections, a sequential similarity detection algorithm is applied to the digital data for detection of recognizable geographic features whose positions are known, and this operation results in a correction to within 60 meters. Because the corrections are applied to digital data and only one reprocessing of the image is required, image quality and resolution are maintained. Corrections made include internal (e.g., scan skew, mirror velocity, and spacecraft attitude and altitude) and external (e.g., earth rotation). The work reported by Baumgardner at LARS indicates similar internal and external corrections have been made to allow for direct overlay of ERTS data with standard UTM maps. An additional feature of the LARS system is a temporal overlay capability. This feature permits rapid and direct overlay of geometrically corrected

---

[1] R. Bernstein, "Results of Precision Processing (Scene Correction) of ERTS-1 Images Using Digital Image Processing." Symposium on Significant Results Obtained from ERTS-1, NASA SP 327, March 1973.

[2] M. Baumgardner, "An Evaluation of Machine Processing Techniques of ERTS-1 Data for User Applications, Symposium on Significant Results Obtained from ERTS-1, NASA SP 327, March 1973.

[3] D. Landgrebe et. al., Third ERTS Symposium, December 1973. (verbal presentation).

CX

ERTS data from successive ERTS coverages with registration accuracy on the order of one pixel. One of the correction software packages available, preferably including the temporal overlay capability, should be included in the land use analysis subsystem.

A third type of software that might be usefully employed in land use digital analysis is the textural/spatial classification procedures, such as those reported by Kirvida and Johnson[1] and Haralick and Shanmugam[2], to cite two examples. Since textural features contain information about the spatial distribution of tonal values within each ERTS band, a textural analysis can supplement the classification obtained from spectral analysis alone. In both cited reports, about a 10 percent improvement was achieved in land use classification skill scores when textural analysis is used in conjunction with spectral analysis. However, that is generally true for classification of larger areas (preselected cells of 64 pixel size, for example), and textural analysis has not been as useful in very heterogeneous areas such as a metropolitan region where the classification must often be at the level of one or two pixels. Nevertheless, as with spectral analysis software a number of texture analysis transform programs are

---

[1]Kirvida, L. and Johnson, G. "Automated Interpretation of ERTS Data for Forest Management" Symposium on Significant Results Obtained from the ERTS-1. NASA, March 1973.

[2]Haralick, R. and Shanmugam, K., "Combined Spectral and Spatial Processing of ERTS Imagery Data". Symposium of Significant Results Obtained From the ERTS-1. NASA, March 1973.

operational and should be included in the land use sub-system

A fourth type of software which is proving valuable in digital analysis is that developed at the Environmental Research Institute of Michigan[1] (ERIM) which includes a proportionate estimate method to calculate the makeup of an individual pixel if it is apparently on a border between two classifications. Additionally, advanced techniques are included to account for the relatively coarse resolution of ERTS data and the variations of atmospheric state over the area of interest. Since advanced processing techniques such as those developed at ERIM are now largely operational, they should be included in a digital analysis system.

A fifth digital component of the land use analysis sub-system is a procedure for correction of rectangular distortion in computer maps which results from line printer spacing not being square. While MITRE did not use the PSU subroutine (L-MAP), the correction is probably reasonably straightforward and mechanical, and should be performed in order to yield the optimum computer products for environmental management use.

A sixth program is required similar to the one used by MITRE (MAPCOMP) for comparison of several classifications over time to show

---

[1]Malila, W. and Nalepka, R., "Advanced Processing and Information Extraction Techniques Applied to ERTS-1 MSS Data". Unpublished paper presented at NASA's Third ERTS Symposium, December 1973.

and quantify land use change. Such programs are readily available, and, as with the others, may be obtained at nominal costs.

Finally, a seventh program is required - a means for selectively removing unwanted data. One good example is cloud and the shadow of each cloud, which usually play havoc with a digital approach to ERTS data analysis. Since rarely in any MSS scene, with the exception of ice and snow, is there a land area as white as a cloud, a simple removal (stripping) program based on a whiteness criteria could be easily developed. The shadow stripping subroutine would also be relatively simple: cloud shadow pixels could be stripped from the data based on the cloud area (number of pixels) removed and the azimuth and elevation angles of the sun available with each CCT.

3.2.1.2 Ground Truth Analysis Description. One of the most useful features of satellite remote sensing is that it replaces costly, time consuming conventional means of compiling land use data. Nevertheless, a minimum of ground truth is essential to initial signature development, and to classification verification. In MITRE's experience, the single most generally helpful ground truth was the USGS 7.5 minute quadrangle map series. Maps of both test sites were very useful in geographical orientation since they were at the same 1:24,000 scale as the full scale computer maps generated from the ERTS CCT's. They were also useful in some land use signature development on a gross scale (e.g., rivers, airports). However, it is clear that other ground truth in addition to the USGS maps is required to classify the 10-15 land use categories usually required by planners and managers. These USGS maps do not contain enough detail, and they are in addition often outdated. Since land uses can change dramatically over several years, a better source of information is required for use in initial signature development and verification of classification. The information needed can be obtained through recent land use maps prepared by conventional means, air photos, or, if practicable, on site inspection. In any method selected, the training area chosen must be sufficiently large to contain an example of each category that is to be classified throughout the area of interest. Once signature information has been developed, automatic classification of the entire area can be accomplished without further reference to ground truth, except for verification to the extent desired. In this way, very detailed ground truth is required in signature development, but only for a small portion of the area to be classified and only for the first ERTS base map produced. Thereafter, reference can be made to the base map for developing signatures for change analysis on subsequent dates.

3.2.1.3 Land Use Sub-system Operation. For the most part, the MITRE recommended land use sub-system of the ERTS environmental monitoring system operates as described in Appendix D and Section 3.2.1.1. Figure 3-1 is the land use sub-system overview. As the first step, detailed recent ground truth of at least a portion of the area to be classified would be collected and the ERTS MSS CCT's of the area

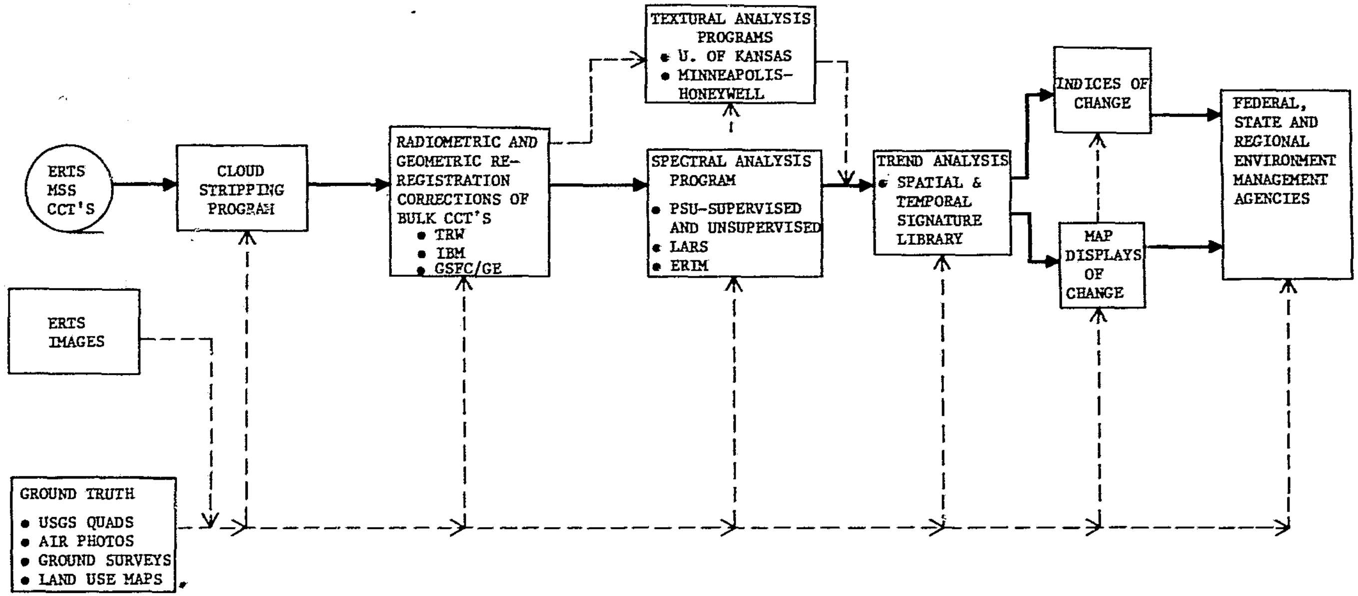


FIGURE 3-1
LAND USE ANALYSIS SUB-SYSTEM

acquired. After cloud stripping and re-registration procedures are performed, uniformity and intensity maps would be produced as described previously, and the interactive process of spectral (cluster analysis and supervised statistical) and perhaps textural analysis would be performed. Reference would be made to the ground truth for geographic orientation and development of all required categories in training areas. When signature information has been developed for all categories required, the total area of interest would be classified. If any gaps or unclassified areas remain on the computer map, the entire process would be repeated for those areas until virtually 100 percent of the area is classified (three iterations have usually been required in the MITRE experience). For especially difficult areas, aircraft photos or a field observation may be required. The sub-pixel proportionate estimate program could be required as well.

The principal products of this stage of the system are (1) thematic computer maps whose most useful range in scale for land use is from 1:24,000 with an interpretation area on the order of an acre, to 1:250,000 with an interpretation area of about 60 acres[1]; and (2) statistics, including the signature information for all categories and the amount of land in each use category (this can be in percent of total and also in acreage, square kilometers, or other areal

---

[1] E. E. Hardy, et. al. ERTS Evaluation for Land Use Inventory, Cornell University Report, July 1973.

measure desired). Once the maps and statistics are produced they would be spot verified with the available ground truth. A complete verification is time consuming, with several man-months of effort required for the typical urban area.

The next major stage of the system would be trend analysis. The procedures described above, completed for one ERTS overflight date, would produce the base data. When subsequent coverages become available they would be similarly processed. From the MITRE experience, at least one good coverage of a region with minimum cloud cover will become available once per season. This frequency is more than adequate for land use trend analysis for satisfying most environmental manager's requirements, and in fact one good coverage per year is probably adequate for the majority of needs. Once coverage beyond the base date coverage has been processed, the two (and subsequent) classifications would be processed by existing computer programs which quantify the amount of land use change by category and illustrate where the change has taken place on a computer map.

The final step in the system would be development of the land use trend information for the ultimate users of the system. The most useful index in the case of land use is also the simplest, and its calculation should be straightforward. The desired information from an index is the amount of change over time on a category by category basis. The comparison program calculates these data and the most reasonable form of display of indices would be a table showing, for the time period under consideration, the amount of acres (or other suitable measure) that were gained or lost by each category to and from the remaining categories. With this index of change provided on a timely repetitive basis to environmental managers, more informed decisions can be made on rates and manner of growth and development.

3.2.1.4 Land Use Analysis Sub-System Costs. The examination of system costs presented here is not as complete and detailed as would be desirable, but a comprehensive effort would have exceeded the scope of MITRE's investigation. Nevertheless, it is felt that a general discussion of costs is beneficial to provide potential system users with at least an order of magnitude estimate of the cost of using an ERTS environmental monitoring system for land use analysis.

The primary costs involved are computer time and manhours. The following are the underlying cost assumptions:

- The environmental management agency will have access to a computer generally equivalent to the IBM 370-165 and to a Bausch and Lomb Zoom Transfer Scope.
- ERTS CCT's and images and NASA aircraft (U-2) underflight IR photographs will continue to be furnished at no cost to the user.
- Recent detailed land use ground truth of at least a portion of the area of interest is available for the initial ERTS spectral signature and base map development.

With these assumptions in mind, the following table (Table 3-4) shows the breakdown of costs for a full scale (every pixel) spectral only land use analysis of a 200 square mile test area for 10-15 land use categories. The costs shown in the table equate to about $10 to

TABLE 3-4

LAND USE ANALYSIS SUB-SYSTEM COSTS
BY SPECTRAL ANALYSIS ONLY

System Step	Computer Cost, $	Man-Hours
• Subset desired area from ERTS CCT	75	5
• Run intensity map of area	60	5
• Compare map and ground truth	-	2
• Run cluster analysis	420	35
• Run supervised classification	135	25
• Compare ERTS classification and ground truth	-	2
• Second iteration of cluster and supervised analysis	60	5
• Compare classification with ground truth to identify remaining problem areas	-	2
• Third iteration of cluster and supervised analysis to classify entire area	270	25
• Verification with ground truth	-	4
• Prepare maps and indices	60	10
TOTAL	1080	120

$15 per square mile.

Although no complete survey has been made of the costs of conventional land use information processing, one reference will be useful for comparison. NASA's Earth Resources Laboratory, in a report on procedures for using air photography in land use classification, indicates that high altitude aircraft photography can be used for land use classification at a total cost of about $10 per square mile[1] for similar types of land use categories. Lower altitude photography and field surveys, which many environmental managers rely on for land use classification, is by comparison on the order of $47 per square mile. At this point in development it appears that the ERTS system can be cost effective compared to conventional means of land use mapping.

[1] P. Vegas. A Detailed Procedure for the Use of Small Scale Photography in Land Use Classification. NASA/ERL Report No. 031 (Undated).

3.2.2 A Water Quality Monitoring System Using ERTS Data

The first step in defining an operational system for water quality analysis requires a knowledge of the eventual users of the system. MITRE'S investigation of ERTS MSS data has revealed that the user that is most likely to profit from the system is the regional water quality and quantity planner. Specifically, MITRE'S contacts in working it's test areas - U.S. Army Corps of Engineers, U.S. Geological Survey, the Regional EPA Office and the Susquehanna River Basin Commission - have found them interested in an ERTS-based system. The EPA and COE are charged with the quality of the water and USGS and COE with the quantity of the water. The Commission is responsible overall for developing, maintaining, scheduling and controlling projects and activities within the basin. The Commission must provide regulation of water quality and development of water supplies for all uses; develop abatement programs for stream pollution and flood damage reduction; and promote forestry projects, develop water-related recreational facilities and hydroelectric power potential.

In Section 3.1.2, the state of the art in remote sensing water quality was reviewed. It was concluded that, except in various fortuitous circumstances, ERTS could supply only relative water turbidity spatially and temporally. The cause and quantity of the turbidity must be inferred from ground truth and where the ground truth is as dynamic and variable as is water, the value of ERTS derived data is not significant at this time. To the extent that ERTS derived relative turbidity can prove useful for analysis, Figure 3-2 illustrates the main components of a water quality monitoring system.

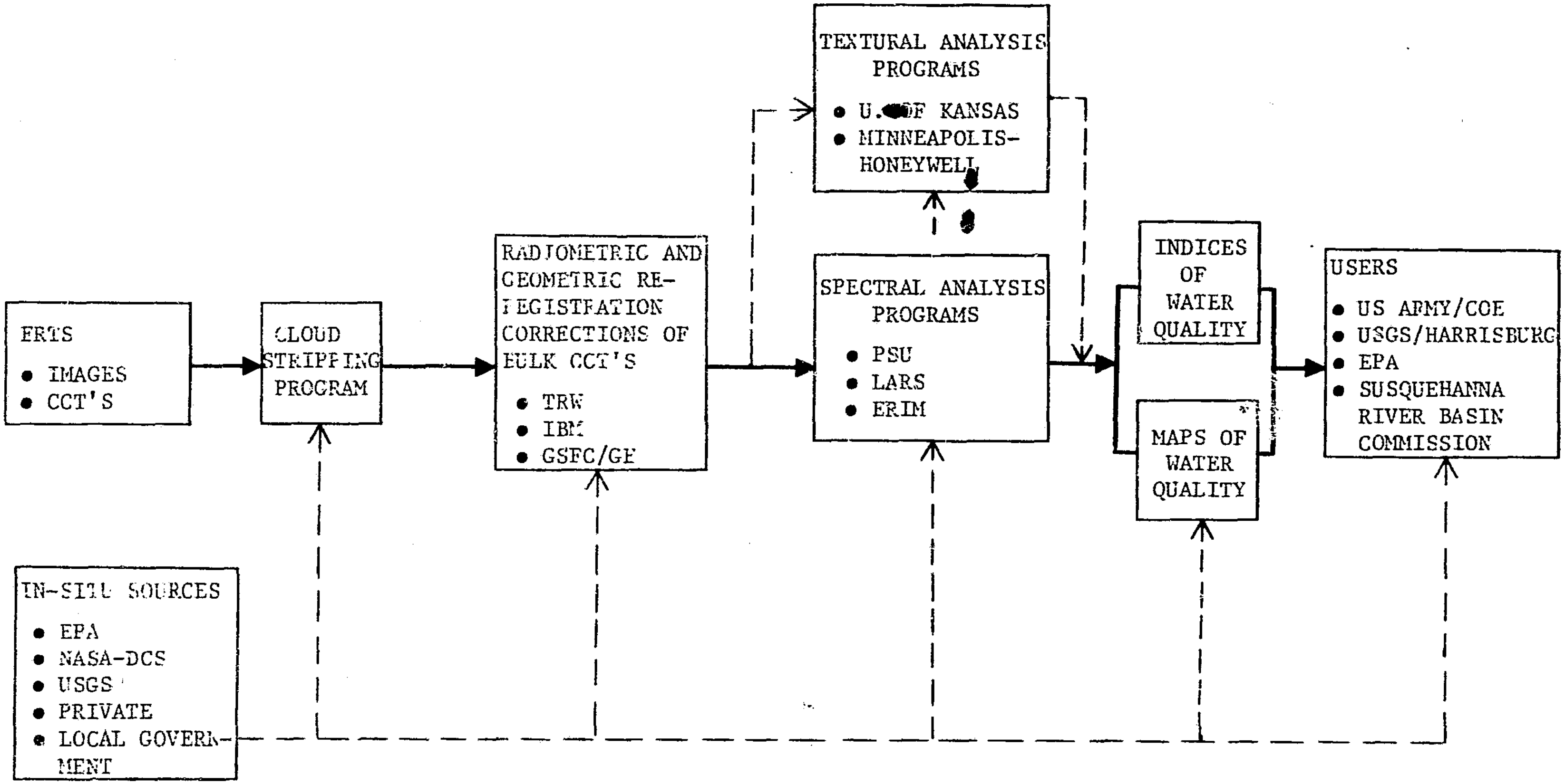


FIGURE 3-2

WATER QUALITY ANALYSIS SUB-SYSTEM

3.2.2.1 Analysis Procedure. ERTS Analysis of water quality can be derived from a photo interpretive technique or digital analysis of the MSS data. The images are useful to spot problem areas. They can also be used to delineate flood inundated areas, to define the location of newly formed bodies of water and to determine the relative quality of the bodies of water.

If, the granularity of the concern is greater than several acres in spatial terms and greater than weeks in temporal terms, then ERTS derived water quality data can be of use. Secondarily, if the quantitive value of the water quality is to be the maximum possible, then digital analysis of the MSS spectral data instead of photo interpretation of the images should be used.

Specifically a subsystem for water quality is defined in Appendix A. In brief, once the images and tapes have been recieved and the test areas located, cluster analysis is performed on each area. The signatures developed through this cluster analysis are inserted into the classification program for condensing. These condensed signatures then become input, again, to the classification program to classify the levels of turbidity in the reach. Indices are computed and all the data are compared with available in-situ data to determine it's relability and usefulness for the users. For specific details of MITRE's digital analysis of water quality for turbidity, see Section 2.3.2. An example of the cost of such a study, using 10 predetermined test areas, is given in Table 3-5.

TABLE 3-5

DIGITAL ANALYSIS COSTS FOR SUSQUEHANNA RIVER CLASSIFICATION
(USING 10 PRE-DETERMINED TEST AREAS)

PROCESS STEP	COMPUTER COSTS, $ (IBM 370-165)	MAN-HOURS
SUBSET MSS COMPUTER TAPE	30	4
INTENSITY MAP, (N-MAP)	150	17
UNSUPERVISED CLASSIFICATION, (A-CLUS or D-CLUS)	120	10
CONDENSING CLASSES, (using A-CLASS or D-CLASS program)	10	3
SUPERVISED CLASSIFICATION, (A-CLASS or D-CLASS)	120	6
	430	40

3.2.2.2 Ground Truth Procedures. It has been found by several ERTS investigators that water gradations can be discerned by ERTS; however if water quality is to be quantified other in-situ information would be needed as input to the system. There were several possibilities that were examined by MITRE; none however could at this point in time supply the information that was necessary.

The agency responsible for water quality was the EPA Field Office in Annapolis. This office had performed water quality studies in our area of interest. However for the year 1970 not more than 20 dates were tested.[1] Unless a specific survey is underway, sampling is done on a random basis. If this is the case, then the sampling time can be coordinated with the ERTS overflight schedule. This way no additional costs would be incurred since the ERTS overflights number approximately 20 per year. This would make available water quality information that could be compared to data from an ERTS coverage.

Another possibility for in-situ information is the use of the Data Collection System (DCS). Each Data Collection Platform (DCP) can collect data from as many as 8 sensors which sample stream conditions. A cost breakdown for several possible DCP configurations is given in Table 2-4. The platforms can be set up to transmit water quality information; however additional costs, over the price of the DCP, are required to maintain the system. That is, weekly attention would be needed in order to keep the water quality DCP operational, (see Section 2.1.2). Therefore, a DCP system would be more costly to

[1] "Consolidated Water Quality Survey of the Potomac", USEPA, Annapolis Field Office, Region III, 1970 Data Report.

maintain but it would give constant coverage of the parameters of interest.

As regards the input from the U.S. Geological Survey (USGS) all comments on procedures will be restricted to experience with the Harrisburg office. Assistance was to come from this office when needed by MITRE. However it was found that water quality sampling was done only at one of MITRE's test sites, i.e., Harrisburg, and only on infrequent dates. A DCS was set up by USGS/Harrisburg and is used for water quantity readings. That is, as a flood warning system to prevent future disasters like the flooding after hurricane Agnes. For USGS/Harrisburg to take manual samples of water quality on a definite schedule would require a change in priorities. This is something which does not seem likely; therefore USGS should not be counted on heavily for support in providing water quality ground truth.

A similar situation exists for private sources; that is, they are quite willing to supply anyone with their results. However, they have their own time schedule set up for sampling and so the data that will be received will vary in usefulness.

Currently in-situ input to the system is lacking; however, there is some available and some sources that could be tapped immediately. Now a look is necessary at what pollutants can be measured using ERTS.

3.2.2.3 <u>Pollutants That Can Be Monitored</u>. The paramters of water quality which can be monitored by remote sensing, along with the spectral range for their detection are listed in Table 3-6. Several of the more common pollutants like BOD or pH cannot be monitored in this fashion so in-situ measurement will have to be used for these parameters.

TABLE 3-6

PARAMETERS OF WATER QUALITY[1]

PARAMETERS	ERTS CHANNEL OR SPECTRUM RANGE
TEMPERATURE	8-14μ (THERMAL INFRARED)
TURBIDITY	CHANNELS 4 OR 5 (0.5-0.7μ)
COLOR	0.4-0.92μ
SUSPENDED SOLIDS	CHANNELS 4 OR 5
FLOATING SOLIDS	CHANNELS 4 OR 5
SEDIMENT	CHANNELS 4 OR 5
SALINITY	9.4-1.265 GH_z
PESTICIDES	2.4-40μ
OIL & GREASE	ULTRAVIOLET
PLANKTON	0.3-1.0μ
ALGAE	CHANNEL 7

[1]Op. cit., Burton, J., Bhutani, J.

For those listed in Table 3-6, some parameters such as, temperature, salinity, content of certain chemicals, pesticides, and oil and grease are totally out of the range or selectivity of the present multispectral scanner. For the remaining pollutants the possibilities of detection are as follows:

- turbidity - caused by the presence of suspended matter. It can be measured by observing the intensity of backscattered light as compared to the intensity of light scattered by pure water. The best results for detection are obtained using Channel 5; there is little information in Channel 7. Channel 4 yields good results; however, the data are affected by atmospheric conditions and haze. Channel 6 is only slightly better than Channel 7.
- color - Channels 4-6 appear to be the best. Color is a useful factor in the determination of what is in the stream, i.e., if there is acid mine drainage then this can be detected through the change in color of the stream. However, the measure of the sulphate from the mine drainage in the stream cannot be determined from color alone.
- suspended solids, floating solids and sediment - are related to the above discussion of turbidity since these are the prime cause of turbidity.
- plankton - is amenable to detection by photography and by the determination of chlorophyll level using induced fluorescence.

Fluoremetric techniques are more sensitive than other remote sensing techniques because fluorescense is less affected by turbidity. For chlorophyll excitation, wavelengths greater than 0.42μ are preferable.[1]

- algae - best detected through the use of the near infrared channel (Channel 7). The algae growth or mats occur on the water surface and are easily detected with this channel.

3.2.2.4 Indices. Once these previous mentioned pollutants are detected and separated they must be related to one another in order to provide an overall picture of the stream or river. With this in mind an index, to describe the pollutants, would be the best means of providing this relationship.

MITRE's index for water quality consisted of a means to determine the relative turbidity of the reach or basin only. Specifically, an index of turbidity P_j is computed as follows:

$$P_j = \sum_{i=1}^{r} \frac{1}{m} \sum_{k=1}^{m} (R_{i,j,k}) \cdot (\alpha_{i,j}),$$

$R_{i,j,k}$ = reflectance in mw/cm^2-ster from channel k of water type i in reach j.

$\alpha_{i,j}$ = percent area of water type i in reach j.

---

[1] op. cit, Burton, et al.

This provides a quick overview of the relative turbidity of the area.

For an index that would cover several pollutants the following concept, demonstrated by Brown[1], could be used. In order to avoid an index based solely on individual judgements, the selection of the parameters, the rating scale and the weighting factors were developed through the use of an opinion research technique known as the Delphi method (developed by the Rand Corporation). Among other advantages this method provides for anonymity of the participant while allowing each respondant to view the total judgement of the entire group.

The procedure consisted of sending three questionnaires to each participant. In all cases not less than 70% of the participants responded. The first questionnaire asked the participants to chose from a list of 35 parameters those which they considered important enough for possible inclusion in the final index list. The participants could also add any parameter not included in the original list which they felt to be important. They were then asked to rate only those parameters which they had included in their list. The parameters were to be rated from 1 to 5 with 1 representing the highest relative significance and 5 the lowest relative significance.

---

[1] Brown, R. N., McClelland, N. I., and Deininger, R. A., "A Water Quality Index - Do We Dare?" National Symposium on Data and Instrumentation for Water Quality Management. University of Wisconsin. July, 1970.

The second questionnaire contained all the responses that were received from the original lists. The participants were asked to review and modify their original judgements if necessary. They were also asked to choose not more than 15 parameters which they considered to be the most important.

In the third questionnaire only 11 parameters from the second list were included; some parameters were grouped which had previously been separated (See Table 3-7). The participants were asked to assign values for the variation in the level of water quality produced by their different strengths. Graphs were produced (for 9 out of the 11 parameters) which had the levels of water quality from 0 to 100 on the vertical axis, and the strengths of the parameters listed along the horizontal axis. The participants responses were then drawn on these graphs. A set of average curves for water quality were produced using all the responses. The two parameters from the final list which were not included were pesticides and toxic elements; these required further study before they can be included.

The third questionnaire also sought information concerning the formation of a weighing factor. The participants were asked to weight the parameters using the scale of 1-5 as previously described. Arithmetic means were calculated for the nine parameters; a temporary weight of 1.0 was assigned to the parameter with the highest significance rating. Other temporary weights were obtained by dividing each individual mean into the highest. Each temporary weight was then divided

TABLE 3-7

LIST OF ELEVEN MOST SIGNIFICANT PARAMETERS

- Dissolved Oxygen
- Biochemical Oxygen Demand (5-day)
- Turbidity
- Total Solids
- Nitrates
- Phosphates
- pH
- Temperature
- Fecal Coliforms
- Pesticides
- Toxic Elements

by the sum of all the weights, this produced the final weights listed in Table 3-8.

The mean weighted index developed from the water quality curves and weights is as follows:

$$WQI = \sum_{i=1}^{m} w_i q_i$$

WQI = water quality index, a number between 0 and 100

q_i = quality of i^{th} parameter, a number between 0 and 100

w_i = unit weight of i^{th} parameter, a number between 0 and 1; $\sum_{i=1}^{m} w_i = 1$

m = number of parameters

This type of index works well if all of the individual parameters are independent of each other (although that is not always the case). Table 3-9 shows the "best" and "worst" WQI that could possibly occur, and Table 3-10 represents a typical index value.

There seems to have been a tendency by the participants to have their judgements influenced by such factors as data availability, and existing analytical methods for measuring the various parameters. These factors, however, should not prevent the establishment of an index of general water quality.

This index takes into effect a weighting factor and quality factor derived from information supplied by participants who are knowledgable in this field. For this reason it should be considered as a means of describing water quality for a basin.

TABLE 3-8

SIGNIFICANCE RATINGS AND WEIGHTS FOR NINE PARAMETERS INCLUDED IN THE WQI

Parameters	Mean of All Significance Ratings Returned by Respondents	Temporary Weights	Final Weights
Dissolved Oxygen	1.4	1.0	0.17
Fecal Coliform Density	1.5	0.9	0.15
pH	2.1	0.7	0.12
Biochemical Oxygen Demand (5-day)	2.3	0.6	0.10
Nitrates	2.4	0.6	0.10
Phosphates	2.4	0.6	0.10
Temperature	2.4	0.6	0.10
Turbidity	2.9	0.5	0.08
Total Solids	3.2	0.4	0.08
		Total = $\sum$ =	1.00

TABLE 3-9

BEST AND WORST POSSIBLE WQI

Best Quality Stream

		Quality	Wt.	
DO	100	98	.17	16.7
FC	0	100	.15	15.0
pH	7.0	92	.11	10.0
BOD_5	0.0	100	.11	11.0
NO_3	0.0	98	.10	9.8
PO_4	0.0	98	.10	9.8
Temp.	0.0 (Equil)	94	.10	9.4
Turb.	0	98	.08	7.9
T.S.	25	84	.08	7.9
			WQI =	97.5

Worst Quality Stream

DO	0	0	.17	0
FC	5	4	.15	0.60
pH	2	4	.11	0.44
BOD_5	30	8	.11	0.88
NO_3	100	2	.10	0.2
PO_4	10	6	.10	0.6
Temp.	+15	10	.10	1.0
Turb.	100	18	.08	1.44
T.S.	500	30	.08	2.4
			WQI =	7.56 = 7.6

TABLE 3-10

TYPICAL APPLICATION OF WQI

Parameters	Measured Values	Significance Ratings	Weight	
D.O. % Sat.	80.0	86	0.17	14.6
Fecal Coliform Density	10.0	68	0.15	10.2
pH	7.5	92	0.12	11.0
BOD_5, mg/l	2.0	75	0.10	7.5
NO_3-N, mg/l	10.0	48	0.10	4.8
PO_4, mg/l	1.0	40	0.10	4.0
Temperature	Equilibrium	95	0.10	9.5
Turbidity, Units	10.0	76	0.08	6.1
Total Solids, mg/l	100.0	82	0.08	6.6

$$WQI = \sum = 74.3$$

3.2.2.5 Recommendations. In this water quality system there is input from ERTS and in-situ sources required. There is a number of pollutants to be monitored and there is a relationship that can be set up to describe the overall water quality of a basin. In order to make this work efficiently there are some recommendations to be considered.

- Cooperation of agencies that do water quality sampling is required. If some arrangement could be worked out, for example if a number of water quality platforms were set up, then there would be a means to relate ERTS data to actual water quality parameters.
- The need for a thermal channel is apparent. This would allow for detection of more water quality parameters.

3.2.3 An Air Quality Monitoring System Using ERTS Data

The development and availability of techniques and instruments capable of remotely detecting air quality, as measured by atmospheric turbidity, would provide solutions to several problems. Further, the utilization of modern satellite (ERTS-1) data for air quality analysis could be used for mesoscale analysis of the properties of the atmosphere and the trends in those properties.

Recent interest in air pollution emissions and attempts to control such emissions, has generated questions regarding the overall trend in the production of air pollutants. Satellite measurements can provide regular microscale and mesoscale monitoring of air turbidity. While measurement of air turbidity does not contain information on the relative concentration of the various gases, it does provide a measure of the total burden of particulates, aerosols and other optically attenuating species. Information of this type could be used to develop long term and yearly trends for different regions throughout the country. In this way compliance with air pollution standards could be judged and, in addition, non-local sources of pollution which degrade the air quality in a certain region could be identified.

In general, there are two approaches which may be used in the determination of the air quality below the spacecraft. In the reflectance mode, a point on the ground is used as a target. The radiance detected is corrected for the path radiance contributed by scattering in the atmosphere and the transmission of the atmosphere is determined from an atmospheric model.[1,2,3] This technique, of course, requires a suitable target which is stable in its condition for long periods of time and whose reflectance is known. The second technique (the scattering mode) is to choose targets with as little reflectance as possible (either by choice of targets or by choice of wavelength band used). Then the detected radiance is provided by scattering from atmospheric constituents.

There are basic differences in these two measurement techniques and their utilization. The reflectance model provides information on the total burden of attenuating material between the spacecraft and the ground. These data are useful in the determination of long-term trends and other pollution features not related to a single event. The scattering mode is more useful in identifying specific pollution emission or meteorological events since it only detects regions of large atmospheric scattering, such as smoke plumes, cloud tops, etc.

The choice of operating technique then determines whether one would find a high reflectance or low reflectance target more satisfactory. As mentioned, this also influences the choice of wavelengths

---

[1] Turner, R. E. et al, "Importance of Atmospheric Scattering in Remote Sensing", in Proceedings of 7th International Conference on Remote Sensing of Environment, Ann Arbor, Mich. May 1971, p. 1651.

[2] Griggs, M., "Determination of Aerosol Content in the Atmosphere", in Symposium on Significant Results Obtained from ERTS, Goddard Space Flight Center, Greenbelt, Md., March 1973, p. 1105.

[3] Rogers, R. H. and K. Peacock, "A Technique for Correcting ERTS data for Solar and Atmospheric Effects" ibid. p. 1115.

bands implemented. Lyons[1] has noted that detection of smoke plumes propagating from major urban areas and crossing the Great Lakes can be best detected in band 5 where the contrast between smoke and water is highest. Griggs[2], however, argues that bands 4, 5 and 6 have comparable sensitivity for the detection of aerosols. This is not, however, a statement of conflict since particulates and aerosols are somewhat independent in origin and characteristics.

A few of the areas of specific interest where satellite data may be useful are noted below. In each case, the appropriate target, atmospheric model and band used must be determined.

Approximations to rural air quality could be determined from rural or inaccessable areas which have satisfactory targets.

Another point of major interest is correlation, on a large scale, of weather patterns and air pollution distributions and their interaction. This is of special importance in urban areas and near airports where some correlation of cloud formation and pollution level has been noted.[3,4]

---

[1] Lyons, W. A. and S. R. Pease, "Detection of Particulate Air Pollution Plumes from Major Point Sources Using ERTS-1 Imagery", Report No. 10 Air Pollution Analysis Laboratory, University of Wisconsin at Milwaukee.

[2] Griggs, M. "A Method to Measure the Atmospheric Aerosol Content Using ERTS-1 Data", Paper E-2 of the Third ERTS Symposium Dec. 10-14, 1973 Washington, D.C. sponsored by NASA/GSFC.

[3] Lyons, W. A., "Inadvertent Cloud Seeding by Chicago-Northwestern Indiana Pollution Sources Observed by ERTS-1", University of Wisconsin-Milwaukee Air Pollution Analysis Laboratory Report No. 9 April, 1973.

[4] Robinson, Elmer, "Effect on the Physical Properties of the Atmosphere" in <u>Air Pollution: Vol. 1</u>, Arthur C. Stern, ed. Academic Press, New York, 1968 p. 379.

Finally, interest exists in establishing the influence of increased air turbidity on natural and cultivated vegetation.[1] Reference 1 discusses several factors in the influence of air pollution on plant growth including models of exposure versus damage and economic considerations of this damage. Influences of this type are also of significance in land use since plant species susceptible to particular damage from specific pollutants need to be appropriately located. The identification of this problem should encourage investigation into the effects of current air pollution sources on the crops presently grown in suburban or rural areas influenced by those sources. Using the land use identification techniques described earlier, this work could be done with reasonable accuracy.

3.2.3.1 Air Quality System Implementation. Establishment of a system for measuring air quality is based on the following sub-system considerations.

- Spacecraft Data
- Ground Support Information
- Appropriate Target Selection
- Atmospheric Models

3.2.3.1.1 Spacecraft Data. For the present time it appears that air turbidity can be provided adequately by data from band 4 but other

---

[1] Brandt, S. C. and W. H. Heck, "Effects of Air Pollutants on Vegetation" in Air Pollution: Vol. 1, Arthur C. Stern, ed. Academic Press, New York 1968 p. 401.

workers have demonstrated the usefulness of recording more than one band. Data are obtained in the form of CCT's and, under the present system, converted to a computer printed map showing relative radiance values (using the N-MAP computer program) as measured by the spacecraft. This technique of data gathering was chosen over the photographic images because of the larger number of quanta steps in the CCT data.

After development of the relative radiance (intensity) map, groups of pixels in the region of interest would be averaged and presented in non-dimensional quantum level units. The data can then be manipulated as described earlier (Section 2.3.3) with the inclusion of the solar elevation to convert these data to the air turbidity. In those cases where modeling does not perform well, ground support measurements may be required.

3.2.3.1.2 Ground Support Information. During the development and initial use of the air quality system, modeling of the atmosphere may not be well developed enough to provide adequate results. In that case, significant support from ground stations will be necessary to

- aid in model development
- monitor results
- evaluate improvements in data processing

As the system becomes more sophisticated the importance of the contribution of ground stations will hopefully be reduced.

Initially, an expanded version of the present measurement system would be used (with a measurement device at each of the intended targets).

Measurements are presently being made daily at approximately sixty stations over the U.S. with the Volz photometer instrument which determines only the solar elevation and the atmospheric turbidity (after some computation). In many cases this data is not adequate, especially when good modeling of the atmosphere is not available.

A more capable instrument is that described by Rogers[1], produced by the Bendix Corporation. In addition to measuring the radiance of the solar disk (which is essentially what the Volz photometer measures) and the solar elevation, the instrument also determines the sky irradiance as a function of azimuth and elevation. Further, it measures the total irradiance from sun and sky and can be used to measure the reflectivity of the target. It can perform these tasks for wavelength bands appropriate to the ERTS sensors so that direct comparison of ground and satellite data can be obtained.

Use of an instrument of this type is deemed necessary by Rogers for the determination of ground reflectivity by a satellite (which is equivalent to the problem of determining the atmospheric attenuation) while other workers (Griggs)[2] intend to use only Volz data to determine air turbidity.

---

[1] Rogers, R. H., "Investigation of Techniques for Correcting ERTS data for Solar and Atmospheric Effects" Report to NASA (Contract No. NAS 5-21863) Sept. 1973.

[2] op. cit., Griggs.

Ground measurements of this type assist the operational system in two ways. During the development phase they provide information to validate the assumptions and results of the air transmission model(s). In the operational stage, ground measurements will provide calibration of the system and periodic checks of its performance. Inputs from the NOAA Turbidity Network as well as horizontal visibility readings taken by airport weather personnel would be used for comparison with the spacecraft measurements.

For those cases where a specific microscale pollution event is to be observed, ground truth photographs and other corroborative evidence will have to be provided. In some cases this will require extensive observations, as in the case of investigation of cloud formations resulting from emission plumes (a micro-mesoscale phenomena). Aircraft underflights or arrays of ground observers would be needed in that case.

3.2.3.1.3 Air Quality Target Selection. Implementation of a program of air quality measurement from a satellite will require a group of targets, each chosen to satisfy the specific needs of the experiment, as previously mentioned. For studies of the turbidity on a mesoscale basis, or for long-term studies, targets with the highest reflectivity will be attractive. For detecting high concentrations of pollutants, as in smoke plumes, a micro/mesoscale problem, a low albedo is preferred and therefore a darker target is more useful.

In any case, the targets chosen must be distributed in reasonable number over the U.S. or other areas of interest and have essentially the same properties throughout the year. Further, each should be large enough to accomodate the relative mapping accuracy in the MSS - ERTS system. This would require a target of at least 2 x 2 pixels (200m x 200m). Several classes of potential targets which fall into these categories are[1]:

Reflectivity (Band 4)	Target	Composition
0.15 - 0.35	concrete airport runways	concrete
0.2 - 0.3	beach areas	sand
0.35 - 0.81	snow	snow
0.02 - 0.10	water	water
0.9	artificial painted targets	paint

Each of these possible targets has some drawbacks. The reflectivity is a function of the dust cover on the area, moisture on target, concentration of vegetation, etc. Snow targets limit the usefulness of the system to winter or to higher mountain areas where ground-truth measurements cannot be made. Water targets which would support plant and animal life, thus influencing its reflectivity, would have a different albedo throughout the year.

Thus most attractive of the high reflectivity targets are those

---

[1]Slade, D. H., Ed. Meteorology & Atomic Energy 1968, U.S. AEC Office of Information Services 1968, p. 15.

which are man-made and covered with a reflective material with known properties. Construction of such areas would tend to be rather expensive and would not be possible in remote or harsh weather regions.

A more reasonable choice would be utilization of already existing airport runways. Measurements would have to be made of the airport runway under a variety of conditions (under water, wet, locally wet, very dry, etc.) so that the appropriate corrections could be made to the spacecraft data. The large number of airports and their distribution throughout the U.S. and Canada would provide information from nearly every region of interest with generally consistent target properties.

Water appears to have the lowest reflectivity coefficient of any of the naturally occurring targets. The high density of water targets of adequate size across the U.S. probably obviates the need for artificially made low-reflectivity targets.

In the final version of the air pollution monitoring system up to 200 high reflectivity targets of appropriate size and characteristics can be anticipated. They would include up to 50 sites specifically constructed for this purpose. In addition, virtually every city has an airport with characteristics appropriate to this purpose. A review of the costs involved in constructing and operating this system is given in Section 3.2.3.3.

3.2.3.1.4 <u>Atmospheric Models</u>. Advances in modeling will be an important factor in a passive satellite system since a primary goal of the work is a completely self-contained determiner of air quality. Models will be needed which use the irradiance seen by the spacecraft, then correct these data for scattering in the atmosphere and other influences and thereby produce a value for the air turbidity. It is assumed that the reflectivity of the various targets are well known, that the spacecraft will measure the solar elevation angle and that the location of the imaged area is known to within one pixel. Further, the spacecraft will have a supply information on the relative cloud cover in the area of the target so that determination can be made of the usefulness of the data taken on a particular day.

In lieu of high quality radiative transfer models of the atmosphere, instruments like the Bendix photometer have been developed which, from the ground, make some of the measurements that would have to otherwise be obtained by use of the model. Elimination of the need for ground support of this type would help to avoid data handling errors, missing data due to neglect of operator and other common problems encountered in collecting and analyzing of data from several sources.

3.2.3.2 Recommended System for Mesoscale Air Quality Monitoring. Several basic areas of a program of this type need development in order to realize a working system. As mentioned, the present models of the atmosphere need to be improved in order to eliminate the need for ground support measurements. An area of particular importance might be investigation of use of information from each of the several bands of ERTS. Scattering and absorption properties of atmospheric constituents are functions of wavelength. Use of bands 4 through 7 could conceivably identify the relative amount of detected radiation which has been scattered to the spacecraft by the atmosphere rather than reflected from the ground. This would be a significant input to the problem since a part of the effort in modeling is to predict the fraction of the albedo produced by atmospheric scatter.

Assuming that such developments can be made so that the spacecraft can be relied on to provide air turbidity data, a system of data organization and implementation would have to be developed. Figure 3-3 illustrates the major inputs to the system and data utilization of outputs.

The system organization chart indicates the variety of inputs required for complete analysis of the problem. They are:

1) Target Conditions - Information of the particular target being studied, its condition at the time of the overflight and significant changes in its characteristics, its location and any other factors of importance.

2) MSS data - All four MSS channels could possibly be utilized. These values provide levels of radiation in quantum steps for each pixel of the viewed area.

3) Solar Elevation - This is needed to correct data for the effective transmission of one atmospheric air mass.

4) Cloud Cover - Information of this type would be needed to classify the usefulness of the data on a particular day. High cloud cover would necessarily limit the system performance.

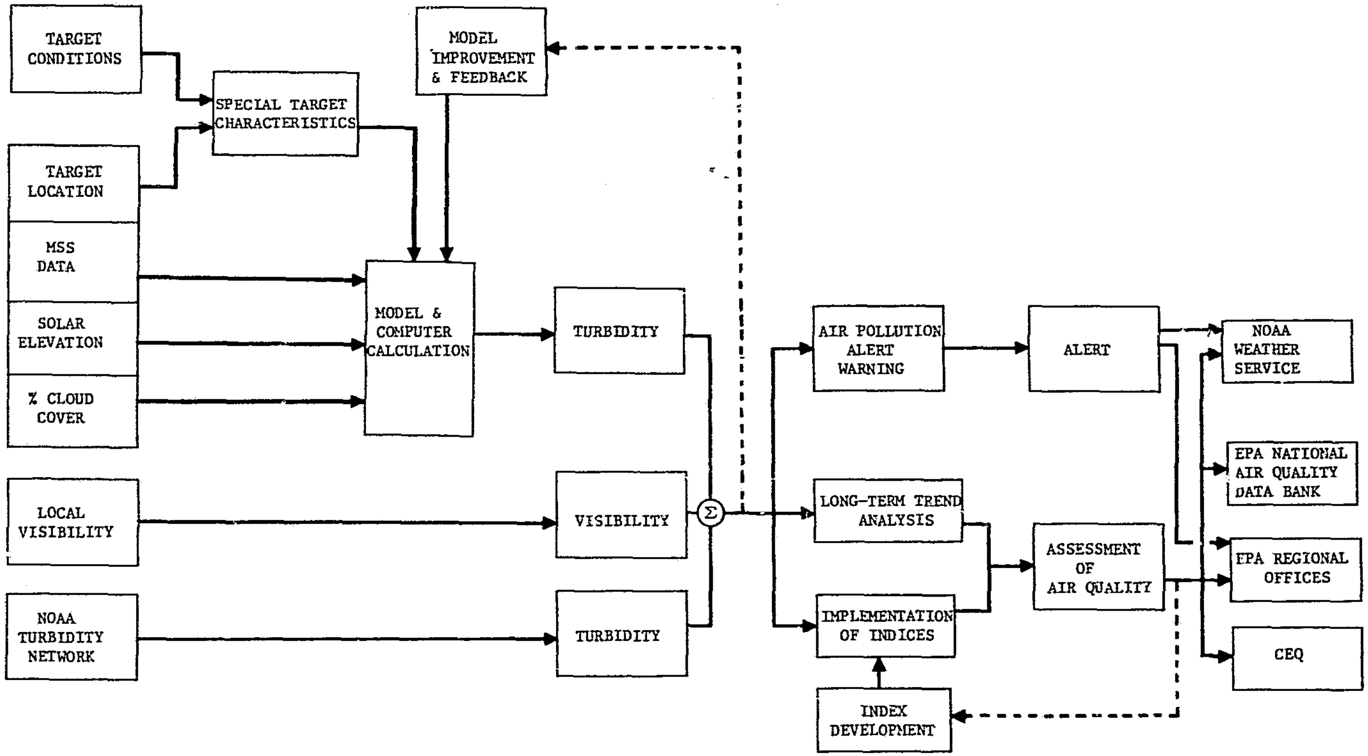


FIGURE 3-3
AIR QUALITY SUB-SYSTEM

5) Local Visibility - Data of this type would be used to both support and check the data obtained from the spacecraft.

6) NOAA Turbidity Network - This information would also serve as support and test data.

The target conditions and location are used together to recall the reflectivity and/or other unique characteristics of the target or its properties at the time of the overflight. This information is entered into the model along with the solar elevation, MSS data and cloud cover data provided by the spacecraft. The computer computations of the model are then performed, providing a value of turbidity or defining the outline of plumes. Those data can then be compared with the ground measurements provided by the NOAA turbidity network and the standard visibility observations made at most airports or urban areas. During the development period of the work, the output data would be revised for correlation with the ground measurements indicating differences and limitations of the model. In this way it is hoped that improvements can be effected and the quality of the analysis improved.

The data can further be utilized in a variety of areas including:

- Sources of non-local pollution
- Air pollution alert warnings
- Long-term trend analysis
- Development and implementation of air quality indices

As an alert device the satellite has several drawbacks (infrequent coverage, dependence on good weather, localized targets) but would still remain a useful tool for long-term urban pollution crises and identification of sources. Determination of the dispersion pattern of the pollution, sources of emissions and correlation of pollution events with general and specific weather conditions would be very useful.

More significant is the capability of the satellite as a monitor, on a long-term basis, of air quality. Only with information on the countrywide trends in air quality can reasonable conclusions be drawn about the effectiveness of current abatement techniques. The satellite also has an advantage in that it would measure micro/mesoscale concentrations while the more conventional ground station is, by definition, limited to monitoring a microscale region at one location. Local weather patterns, urban development or geography can seriously distort results measured on a microscale by in-situ air quality monitoring thereby leading to inappropriate conclusions. In this context, long-term refers to times on the order of years although variation noted during a year would be recognizable since data are available approximately once every 18 days.

A further application of the ERTS data, especially in the two forms discussed above, is in the area of the development of air quality indices and the utilization of those indices based on spacecraft measurements. As a goal, the index (or indices) derived from the spacecraft measurements could be used to generalize the conditions in the atmosphere with respects to special features:

- total turbidity
- scattering properties
- relative concentrations of aerosols and particulates
- total solar radiation
- number and location of emission sources

It has been pointed out[1] that the total solar radiation reaching the earth influences:

- power consumption for heating and light
- human health
- photo-chemical activity in plants
- atmospheric photo-chemistry

As a result of these important factors and because several groups regularly monitor solar radiation levels, the development of atmospheric models which can use spacecraft data to predict total solar radiation at the earth would be very attractive. Presently the following groups regularly monitor solar radiation:

- National Weather Services
- Universities
- Smithsonian Observatories
- U.S. Army
- U.S. Air Force
- Researchers in other countries

---

[1]Bisselle, C. A. et al, "Monitoring the Environment of the Nation", MITRE document MTR-1660 April 1971.

The goal of the work is to identify trends and develop indices based on these possible parameters:

- number of sunshine days (adjusted for location, time of year, geography, etc.)
- pollution-related attenuation
- total radiation relative to older measurements
- changes in wavelength distribution of solar radiation

As a more sophisticated understanding of the influence of air quality development, economic indices could also be developed which reflect the cost impact of the various factors of air pollution. These include the influence of air turbidity on:

- Agricultural production
- Growth of natural vegetation
- Oxygen production by phytoplankton in the oceans
- Influences of pollution on weather and the related costs
- Warming/cooling trends and their economic impact

Of course, the development of economic indices for air pollution will not be based solely on the results of satellite monitoring, but will use other data and related studies as well. However, cost effectiveness of the satellite monitoring program would have to be considered.

In addition to the costs of vehicle launch and ground support maintenance the following costs will be incurred as regular operating expenses:

- construction of targets
- maintenance costs per year

Further, the expenses for analyzing a specific region are:

- Processing of CCT's into appropriate format
- Implementation of support data
- Exercise of model
- Production of final map of turbidity or plume location

Each of the 200 targets will be viewed approximately 20 times per year. The target would include 20 to be built, 10 natural targets and 170 airport targets. In order to take advantage of this full coverage, a photometer (either Volz or Bendix) will be deployed at each target. It is assumed that at each location a capable operator can be found who will make the photometry measurements and any necessary meteorological observations. The figures below (in Table 3-11) assumed that the CCT's are provided at no cost and that information from the NADB, National Weather Service, NOAA and other sources can be obtained at little or no cost. As the program matures and the sophistication of the model improves input from the ground stations could be reduced somewhat.

3.2.3.3 Suggestions for Active Targets. A supplement to the passive target system might be the utilization of a laser (or other) transmitter system located at sites of interest and used to excite the ERTS remote sensors given an appropriate tracking capability. A facility of this type would be particularly useful since the emitted power could be measured to high accuracy, thus eliminating the need for knowledge of the reflectivity of a target. Since the total attenuation of a narrow beam in a standard clear atmosphere is approximately 30%, substantial power could be delivered to the spacecraft.

TABLE 3-11

COST ANALYSIS OF AIR MONITORING SYSTEM

Category	CPU time/event (sec)	Cost ($)	YEARLY COST ($) 1st Year	YEARLY COST ($) 10 year pro rata
Construction (20 sites)	-	20,000/site	400,000	40,000
Maintainance (20 sites)	-	5,000/site	100,000	100,000
Processing* (200 sites)	90	10.80/event	40,000	40,000
Support Data	10	1.20/event	4,800	4,800
Model	50	6.00/event	24,000	24,000
140 Volz photometers	-	500 each	70,000	7,000
60 Bendix photometers	-	3000 each	180,000	18,000
Labor	-	10/event	40,000	40,000
Total			858,800	273,800

*$0.12/CPU second

The laser source would have to provide continuous output during the overflight and the power level would have to exceed the level of the smallest quantum step detectable in each band. The lowest levels are 1/64 of the maximum radiance levels allowed in each band as shown:

Band	Max. Specified Radiance (mw/cm^2 ...)
4	2.48
5	2.00
6	1.76
7	4.60

A number of gas lasers exist which provide power into beams which diverge ~1 mr. Scattering over the vertical path to the spacecraft will certainly expand the effective beam diameter to 50 mr or more. For a spacecraft at ~1000 km altitude, the spot size will be ~50m which represents an area of ~2000m^2. Each sensor has a field of view of 0.086 mr which represents a solid angle of 0.54 sr. In band 4 this suggests a minimum irradiance of

$$\frac{1}{64} \times 2.48 \times 0.54 = 0.021 \ mw/cm^2$$

or 2.1×10^2 mw/cm^2. The initial power required from the laser to satisfy this requirement would be

$$2.1 \times 10^2 \frac{mw}{m^2} = \frac{\text{initial power} \times (0.30)}{1963.5 \ m^2}$$

$$\text{Power} \cong 137 \text{ watts}$$

Powers of this level are available in some more developed cw lasers at this time (notable CO_2) but those devices are generally laboratory type models, not suitable for application due to high initial and maintenance costs.

However, as devices with adequate power, wavelength and beam spread become available, the deployment of a system of transmitters could be an important tool in the exploitation of satellite air pollution remote sensing.

4.0 NEW TECHNOLOGY

There was no specific new technology produced in the course of this investigation.

5.0 CONCLUSIONS

From the experiences gained in this investigation, the single most overall conclusion arrived at is that ERTS data can in some cases have more application, and in some cases less application, to the fields of environmental management than was initially anticipated. The overall objectives of the MITRE investigation were 1) determine indices for land use change, water quality, and air quality from ERTS data and 2) determine the specifications for an environmental monitoring system for those three media based on ERTS data. To a degree, which varies for each media, those interrelated overall objectives have been achieved.

The most successful application, as a majority of ERTS investigators concur, has been in the field of land use planning. In the accepted proposal and approved Data Analysis Plan, MITRE's investigation in the environmental medium of land use change had as a goal the determination of indices and specifications for a system which would provide useful information to environmental managers on eight important land use categories.[1] One of the original proposal categories, wetlands and estuaries, was not included in the data analysis plan list since there were no significant areas of that category within the two approved test sites. The investigation was successful in classifying and quantifying change in the remaining seven land use categories, and in determining that much more discrimination was possible if required. In just one of the categories, for example, four distinct levels of strip mining activity were detected from analysis of ERTS data.

[1] See Section 2, p. 21, and Appendix A, p. A.2.

In the medium of water quality analysis, the initial goal was to detect and describe a system for monitoring seven water quality parameters and a number of sub-parameters. This was reduced to four in the Data Analysis Plan. The current state-of-the-art in in-situ water quality analysis is that there is no system for routine unattended monitoring that yields consistent reliable ground truth data. Also, the ground truth data required for water quality signature development was generally unavailable from other sources. Because of the problems discussed in this report and those of other investigators concerned with water quality analysis, as well as the inherent limitations of ERTS-1 MSS instrumentation for discriminate water quality analysis, the objective that was achieved by the MITRE investigation was a relative measure of total water turbidity at various gradations from point to point. While specific quantification of water pollution constituents was not achieved, the ability to quantify overall water pollution burden is considered significant and useful to the environmental manager.

In the third environmental medium, air quality, the goal was initially the most ambitious of the three media - analyze ERTS data and develop indices for 10 parameters (plus several sub-parameters) of air pollution. As with the water quality medium, MITRE found that analysis of air quality from ERTS-1 data is presently limited to monitoring total air turbidity. Consequently, the approved Data Analysis Plan reduced the scope of the air quality analysis to two parameters. The concentration of the air quality portion of the investigation was consequently on measuring total air turbidity burden and detecting point sources of air pollution. Gross correlation was found between ERTS and ground truth measurements of atmospheric turbidity, and with further work a reliable index of total air turbidity could be developed from ERTS data. Additionally, several large air pollution point sources were identified in the Harrisburg Site.

Conclusions for each of the three environmental media are given in the following sections in more detail.

5.1 Conclusions - Application of ERTS Data in Land Use Analysis

- Federal, state, regional, and local environmental and land use managers need synoptic (at least once a year) updates of their basic land use maps. Such thematic maps can be provided by ERTS.
- Photo interpretive analysis of ERTS images can result in land use mapping equivalent to that available by conventional (aircraft photographic surveys) methods at scales on the order of 1:125,000 and above.
- At small scales (1:125,000 and above) photo interpretative analysis of ERTS images for land use mapping appears to be more cost effective than conventional methods for up-dating base maps.
- Digital analysis of spectral content of ERTS MSS CCT data results in superior land use classification at scales ranging from 1:24,000 to 1:125,000 than photo interpretation.
- Digital analysis provides a rapid method for calculation and location of land use changes over time.
- Besides demonstrating a capability to monitor land use change affecting 10-15 categories, an ERTS system can focus on a single category (in the MITRE case, strip mining) and achieve a level of analysis equivalent to the USGS Level III land use down to the 10 acre range.

- ERTS data will not obviate the need for some costly accumulation of land use ground truth data entirely, but they will provide a much needed complement to conventional sources of data, and they can offer the best, most frequent, and least costly updates of land use information once current base land use information is established.
- USGS topographic maps are excellent for geographical orientation of ERTS digital analysis maps and for some Level I land use verification, but they lack the currency and detail for land use signature development.
- For the level of analysis achieved in the MITRE investigation, construction of the first ERTS land use computer map requires aircraft photography, a recent land use map, or a ground survey of a portion of the test site containing examples of each category on which classification will be attempted. This ground truth need not cover the entire area of interest, but it must include examples of all the categories that are to be classified in the area.
- Specifications for an ERTS land use analysis system have been completed and are contained in Section 3.1.1 and 3.2.1.

5.2 Conclusions - Application of ERTS Data in Water Quality Analysis

- Digital or photo interpretative analysis of ERTS data for water targets can result in classification of at least six gradations of turbidity.
- Where appropriate water quality sampling stations are available and properly maintained, correlations can be made between ERTS measurements and ground truth measurements of turbidity.

- Until better, more comprehensive measurement of water pollution constituents can be made throughout a test area for calibration purposes, ERTS holds little promise of discriminating specific pollutants.
- Because the ERTS coverage of a test site is on the order of once per 18 days or greater, ERTS is not suited for real time monitoring of water quality. However, the coverage is sufficient for the important monitoring of longer term effects such as algae growth, sedimentation of reservoirs, etc.
- Specifications for an ERTS water quality analysis system were completed and are contained in Sections 3.1.2 and 3.2.2.

5.3 Conclusions - Application of ERTS Data in Air Quality Analysis

- Average intensity calculated from ERTS data appears to exhibit gross correlation with turbidity measurements made at various ground based sampling sites.
- Using atmospheric models, constructed to eliminate interferences as well as to insure that ground stations and ERTS are comparing the same data, good correlation over land and water targets except for the winter months is obtained.
- MITRE's experience and that of other investigators in this field is that ERTS shows promise of providing a mesoscale measure of total turbidity.
- Specifications have been developed for an ERTS air quality analysis system and are contained in Section 3.1.3 and 3.2.3.

6.0 RECOMMENDATIONS

The following recommendations are based on the experience of the MITRE investigation, and the experience of other investigators in related environmental fields. These recommendations are offered with a view toward improving the application of ERTS data to environmental management requirements.

- The primary recommendation is that NASA establish a central library/depository of documentation for all computer programs and digital analysis techniques that have been applied to MSS and RBV data under NASA contracts. The library, established at Goddard Space Flight Center or other appropriate location, would be available to all investigators approved by NASA. Examples of such software are spectral analysis programs, textural and contextural analysis programs, programs for radiometric and geometric correction of bulk MSS data, sub-pixel proportionate estimation procedures, and programs for temporal overlay and comparison. It would be in the common interest of NASA and the investigators to develop the better means of timely sharing of the accumulated wealth of knowledge of MSS and RBV digital analysis techniques.
- Of similar benefit would be the centralized compilation of signature information for standard land use categories for various coverage dates across the country. This would greatly aid land use analysis and, when the temporal variation algorithms are developed from analysis of the accumulated signature information, much of the costly repetitive processing of successive coverages can be eliminated.

- NASA should encourage Federal, state, regional and local users of ERTS land use information to develop uniform digitized land use libraries. Such digitized land use, with a resolution of four or five pixels, would greatly aid investigators in initial classification and verification of ERTS data. The investigator, in turn, could assist the environmental and land use managers in updating land use inventories much more rapidly and at less cost than by presently used means.
- NASA, perhaps in cooperation with EPA, should promulgate general guidelines which list the minimum requirements environmental ground truth must meet before it is used for calibration of ERTS data, and to justify the allocation of DCP's.
- NASA should establish standardized training and test procedures for ERTS data analysis systems in controlled training areas. In this way investigators and the users will have a more accurate means of measuring the success of their system against some standard, rather than trying to compare skill scores of systems which often are tested under widely varying conditions.
- NASA (or a contractor) should investigate hybrid computer systems which would in some circumstances permit a much more rapid search, location, and analysis of features of interest imbedded in the mass of data in MSS CCT's of large areas. This capability will be increasingly important for repetitive multi-state and national environmental analysis. Examples of state-of-the-art are the Spectral Analysis and

Recognition Computer (SPARC)[1] used in the ERIM work, and the Electronic Satellite Image Analysis Console (ESIAC)[2] presently being used at the Stanford Research Institute.

---

[1] Wagner, T., and Polcyn, F., "Progress of an ERTS-1 Program for Lake Ontario and Its Basin" Symposium on Significant Results Obtained from the ERTS-1, March 1973.

[2] Evans, W., and Serenbreny S., "Analysis of ERTS Imagery Using Special Electronic Viewing/Measuring Equipment" Symposium on Significant Results Obtained from the ERTS-1, March 1973.

APPENDIX A

DATA ANALYSIS PLAN

A.1.0 DAP INTRODUCTION

This Data Analysis Plan (DAP) is the plan of work for MITRE's Phase III, Continuing Data Analysis Phase. This DAP is a replacement for the preliminary DAP submitted in the MITRE proposal, "Investigation of Environmental Indices from the Earth Resources Technology Satellite", M71-16 Revision 1. dated 14 February 1972.

The DAP plan calls for eleven months of analysis following the completion of Phase II Quick-Look Phase, with a completion date of 31 December 1973. No increase in funds is requested. Use of funds initially earmarked for ground truth hardware in our proposal have been redirected to cover techniques development support at Pennsylvania State University (PSU) and an end date extension of three months. This extension was due to late delivery of ERTS-1 products. The ground truth hardware and operational support is being supplied to this project without charge by the United States Geological Survey Harrisburg Office in conjunction with their ERTS-1 Susquehanna River experiments and their on-going water quantity or quality programs.

A.1.1 DAP Objectives

The objectives of this investigation, as stated in our proposal, are to develop, demonstrate and verify the capability to calculate indices of specific environmental characteristics from ERTS space observations. All efforts are being made to devise a fully automatic approach for handling ERTS products to produce the following outputs.

- Environmental thematic maps of land use, water quality, and air quality.
- Environmental temporal and areal trends (indices) covering selected observation dates within the August 1, 1972 through December 31, 1973 time period.
- Specifications for the procedure(s) and system(s) developed to produce the indices and thematic maps.

The DAP plan presented here, however, requires several operations in which manual- man in the loop- processes are required. Success in the elimination of these "manual" operations is the ultimate goal and the specifications of the most realistic system will be the major product of this contract.

A.1.2 Environmental Indices

Three categories of environmental indices are being developed covering the following characteristics.

Shifts in land use with emphasis on:

- agricultural areas
- timber lands
- waterways
- urban/suburban areas
- eroded areas
- transportation
- construction, strip and open pit mining, other man-disturbed areas

Pollution of inland lakes and rivers with emphasis on:

- oil spills
- algae blooms
- other surface observables
- silting of dams and waterways

Pollution of urban and rural air with emphasis on:

- atmospheric turbidity
- damaged vegetated areas

More emphasis, however, is being placed on land use shift and air pollution. See section A.2.0 for reasons for this change in emphasis.

Each index will be a combination of measurements of one or more parameters observed from space into a number or set of numbers which can serve a useful purpose in characterizing that portion of the environment.

The indices outlines above have been suggested from consideration of the responsibilities of the council on Environmental Quality, the Environmental Protection Agency- Headquarters and Region III, and various Federal and state agencies responsible for protecting and improving the environment of the nation. Table A-1 contains a list of specific point and area training areas within the two test sites (Harrisburg area and Wilkes-Barre, Scranton area) selected.

There are three major uses of these indices. First, the indices will provide an initial measurement of the status of the environment. There are many portions of the environment for which currently we do not have a comprehensive description. For instance, we do not have nation-wide or even statewide compilation of land use. Also we do not have a complete picture of surface water pollution across the country. Second, these indices calculated from measurements taken over a period of time will indicate trends in the state of the various elements of the environment. For instance, we should know how much land area is being shifted from farmland to suburban housing and shopping areas, and how much estuary and coastal land area is being drained and built up. We should be able to measure how overall pollution is increasing or decreasing as major governmental programs get under way. Third, changes in the values of certain indices can in some instances alert us to take rapid action in case of a sudden deterioration of that portion of the environment.

TABLE A-1

Possible ERTS Point and Area Training Areas

SITE	TARGET AREA	TARGET QUANTITIES	LAND AIR, OR WATER	SUGGESTED BY
1	HOLTWOOD DAM LAKE	ALGAE, THERMAL, SILT	W	EPA REGION III; PA. W.Q.
1	CONOWINGO DAM LAKE	" , " , "	W	" " " ; " " "
1	SAFE HARBOR LAKE	" , " , "	W	" " " ; " " "
1	CODORUS CREEK LAKE (INDIAN ROCK)	" , SILT	W	" " " .
1	BRUNNER ISLAND EFFLUENT	THERMAL, CHEMICALS, SILT	W	" " " .
1	CONEWAGO CREEK MOUTH	THERMAL, SILT	W	" " " .
1	LIME KILN AT ANNVILLE	PLUME DYNAMICS & LONG TERM EFFECT ON VEG.	A	" " " .
1	HARRISBURG	HAZE, ALL AIR & WATER QUALITY PARAMETERS	A,W	-
1	SUSQUEHANNA RIVER-SUNBURY TO MD.	WATER QUALITY	W	-
1	LANCASTER	HAZE, ALL AIR QUALITY PARAMETERS	A	STATE OF PA.
1	YORK	" , " " " "	A	" " "
1	SWATARA CREEK MOUTH	SILT	W	USGS/HARRISBURG
1	CONESTOGA CREEK MOUTH	SILT, OIL	W	" / "
1	JUNIATA RIVER MOUTH	SILT	W	" / "
1	THREE MILE ISLAND	ALL AIR & WATER QUALITY PARAMETERS	A,W	PSU
1	ALL OF SITE 1	LAND USE	W,L	-
1	ALL OF SITE 1	ANY DENUDED AREAS	L	STATE OF PA.
2	ALL OPEN PIT MINES	LINEAR DIM., AREA, & VOLUME; PH, THERMAL	L,W	EPA REG.III; PA. W.Q.O.
2	" REFUSE BANKS	" " , " , & " ; " "	L,W	" " " ; " "
2	SUSQUEHANNA RIVER	ALL WATER QUALITY PARAMETERS	W	-
2	" " AT DANVILLE	" " " "	W	-
2	" " AT HUNLOCK CREEK	" " " "	W	-
2	SCRANTON	HAZE, ALL AIR QUALITY PARAMETERS	A	STATE OF PA.
2	WILKES-BARRE	" , " " " "	A	" " "
2	ALL OF SITE 2	LAND USE	W,L	-
2	" " " 2	ANY DENUDED AREAS	L	STATE OF PA.

A.2.0 DAP CHANGES

In our original DAP, three tasks were of a different design and complexity than being presented here-- (1) the use of data collection packages (DCP's) for ground truth, (2) the use of aircraft underflight data in the signature analysis procedure of the ERTS-1 satellite multi-spectral scanner (MSS) data, and (3) the depth in which each media (land, water, and air) is being analyzed.

The two DCP's supplied are being deployed along the major river of Harrisburg test site in cooperation with the U.S. Geological Survey--Harrisburg Office (USGS/H). Results from these stations and two stations being deployed by USGS/H in this river basin will give some insight into the dynamics of river water quality and quantity but are too few in number to give sufficient areal and temporal information to correlate with results derived from MSS tapes and imagery.

Many more in-situ sensor stations are needed to supply sufficient water quality ground truth. Federal and state in-situ stations have been examined and found to be too few in number and/or reports to give satisfactory water quality areal and temporal ground truth information.

The second major change is the use of aircraft (RB-57 and/or U-2) color and color infrared (IR) photography in the signature analysis process. Work performed in Phase II, the Quick-Look Phase, has uncovered the need for higher resolution imagery than ERTS-1 imagery and more recent land use information than obtainable from USGS 7.5 and 15 minute topographic maps presently available for our two test site areas. See Section A.3 for a detailed description of how computer derived land use maps are compared with U-2 and/or RB-57 photography for signature improvement development for digital data analysis. Such a comparison was found to be necessary in order to reach the levels of classification required to produce the list in Section A.1.2.

The third change is in the depth in which each media (land, water, air) is to be covered in Phase III. Land use indices (trends) can be developed satisfactorily to levels shown in Section A.1.2 with the use of recent aircraft color and color IR photography for selected test areas. The air pollution indices approach is being performed using the EPA/NOAA atmospheric turbidity data network (see Section A.3 for description of this network and data). The water quality indices development, however, needs ground truth data in synchronization with the ERTS spacecraft and for aircraft overflights. All water quality data bases which might provide such ground truth data have been examined and found to be deficient from either area (granularity) point-of-view or the temporal point-of-view. Thus it has been decided to spend our remaining resources on the land use and air pollution indices and to perform a water quality index analysis for only one overflight date to prove out the acceptability of the approach presented in Section A.3. Since the water quality approach is similar to the land use approach and thus exercise of the approach for land use over several observation dates will be sufficient to develop the systems specification for the final report presentation, it was felt that this de-emphasis was warranted at this time.

A.3.0 DETAILED DESCRIPTION OF THE DATA ANALYSIS APPROACHES

A.3.1 General Remarks

A step-by-step analysis system has been designed for machine and manual processing of ERTS data. Basically the software involved in the data analysis system is a combination of existing training area classification programs with a next-generation extension of cluster analysis techniques similar to those developed by the Laboratory for Applications of Remote Sensing at Purdue University.[1] Manual imagery interpretation is used to complement and verify computer analysis. The whole system comprises four main levels of data processing:

- Preliminary Reduction: MSS Scan line and element limits of CCT are set to determine the area to be examined; cloud cover is identified and blanked out; definable spectral boundaries are delineated.
- Level 1 Mapping: Ground truth data and MSS digital output are compared to select best training areas and classification of features within and near those areas are performed using supervised analysis software.
- Level 2 Mapping: Signatures within and near training areas are again determined independently by applying un-supervised analysis software (cluster analysis) and comparing to results from Level 1 supervised analysis.
- Level 3 Mapping: With approximately 75 percent of the area now generally defined, the final phase is a reiteration and refinement of Level 1 and Level 2 procedures so that the maximum possible amount of area can be classified.

Each of the four main data processing phases will be discussed in more detail.

---

[1]H. Swain and Staff, LARS Purdue University "Advancements in Machine Processing of Multi-spectral Data." Fourth Annual Earth Resources Program Review (NASA, January 1972).

A.3.2 Signature Analysis Software Description

The preliminary reduction involves reviewing ERTS imagery to identify and define the boundaries of the selected test site or sites. Scan line and element limits are determined for an area of ERTS imagery which corresponds to the boundaries of the chosen test site. From these limits a tape is generated using the Pennsylvania State University Program (SUBSET[1]) which thus becomes our working tape. The main purpose of this phase is to reduce analysis of extraneous data and to avoid costly bypassing of unwarrented data if further analyses of the data are necessary.

The next step is the use of the PSU intensity map program, (N-MAP[2]). This program generates a vector representation to each observation and then develops an output map showing the RMS of the intensity pattern of reflected sunlight. That is, let $\bar{X}_{i,j,p,}$ represent the value of reflected energy sensed in channel (p) for a single element (j) in scan line (i). The geometric length of the vector is defined by

$$\|\bar{X}_{i,j}\| = \sqrt{\sum_{k=1}^{p} \bar{X}^2_{i,j,k}}$$

This length is transformed into a percentage of the maximum possible length, M, which is then used for computer mapping of the test site.

$$M = \frac{\|\bar{X}_{i,j}\|}{\sqrt{128^2\ p}}$$

128 = number of discrete levels (grey scales) in each channel (p) in the MSS data recorded on CCT.

---

[1] A more complete documentation of this program may be found in Borden and Lackowski, ORSER-SSEL Technical Report 3-71: SUBSET Program Description, The Pennsylvania State University (October 1971).

[2] Borden, F. Y. ORSER-SSEL Technical Report 2-71: N-MAP Program Description, The Pennsylvania State University (October 1971).

The digital N-MAP is compared with the U.S. Geological Survey (USGS) topographic maps and underflight imagery to determine if the correct section of ERTS imagery was selected.

In the next phase of the reduction the PSU program U-MAP[1] is used to compute the absolute Euclidean distance (d) to determine uniformity of each pixel to its neighbor.

$$d^2 = \sum_{i=1}^{p} (\bar{X}_{1i} - \bar{X}_{2i})^2 .$$

Four distances are computed for each observation $\bar{X}_{i,j}$ using neighboring observations $\bar{X}_{i+1,j}$, $\bar{X}_{k,j+1}$ and $\bar{X}_{i+1,j+1}$. They are defined as follows:

$$D^2_{1,i,j} = \frac{1}{d_1} (\bar{X}_{i,j} - \bar{X}_{i,j+1})^2$$

$$D^2_{2,i,j} = \frac{1}{d_2} (\bar{X}_{i,j} - \bar{X}_{i+1,j})^2$$

$$D^2_{3,i,j} = \frac{1}{d_3} (\bar{X}_{i,j} - \bar{X}_{i+1,j+1})^2$$

$$D^2_{4,i,j} = \frac{1}{d_4} (\bar{X}_{i,j+1} - \bar{X}_{i+1,j})^2$$

The values of $\frac{1}{d_k}$, (k = 1, 2, 3, 4) represent the spatial increments separating two neighboring elements. $D'_{i,j}$ is assigned to the maximum distance computed from the above equations. This value is then translated to a 0-100 scale represented by $D_{i,j}$

$$D_{i,j} = \frac{100\ (D'_{i,j} - D_{min})}{D_{max} - D_{min}}$$

$$D_{min} = 0 \qquad D_{max} = \sqrt{128^2\ p}$$

---

[1]Borden, F. Y. ORSER-SSEL Technical Report 2-71: U-MAP Program Description, The Pennsylvania State University (October 1971).

Areas which have wide spread uniformity (i.e. small values of $D_{i,j}$) are chosen as possible training areas. These training areas are again cross-checked with USGS maps and underflight imagery to keep the area of interest pinpointed.

Level 1 Mapping will make optimum use of ERTS imagery, aircraft underflight imagery and U-MAP to determine optimum training areas. Once these are defined, a preliminary attempt is made at classification using the PSU STATS[1] program. The statistical analysis of the data includes the following signature information.

mean	$\mu_1 = E(X) = XF(X)$
variance	$\sigma^2 = E(X^2) - \mu^2$
standard derivation	$\sigma = \sqrt{\sigma^2}$
covariance	$C = E(XY) - \mu_1 \mu_2$
correlation coefficient	$\rho 12 = \dfrac{E\left[(X-\mu_1)\ (Y-\mu_1)\right]}{\sigma_1\ \sigma_2}$

For any category, a "good" signature on each ERTS channel will be defined as one with a low standard deviation and/or a bell-shaped histogram of pixel D values.

While this may identify the training areas, there still will be adjacent non-uniform areas which need classification. A-CLASS[2] is the PSU program that attempts to classify these areas by using the signatures just determined in STATS. The classification is done according to the angle of separation, θ, between vectors. In general, let $\overline{A}$ and $\overline{B}$ be vectors, (d) the distance between their end point, (θ) the angle between $\overline{A}$ and $\overline{B}$,

$$\sin\left(\frac{\theta}{2}\right) = \frac{d}{2}$$

$$\theta = 2 \sin^{-1}\left(\frac{d}{2}\right)$$

---

[1] Borden and Lackowski, ORSER-SSEL Technical Report 5-71: STATS Program Description, The Pennsylvania State University (October 1971).

[2] Borden, F.Y. Technical Report 6-71: A-CLASS Program Description, The Pennsylvania State University (October 1971).

For ERTS classifications the angles between a standard length vector (I) and all known signatures (from STATS) are computed. θ_{min} is the minimum angle computed using signature category (A). θ_{min} is tested against a pre-determined critical angle, θ_c. If $\theta_{min} < \theta_c$ the vector (I) will become classified as category A, otherwise it will be classified as "other". We proceed in this manner until the maximum possible number of vectors are classified into categories, that is, until the number of observations in "other" is one percent or less. As a final step photo-interpretation of imagery is performed to verify results or correct misinterpretations.

Level 2 Mapping is the reduction of remaining unknowns in the data analysis effort using an unsupervised-automatic procedure. Here, cluster analysis (A-CLUS[1]) is combined with aircraft visible and infrared imagery to classify particularly small or non-uniform areas. A-CLUS uses unsupervised classification by developing its own set of signatures. Cluster analysis randomly selects the required number of sample points from the data. A trial group of centroids is determined from the first scan line of data using a critical angle, θ_c. That is, for vectors Z_1 and Z_2, (θ) the angle between, if $\theta < \theta_c$ vector Z_1 becomes the first centroid C_1. If, however, $\theta > \theta_c$ $C_1 = Z_1$, and $C_2 = Z_2$. Every other vector is checked against the initial centroids using the same criteria. The centroids coordinated are recomputed with each observation assigned to it, as is a value of standard deviation. Once all observations have been considered small unrepresentative clusters are dropped. Any clusters overlapping one another by one standard deviation are combined. This process continues till 10 clusters remain. This program is continued for all non-uniform areas until the maximum possible classifications are made.

The final phase in the ERTS data analysis system (Level 3) consists mainly of reiteration, refinement, and optimum use of all earlier

---

[1]Turner, B. Cluster Analysis of Multi-Spectral Scanner Remote Sensor Data. The Pennsylvania State University Journal Paper 4147 (1 March 1972).

addressed techniques. In some cases it will be useful to redefine smaller areas or to repeat previous steps. These choices will be made in order to culminate with the most efficient distillation of data into useful reliable information.

A.3.3 Data Analysis Plan Details for Land Use, Water Quality, and Air Quality

From the general introduction explaining the analysis and validation techniques to be applied in the Data Analysis Plan, we now proceed to a description of how the Plan applies specifically to the three environmental categories of interest: land use, water quality, and air quality.

A.3.3.1 Land Use Analysis

The objectives of the analysis of land use data are (1) development, if feasible, of signature variation algorithms which will eventually permit purely digital analysis of land use trends; and (2) development of the specifications for the optimum ERTS-type system to provide the data required for signature algorithm generation and update. To build toward the achievement of these two main objectives, both photographic interpretation (PI) and digital interpretation (DI) are employed. The PI methods employed in land use analysis include ERTS and aircraft photo interpretation (color and color infrared), and comparison of these results and conventional topographic and land use maps with maps derived by analysis of digital ERTS data.

The interrelated PI/DI analysis proceeds through several phases. First, DI analysis is performed on ERTS data tapes of the first test area of interest (Harrisburgh, Pa. area) on a particular date for Preliminary Reduction and Level 1 Mapping. USGS topographic maps, ERTS photography, and aircraft photography if available are used to locate the test area on digital maps and define training areas. The STATS and A-CLASS programs described above are then run on the selected training areas to classify features and provide tables of statistics on signatures of interest. These signatures include, at this stage of investigation, agriculture, forest and woodland, waterways, erosion areas, urban/suburban, transportation, earth moving events, and wetlands/estuaries. Throughout Preliminary Reduction and Level 1 Mapping, there are continual inputs and feedback consisting of aircraft photography, conventional maps, and ground truth used to verify and enhance the digital analysis of ERTS-1 MSS data.

With the knowledge gained to this point, analysis proceeds to Level 2 Mapping. Here the A-CLUS program described above is run on the ERTS-1 MSS data covering sections of the selected training area where more specific identification and classification of land use parameters is desired. As an oversimplified summary, Level 1 Mapping generally outlines major features in an entire training area, and then Level 2 Mapping provides a more detailed identification and classification of land use features in specific areas of interest in the training area. Experience thus far indicates that after completion of Level 1 and Level 2 Mapping, approximately 75 percent of the training area may be defined in terms of the land use parameters.

Level 3 Mapping, the last mapping stage, is a reiteration, reevaluation, and refinement of the techniques employed in Levels 1 and 2, including the maximum available input of aircraft photography, conventional maps, and other ground truth data. The objective of this level of analysis is the maximum possible definition of land use parameters in the area of interest using state-of-the-art techniques and equipment. Reduction of over-classified areas is performed here.

In applying the Data Analysis Plan to land use parameters, as well as to those of water quality and air quality, interaction between the several levels of digital thematic mapping and aircraft color photography products is necessary for the verification and enhancement of signature information. The interaction is accomplished by use of the Bausch and Lomb Zoom Transfer Scope available for use at USGS, McLean, Virginia and

PSU cartographic devices. Aircraft photography (U-2, RB-57, C-130) will be superimposed on digital thematic maps developed by the techniques described above to improve our determinations of MSS data significance. Our digital maps have an approximate scale of one to 24,000 (7½ minutes USGS) and comment on pixel areas of about 75 meters square. By superimposing the photographic products on the digital maps through successive reiterations, more accurate signature development is possible.

Once land use parameters in the training area are defined by the procedures described above, the next step for reaching investigation objectives is analysis of the signature information that has been derived. This is accomplished chiefly by comparison of signature information derived from ERTS-1 data with "known" information on the training area. The "known" information sources include land use studies; large scale topographic, geologic and land use maps; low-altitude aircraft photography; and other available ground truth information. The purpose of comparing digital signature information with ground truth land use information is two-fold. First, the accuracy and validity of the digital analysis approach is checked. The approach either is validated, or areas where improvement is needed are identified. In this way, any "weak spots" in the DI analysis techniques can be isolated and corrected. The second reason for comparison of digital and ground truth information at this stage is that it may be possible to detect land use trends using only one flightline date of ERTS-1 MSS data. This is possible because much of the ground truth data (maps, studies) will be at least several years old, and ERTS data may well reveal changes (e.g., urban/suburban development) since the time ground truth information was recorded.

While it may be possible to proceed directly from this point to develop signature algorithms and determine specifications, the total approach up to this point has dealt with a single training area and one date of ERTS-1 data. For more reliable validation, and for an opportunity to detect land use trends from one ERTS observation to another, the entire process is repeated on each available set of ERTS-1 data covering the training area, and sequential observations are available for analysis. Analysis of the signature information over several dates of observation is expected to reveal some changes which would be indicative of changing land use patterns in the training area over time. From this information, in turn, it is hoped that accomplishment of one of the main objectives of the investigation will be possible: namely, the derivation of signature change algorithms which will allow rapid automatic interpretation of land use trends from ERTS-1 MSS digital data. Additionally, analysis of signature information on the same area over sequential dates, and other areas as well for corroboration, will hopefully lead to accomplishment of the second main objective: namely, a delineation of specifications for an optimum ERTS-type system for land use trend monitoring.

Figure A-1 shows the data analysis flow for the land use portion of the investigation.

A.3.3.2 Water Quality Analysis

The water quality parameter investigation will be applied after sufficient experience has been attained in analysis of the relatively less difficult land use parameters. The main procedures are essentially the same as in land use analysis, obviating the need for repeating the description of the entire process here. The ERTS CCT is processed by the same software through Levels 1, 2, and 3 Mapping of training areas containing rivers, lakes, reservoirs or other water bodies of interest for the date of interest. The signature verification inputs include the conventional maps and the aircraft photography employed for land use analysis. In addition, the water quality analysis will review and use data inputs from the Environmental Protection Agency's Region III STORET data bank (a data base of water quality measurements for the Region), daily in-situ water quality reports when available, state and USGS/H water quality information, and any available water quality or hydrological studies of the area of interest.

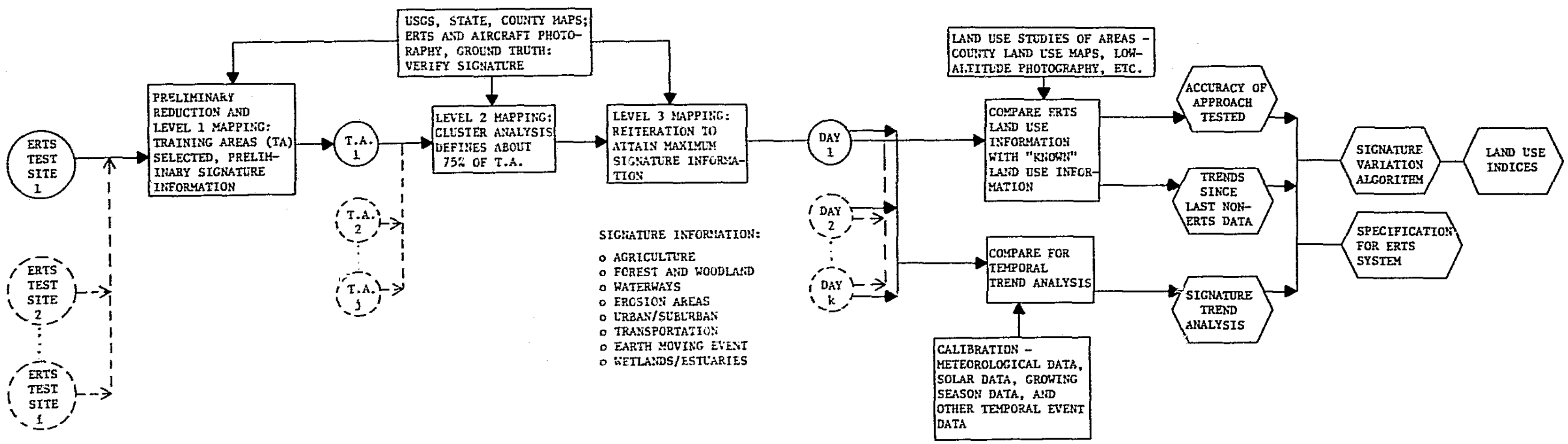


FIGURE A-1

ERTS-1 DATA ANALYSIS PLAN: LAND USE

The product of the verified digital analysis is a set of signatures defining as many water quality parameters as possible. With the data currently available from ERTS-1, it appears that discriminant signatures may only be obtainable for turbidity, surface oil, and possibly siltation and chlorophyll. Nevertheless, an attempt will be made to classify signatures for all parameters on the investigation list. In addition to those cited, they include industrial chemicals, eutrophication, and at least five specific water quality characteristics (pH, D.O., B.O.D., temperature, and conductivity).

Once signatures are obtained for training areas by the process described above, the signature analysis of water quality parameters is compared with all available ground truth analysis at or near a given date. The comparison will result in a check on the accuracy of the signature analysis, and if the two analyses cover somewhat different time periods an indication of areal water quality trends may be observable.

From this point it may be possible to attempt directly to derive signature variation algorithms and develop optimum ERTS system specifications. The method for analysis for water quality is similar to that for land, and thus <u>only</u> <u>one</u> over-flight date will be analyzed for the two test sites. Proof of the DI and PI approaches will thus be obtained. Further dates are not warranted because of the inadequacy of good areal and temporal ground truth water quality data.

Figure A-2 shows the data/information flow for the Data Analysis. Plan applied to water quality parameters but only one date (day) will be produced in this contract effort.

A.3.3.3 <u>Air Quality Analysis</u>

Experience thus far in the investigation of environmental categories indicates that air quality is the most difficult for obtaining specific signatures for all the parameters of interest. Initially the major effort is directed toward defining total atmospheric turbidity

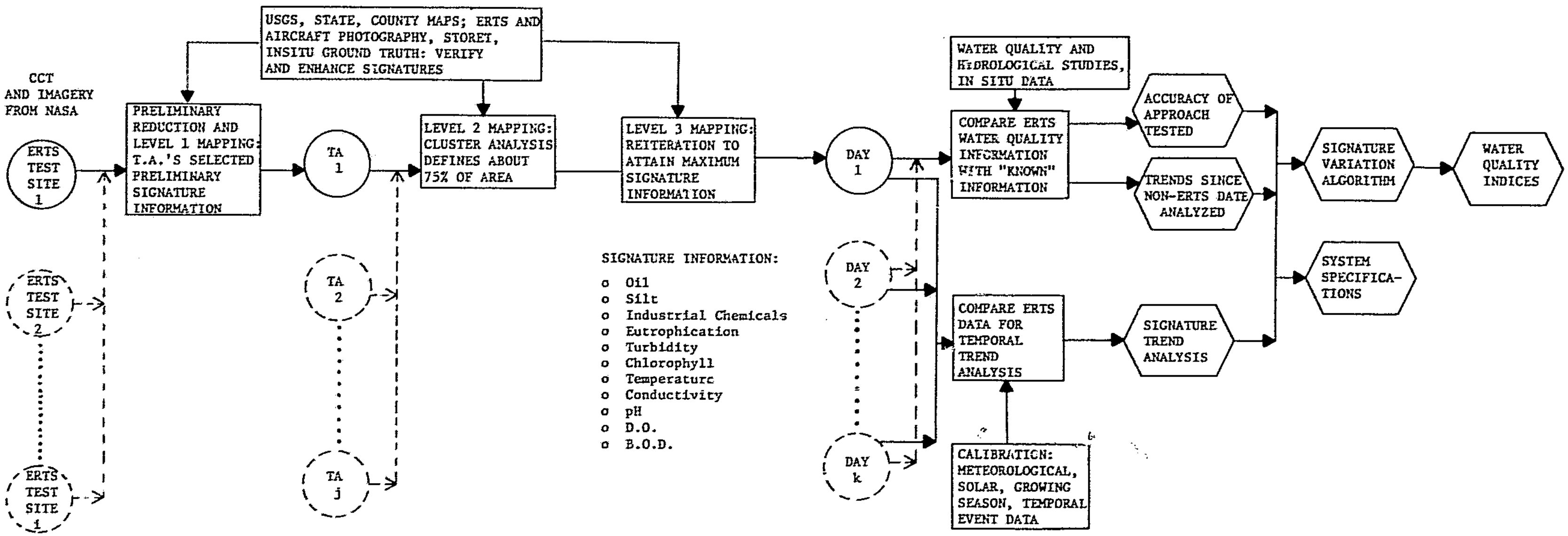


FIGURE A-2

DATA ANALYSIS PLAN: WATER QUALITY

over the test area-- mesoscale* analysis. Once this is achieved, an attempt will be made to define the other air quality parameters of interest to the investigation-- microscale* analysis. These include black intensity (soot), brown intensity (NO_x), blue intensity (fine particulate), white intensity (moisture), air pollution effect on vegetation, and the specific pollutants SO_2, CO, and O_3.

The Data Analysis Plan for air differs somewhat from that applied to land use and water. In the first place, there are two approaches rather than one: an analysis of mesoscale air quality, and a separate analysis of microscale air quality. The mesoscale analysis has, as a preliminary objective, characterization of the atmosphere over the entire test area. Microscale analysis, on the other hand, involves specific examination in training areas in an attempt to identify air pollution sources and trends. Each approach will be described in more detail below.

Since the mesoscale analysis is concerned with general air quality trends over a large area, much of the detailed ERTS-1 data analysis previously described will not be required; however, more ground truth data are needed. The ERTS data analysis proceeds to Level 1 Mapping, at which point the general features in the test area are classified and tabulated for a given date. This information is then correlated with validated air quality data made available as ground (or in this case "air") truth. The ground truth primarily consists of measurements in and near the test area, provided by NOAA/EPA Turbidity Network. These turbidity data are supplemented by any air quality data available from Region III National Aerometric Data Information Service (NADIS), the state Commonwealth of Pennsylvania Air Monitoring System (COPAMS), and local agencies. Thematic maps and statistics derived from the ground truth data, when correlated with the ERTS-derived maps and

---

*The definitions of mesoscale and microscale areas, as used in this investigation, are generally consistent with meteorological definition: the former encompasses on the order of 100 miles square, and the latter, 10 miles square or smaller.

statistics, will provide the basis for developing air turbidity signature algorithms. When the mesoscale analysis is carried out on several different training areas and dates for the test area, it may be possible to observe broad air quality trends and develop indices.

A brief description of the Turbidity Network, primary source for ground truth data in the air quality investigation, may be helpful. The Turbidity Network is operated basically as an adjunct to selected U.S. meteorological measurement stations under the aegis of the National Oceanic and Atmospheric Administration and the Environmental Protection Agency. No station is located within MITRE's test area. Stations around the test area whose data will be used include Atlantic City (NJ), Beltsville (Md.), Baltimore (Md.), College Park (Md.), Elkins (W. Va.), Toledo (O.), Upton (NY), Washington (D.C.), and Youngstown (O.)[1].

Measurements at each station are taken with Volz-type sunphotometers usually three times a day when line of sight to the sun is cloud free. The instrument measures meter deflection in microampheres at 0.38 μ and 0.50 μ, which is directly proportional to the spectral irradiance received at the ground station through the atmosphere. At a given elevation, the measurement is related to the extinction produced by the variable amount of dust, haze, and water vapor in the atmosphere--in short, a measure of atmospheric turbidity[2].

In the mesoscale approach to MITRE's air quality investigation, measurements reported from the stations mentioned above are plotted for

---

[1] A listing of worldwide stations and their data may be found in the Department of Commerce series Atmospheric Turbidity Data For the World available through the Superintendent of Documents, G.P.O., Washington, D.C. 20402.

[2] A more detailed discussion of turbidity measurement, turbidity coefficient, and related equations are found in McCormick et al "Atmospheric Turbidity Over the United States" in Journal of Applied Meteorology (Vol. 8, No. 6, Dec. 1969, pp. 955-962).

the dates that ERTS coverage of the test area is available. The Turbidity Network data will be analyzed and used in conjunction with meteorological data to develop isopleth maps of the test area at 0.5 μ. These maps are then compared to ERTS-derived average greyness observed from N-MAP in Channel 4 (0.5 to 0.6 μ) statistics to develop correlations. The objective of successful correlation analysis is the development of atmospheric turbidity signature algorithms and the consequent observation of air quality trends based on ERTS data.

The second approach in air quality analysis, microscale, makes use of the same ground truth data as mesoscale, with more specific application to training areas within the test area. Microscale analysis will be conducted only if time permits. The ERTS data analysis for microscale does not stop at Level 1: Digital analysis proceeds through all three levels to provide maximum definition in each training area, and to classify signatures for as many of the air quality parameters as possible. The objectives of the microscale analysis are to identify observable local air pollution trends, pinpoint local sources of air pollution, detect pollution damage to vegetation, and develop signature algorithms. As with land use and water, the final objective of both meso- and microscale analysis of air quality is to develop specifications for an optimum ERTS monitoring system.

Figure A-3 shows the data/information flow for air quality data analysis.

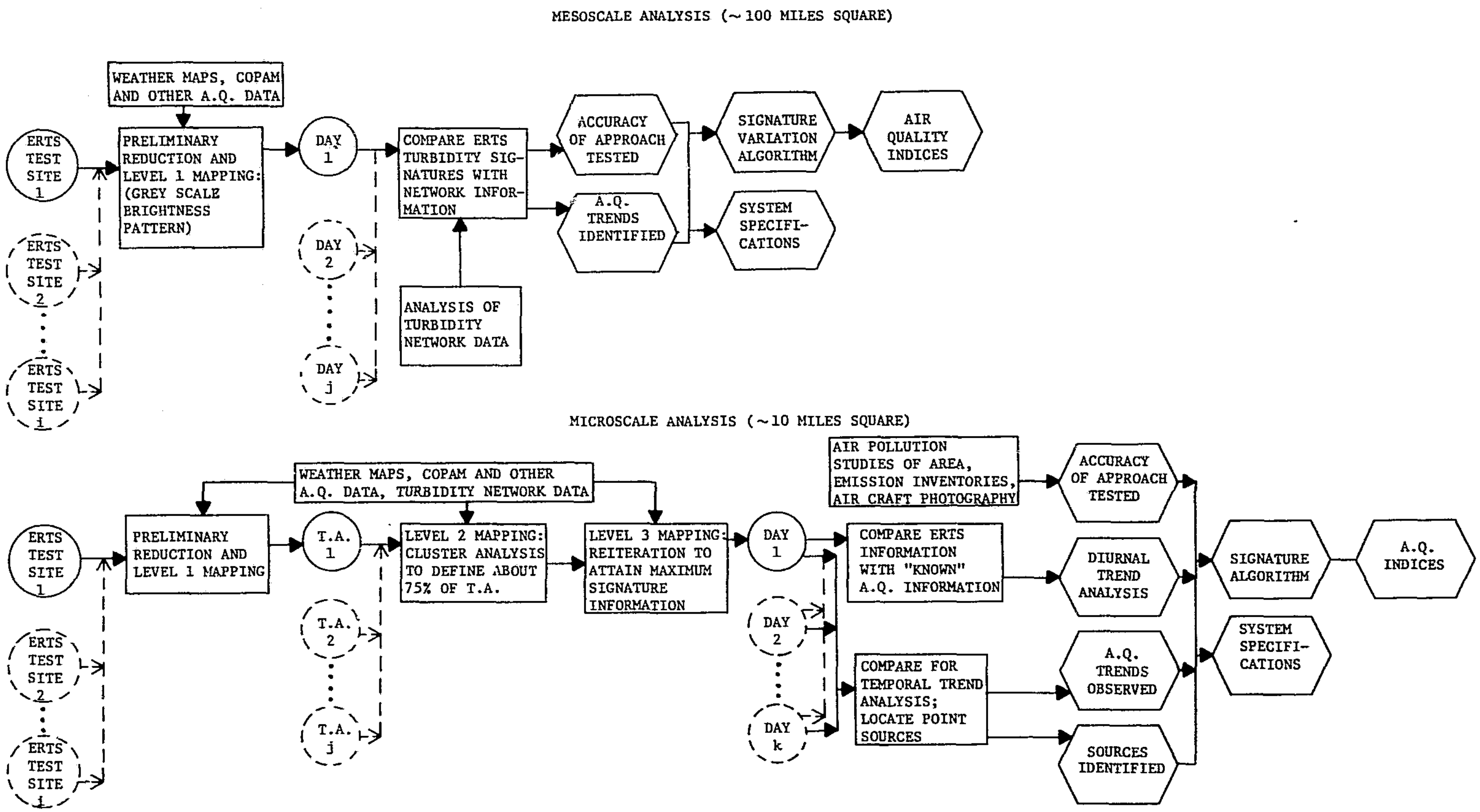


FIGURE A-3

ERTS-1 DATA ANALYSIS PLAN: AIR QUALITY

A.4.0 SCHEDULE

The schedule for the completion of the data analysis tasks described in preceeding sections is shown in Figure A-4. The schedule is tentative at this point because of the research nature of ERTS-1 investigations. For example, as Table A-2 shows, only eight of 29 possible opportunities for ERTS-1 data over the Harrisburg test site 1 have been acceptable, as of December 1972, according to the first criteria of no more than 20 percent cloud cover. Of these eight, only three thus far have had all four channels recording data adequate for comprehensive digital interpretation (DI) analysis, and all three were portions of the same test site or two consecutive days' coverage. Moreover, technical probelms involved with collecting and analyzing both ERTS and ground truth data cannot be predicted with accuracy as estimates are made of the time required in each stage of analysis. Because of these factors, we have attempted to allow adequate flexibility in the schedule to make possible the accomplishment of the objectives stated in Section A.1.1.

The schedule essentially follows the development of the Data Analysis Plan as described in Section A.3. The first environmental category analyzed, and the one which will involve the bulk of the total investigation effort, is land use. It is estimated that a minimum of three dates for each test site will receive three-level analysis, trend study, and signature algorithm derivation. The initial effort and the majority of total analysis time will be expended on land use. Successful development of the techniques in land use are expected to be applied as a model for the two remaining categories-- microscale air quality and water quality.

With land use analysis serving as the model for signature derivation, and in the expected absence of adequate supportive water quality ground truth data during the period of the ERTS-1 investigation only one date of ERTS coverage is scheduled for comprehensive analysis of water quality

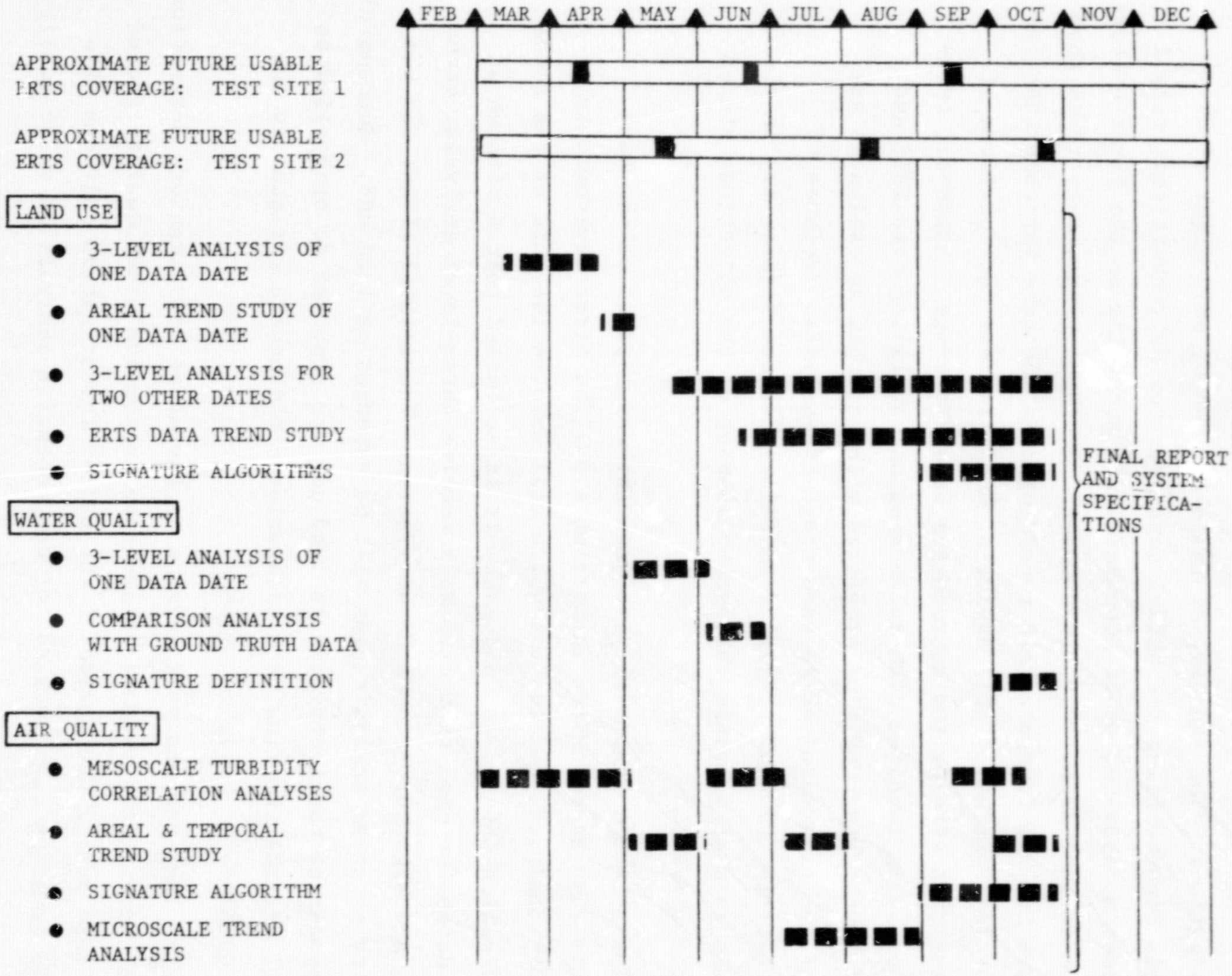


FIGURE A-4

ERTS-1 DATA ANALYSIS SCHEDULE - CY 1973

I. D. NUMBER					CLOUD COVER	ORBIT NO.	RBV			MSS				DATE	SITE NO.		REMARKS	DATE RECEIVED	
SATEL-LITE NO.	DAYS SINCE LAUNCH	HR.	MIN.	TENS OF SECONDS	(%)		1	2	3	4	5	6	7		1	2		TAPE	IMAGES
1	007	15	12	4	100	96	G	G	G	G	G	G	G	Jul 30		X	-	-	-
1	007	15	13	1	100	96	F	F	F	G	G	G	G	Jul 30	X		-	-	-
1	008	15	18	0	100	111	G	G	G	G	F	G	G	Jul 31		X	-	-	-
1	008	15	18	3	100	111	P	P	P	G	F	G	G	Jul 31	X	X	-	-	-
1	008	15	18	5	100	111	G	G	G	G	G	G	G	Jul 31	X		-	-	-
1	009	15	24	1	40	124	G	G	G	G	G	G	P	Aug 01	X		Special Ordered 9/28/72	11/6/72	11/25/72
1	009	15	24	4	20	124	G	G	G	G	G	G	P	Aug 01	X		Special Ordered 9/28/72	11/6/72	11/25/72 (-[illegible])
1	025	15	12	4	100	347	-	-	-	F	G	G	G	Aug 17		X		-	-
1	025	15	13	0	100	347	-	-	-	G	G	G	G	Aug 17	X			-	-
1	026	15	18	0	90	361	-	-	-	G	G	G	G	Aug 18		X		-	-
1	026	15	18	2	80	361	-	-	-	G	G	G	G	Aug 18	X	X		-	-
1	026	15	18	5	80	361	-	-	-	G	G	G	G	Aug 18	X			-	-
1	027	15	24	2	60	375	-	-	-	G	G	G	G	Aug 19	X		Reviewed at GSFC (No Good)	-	-
1	027	15	24	5	60	375	-	-	-	G	G	G	G	Aug 19	X		Reviewed at GSFC (No Good)	-	-
1	043	15	13	0	70	598	-	-	-	G	G	P	G	Sep 04	X	X	Reviewed at GSFC (No Good)	-	-
1	044	15	18	2	50	612	-	-	-	G	G	P	G	Sep 05	X	X		-	-
1	044	15	18	5	90	612	-	-	-	F	F	P	G	Sep 05	X			-	-
1	045	15	24	3	10	626	-	-	-	G	G	P	G	Sep 06	X		Tape Ordered 10/27/72	-	10/26/72
1	051	15	12	5	30	849	-	-	-	G	G	G	G	Sep 22		X			
1	062	15	18	1	20	863	-	-	-	G	G	P	G	Sep 23		X	Cloud cover 100% over Site 2	-	10/30/72
1	062	15	18	4	40	863	-	-	-	G	G	P	G	Sep 23	X	X	Cloud cover 100% in ctr Site 1	-	-
1	063	15	24	2	90	877	-	-	-	G	G	G	G	Sep 24	X			-	-
1	079	15	13	1	0	1100	-	-	-	G	G	G	G	Oct 10		X		12/6/72	11/14/72
1	079	15	13	3	10	1100	-	-	-	G	G	G	G	Oct 10	X			12/6/72	11/14/72
1	080	15	18	3	0	1114	-	-	-	G	G	G	G	Oct 11		X		12/5/72	11/17/72
1	080	15	18	5	0	1114	-	-	-	G	G	G	G	Oct 11	X	X		12/5/72	11/17/72
1	080	15	19	2	0	1114	-	-	-	G	G	G	G	Oct 11	X			12/5/72	11/17/72
1	081	15	24	4	100	1128	-	-	-	G	G	G	G	Oct 12	X			-	-
1	081	15	25	0	80	1128	-	-	-	G	G	G	G	Oct 12	X			-	-
1	097	15	13	3	100	1351	-	-	-	G	G	G	G	Oct 28	X			-	-
1	098	15	18	5	100	1365	-	-	-	G	G	G	G	Oct 29	X	X		-	-
1	098	15	19	1	100	1365	-	-	-	G	G	G	G	Oct 29	X			-	-
1	099	15	24	3	90	1379	-	-	-	F	G	G	G	Oct 30	X			-	-
1	099	15	25	0	70	1379	-	-	-	G	G	G	G	Oct 30	X			-	-
1	115	15	13	4	100	1602	-	-	-	P	G	G	G	Nov 15	X	X		-	-
1	116	15	19	0	50	1616	-	-	-	G	G	G	G	Nov 16		X		-	-
1	116	15	19	2	10	1616	-	-	-	G	G	G	G	Nov 16	X	X	Prods. not rec'd as of 12/31/72		
1	117	15	25	1	70	1630	-	-	-	G	G	G	G	Nov 17	X			-	-

TABLE A-2

ERTS-1 IMAGERY LOG FOR SITES I (HARRISBURG) & 2 (SCRANTON) signatures at this time. The effort allotted to water quality should be sufficient to define parameter signatures and develop system specifications for remote monitoring of some aspects of water quality.

The air quality analysis effort will concentrate on mesoscale turbidity analysis over a minimum of three dates of ERTS coverage for each test site. If high correlation with ground truth data is achieved, ground air quality trend analysis and signature algorithms will be developed over the period of the investigation. Microscale air quality analysis will proceed through the middle portion of the investigation at a lower level of effort. If successful, the microscale analysis will define localized pollution trends, identify point sources, and locate air pollution sources.

A.5.0 NEW SUPPORT REQUIRED

The DAP presented herein, requires the following support not presented previously in the MITRE original DAP.

- Aircraft photography of the two test sites once per season. To be supplied by NASA ERTS Project Office.
- Reduced and calibrated air turbidity data from approximately 18 stations. To be supplied at no cost to this project by NOAA/EPA at Environmental Data Service - Ashville/Division of Meteorology - Research Triangle Park.
- Use of a Bausch and Lomb Zoom Transfer Scope. To be supplied at no cost to this project by USGS at McLean, Virginia.
- Water quality and quantity sensors and operational maintenance for two DCP's on the Susquehanna River. To be supplied at no cost to this project by the USGS at Harrisburg, Pennsylvania.

All agencies except NASA have given verbal promise of support through the end date of this contract, 31 December 1973.

The required support from NASA listed above has the following specifications.

(1) <u>Aircraft Data</u>

(a) U-2 and/or RB-57 photography (of the order of one to sixty thousand scale) is required. These photography products should be both color and black and white 70 mm, positive transparencies covering the visible and near IR frequencies. These flights should have occurred once a season over at least one training area in each of the two test sites. U-2 flights (71-070, frame 0063) in December 1971 and (72-124, frame unknown) in July 1973 over Harrisburg, Pennsylvania are specifically requested.

(b) Data from any U-2, RB-57 or C-130 flight lines covering the Susquehanna River from the confluence at Sunbury to its mouth and the Wyoming Valley from Carbondale to Nanticoke are requested also.

(c) C-130 and C-54 color transparencies taken from low-altitudes (5,000 and 10,000 feet) taken in July 1972 and January 1973 are requested also as backup information.

(2) <u>Data Interpretation Software</u>

(a) Copies of the latest versions of MSS data analysis software and descriptive materials developed by Purdue University, Bendix and Pennsylvania State University suitable for ERTS-1 use are requested.

(3) <u>ERTS CCT and Imagery</u>

(a) Continued supply of 9½ inch bulk black and white positive transparencies for the two test sites for all occasions in which the cloud cover is less than 20% are requested.

(b) Automatic shipment of bulk CCT for areas passing (3a) constraints when all four channels are classified as Good (G) are requested.

(c) Automatic shipment of 9½ inch color composite positives passing (3a) constraints are desired.

APPENDIX B

POTOMAC RIVER STRIPING ANALYSIS

On 15 June 1973 MITRE received a corrected set of tapes covering the Potomac scene (1080 - 15192). The first step in the analysis of the data was to run an intensity map of the Quantico, Virginia area again. There was difficulty in locating this test area; therefore, another intensity map, covering a larger area was run. It was found that for all data on the new tapes there is an 84 line shift from the old tapes. Therefore any comparison of the Quantico maps run with the uncorrected tapes to those maps from the new tapes should not be affected by the difference in line number.

With our test area properly located, separate channel intensity maps were run for Quantico (Figure B-1). We could still see the striping in this map (suspect lines indicated by a dot, (•)) and in the other three channels. At this point a meeting was arranged by the NASA Technical Monitor with Mr. Saul Portner and several other GE engineers, who had worked on the software to correct this problem. Mr. Portner had run intensity maps covering the Susquehanna River Mouth which did not show striping. (Figures B-2, B-3, B-4, channel 7 not included). Unfortunately, we only had digital maps covering the Potomac River and therefore could not directly compare outputs. In trying to help us solve our problem Mr. Portner focused on Table B-1 accompanying Figure B-1. Mr. Portner informed us that the data are only

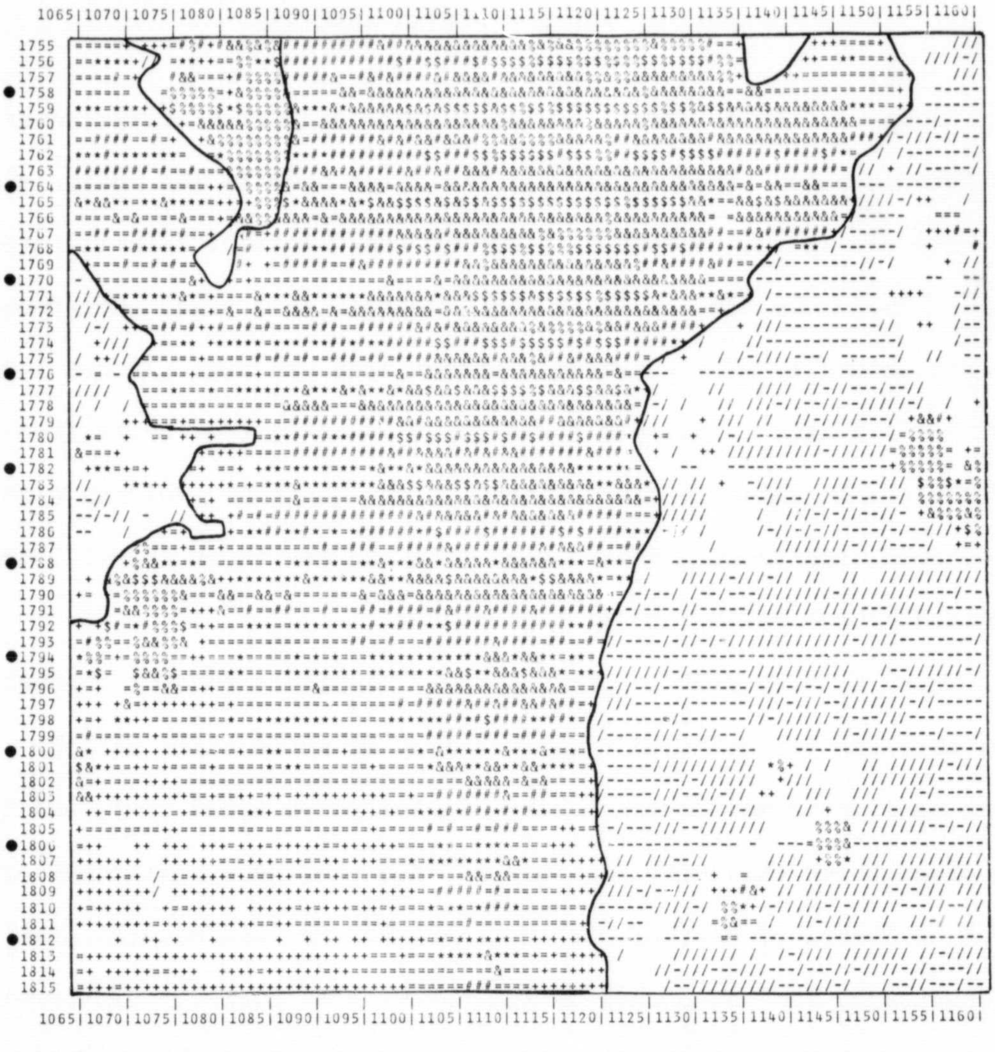


FIGURE B-1
QUANTICO CHANNEL 4
INTENSITY MAP, IMPROVED TAPES

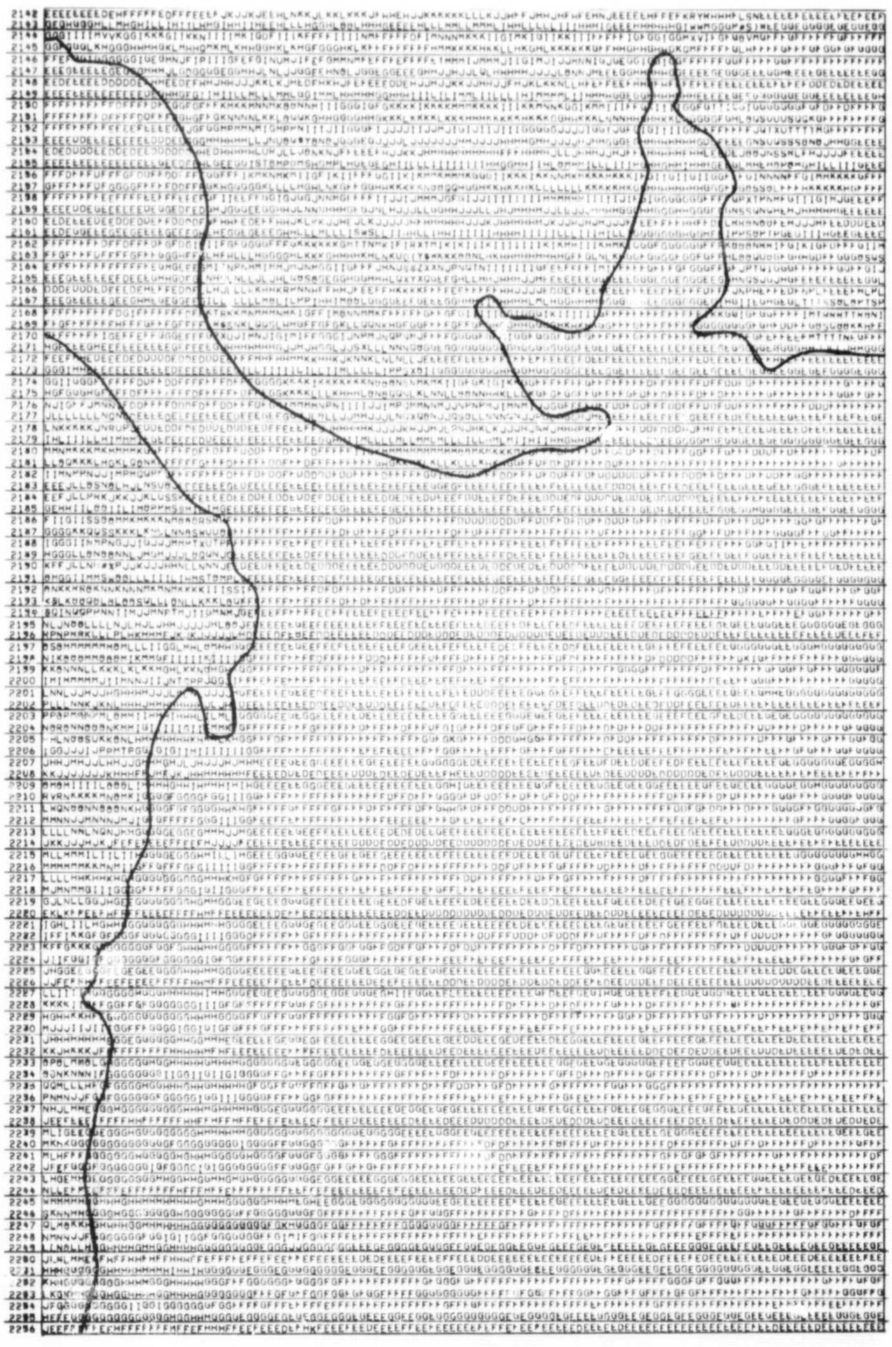


FIGURE B-2
SUSQUEHANNA RIVER MOUTH
GE's CHANNEL 4 INTENSITY MAP

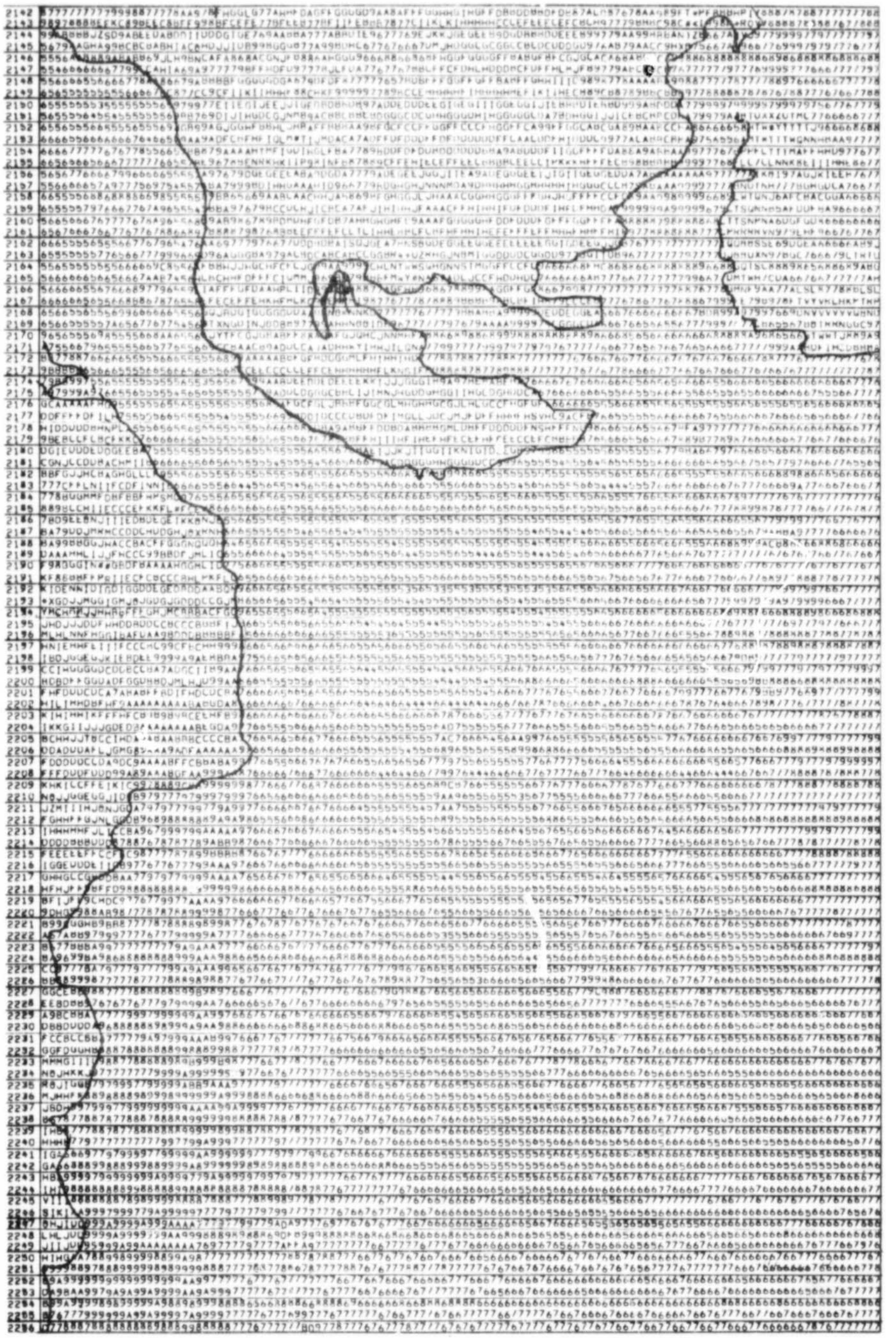


FIGURE B-3
SUSQUEHANNA RIVER MOUTH
GE's CHANNEL 5 INTENSITY MAP

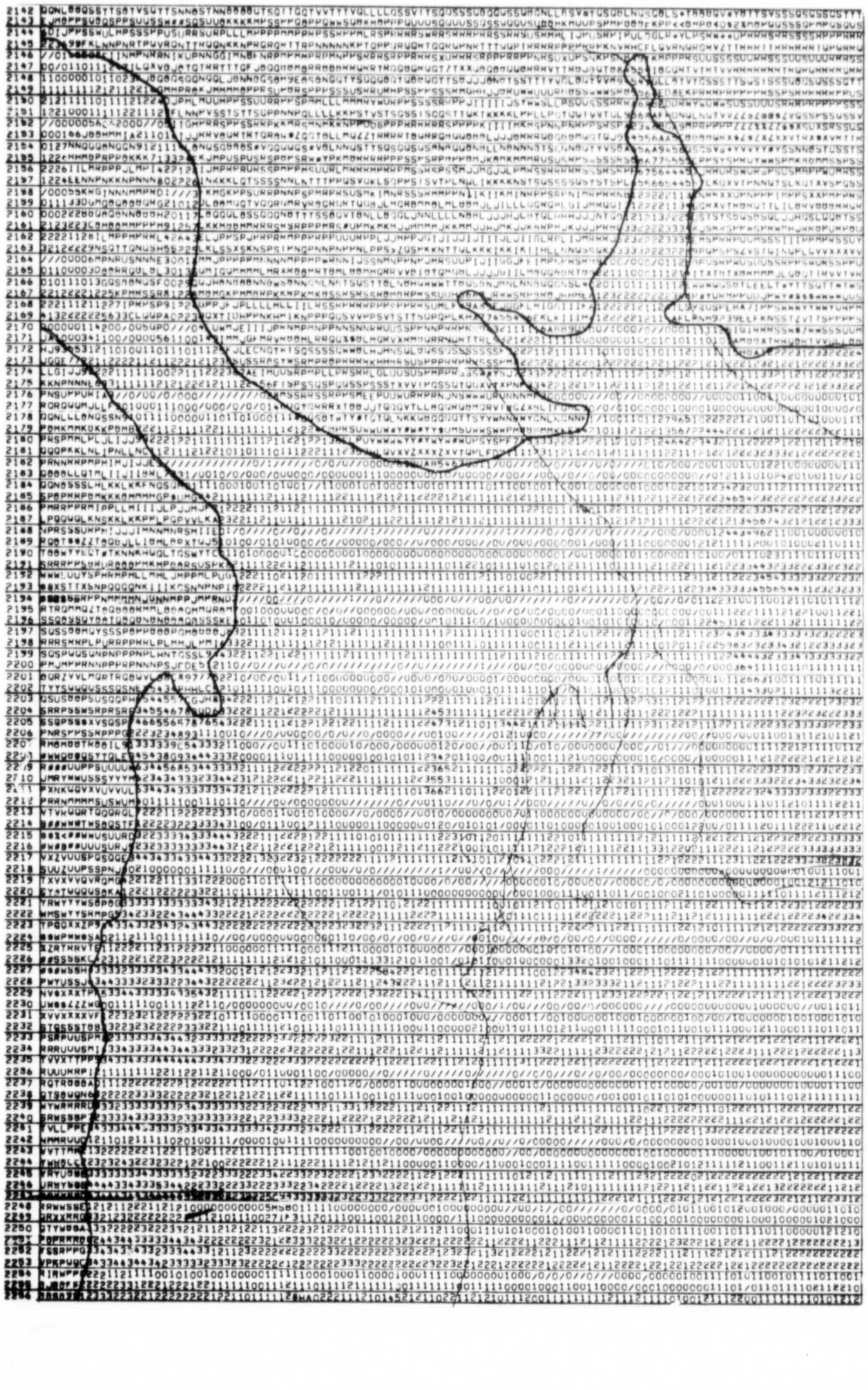


FIGURE B-4
SUSQUEHANNA RIVER MOUTH
GE's CHANNEL 6 INTENSITY MAP

TABLE B-1

SUMMARY TABLE FROM INTENSITY

MAP OF QUANTICO

SYMBOL	LIMIT	COUNT	PERCENT	QUANTA* LEVEL
-	15.0	767	13	19
/	16.0	705	12	20
	19.0	563	10	24
+	21.0	560	10	27
=	22.2	1006	17	28
*	23.0	380	6	29
#	24.0	554	9	31
&	25.5	908	16	33
$	26.0	206	4	34
%	100.0	207	4	128

* Not printed out by computer - this is Quanta Level for appropriate limit shown.

good within the limits of $\pm$ 1 quanta, and that our choice of limits less than $\pm$ 1 quanta was too much of a demand on the ERTS data. Mr. Portner suggested that we widen our limits for the intensity mapping and then we should have no further problems with striping.

Our first attempt to correct the data involved running intensity maps for the Susquehanna River Mouth (Figures B-5, B-6, and B-7). Within the above criteria, these maps showed no striping. We then proceeded to start again on the Potomac River (Figures B-8, B-9, B-10, and B-11 are channels 4-7 respectively). Once again striping showed up clearly in all but channel 5 (channel 5 has a bad line, i.e., 1804). Mr. Portner was again contacted about our findings. He agreed to run a GE program, similar to our intensity mapping, on this area; these are included as Figures B-12, B-13, B-14, and B-15, channels 4-7 respectively. These maps also show striping, but it appears within the constraints of $\pm$ 1 quanta and therefore the data are considered usable by GE.

It has been found that both MITRE's and GE's maps for Quantico still show striping. We, therefore, believe the problem to be in the data and not inherent in our software or our use of it (i.e., our choice of limits). Therefore, the data as such are not useful for water quality analysis, and should be the focus of further study and correction at GSFC.

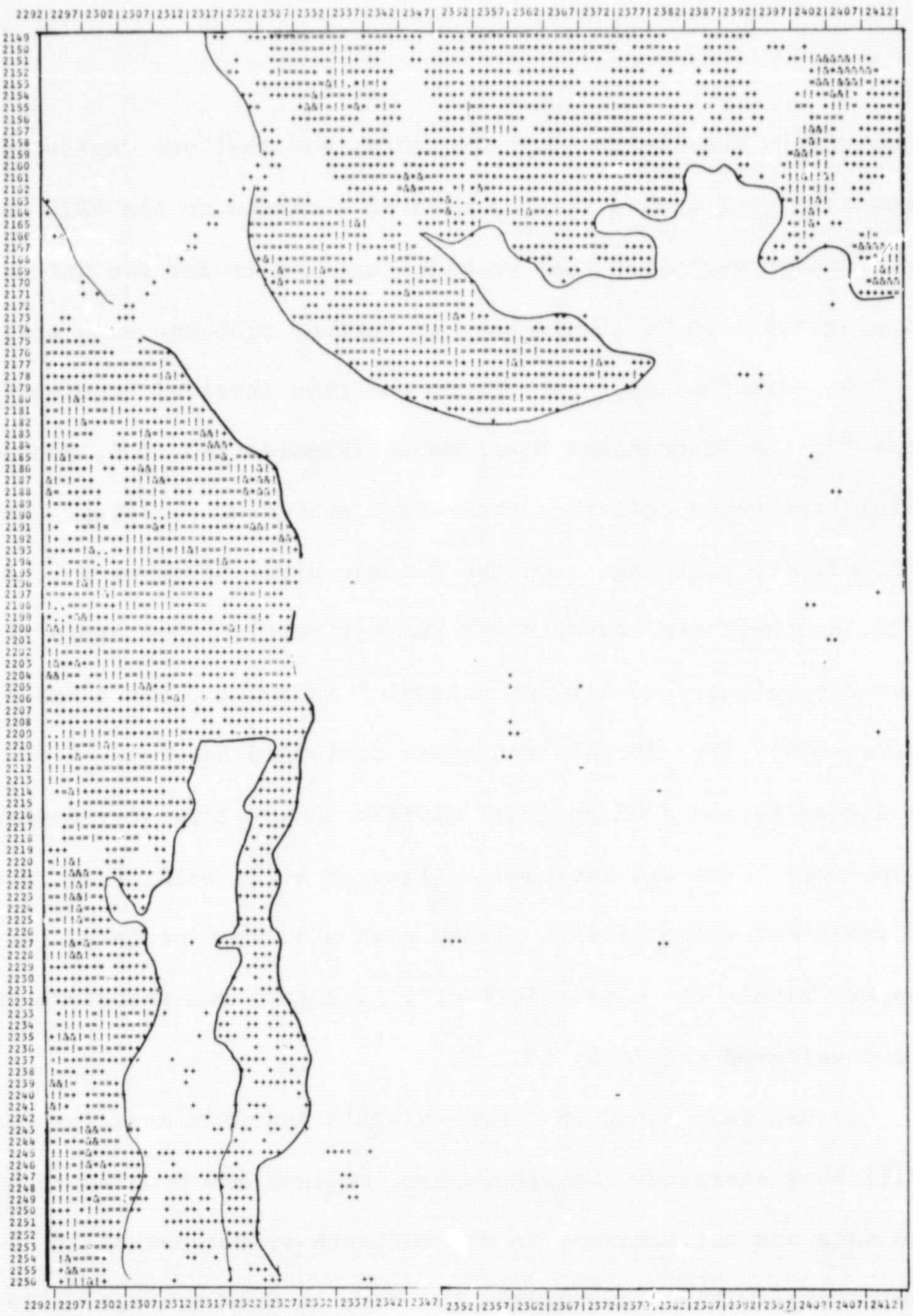


FIGURE B-5
SUSQUEHANNA RIVER MOUTH
MITRE's CHANNEL 4 INTENSITY MAP

FIGURE B-6
SUSQUEHANNA RIVER MOUTH
MITRE's CHANNEL 5 INTENSITY MAP

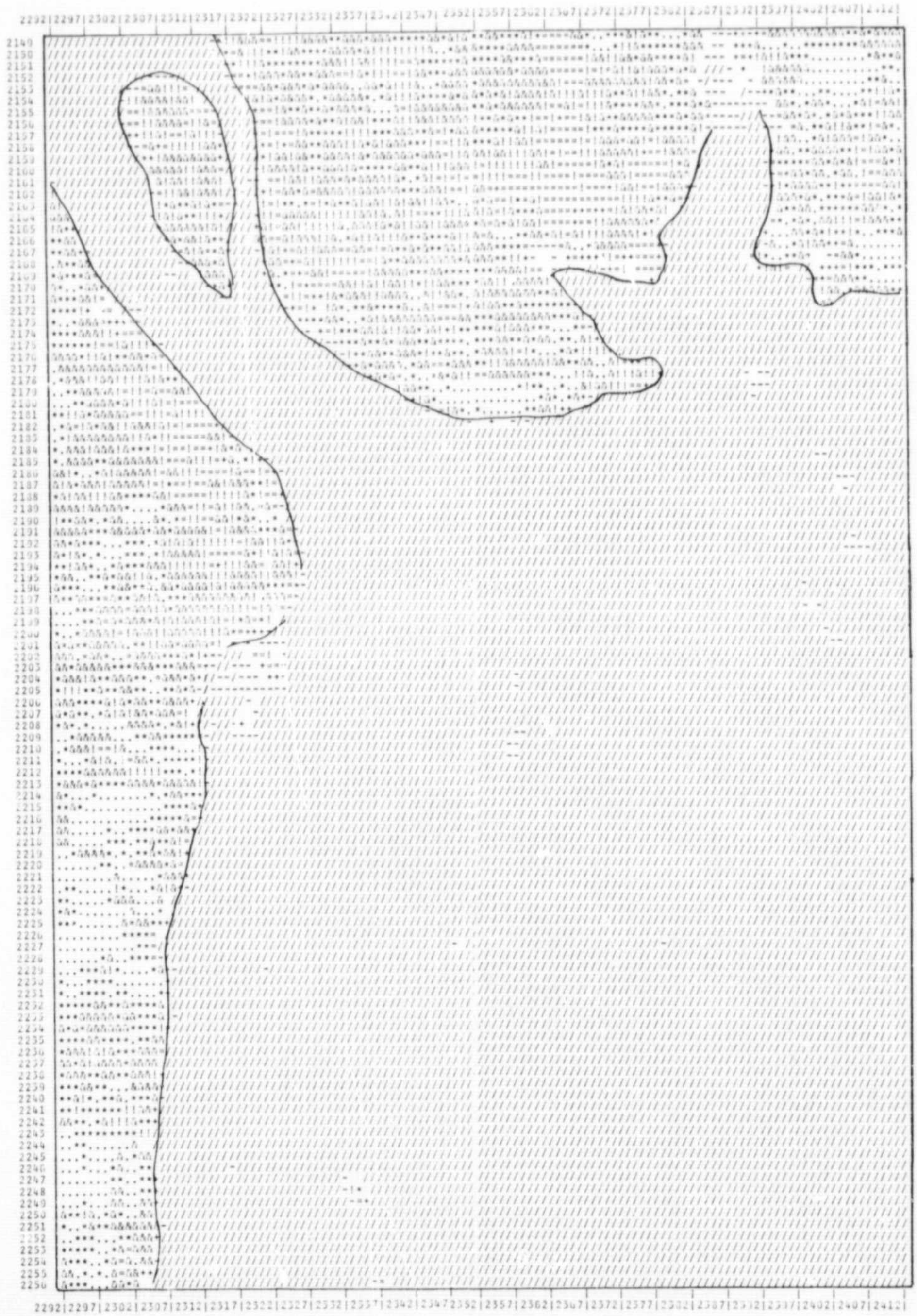


FIGURE B-7
SUSQUEHANNA RIVER MOUTH
MITRE's CHANNEL 6 INTENSITY MAP

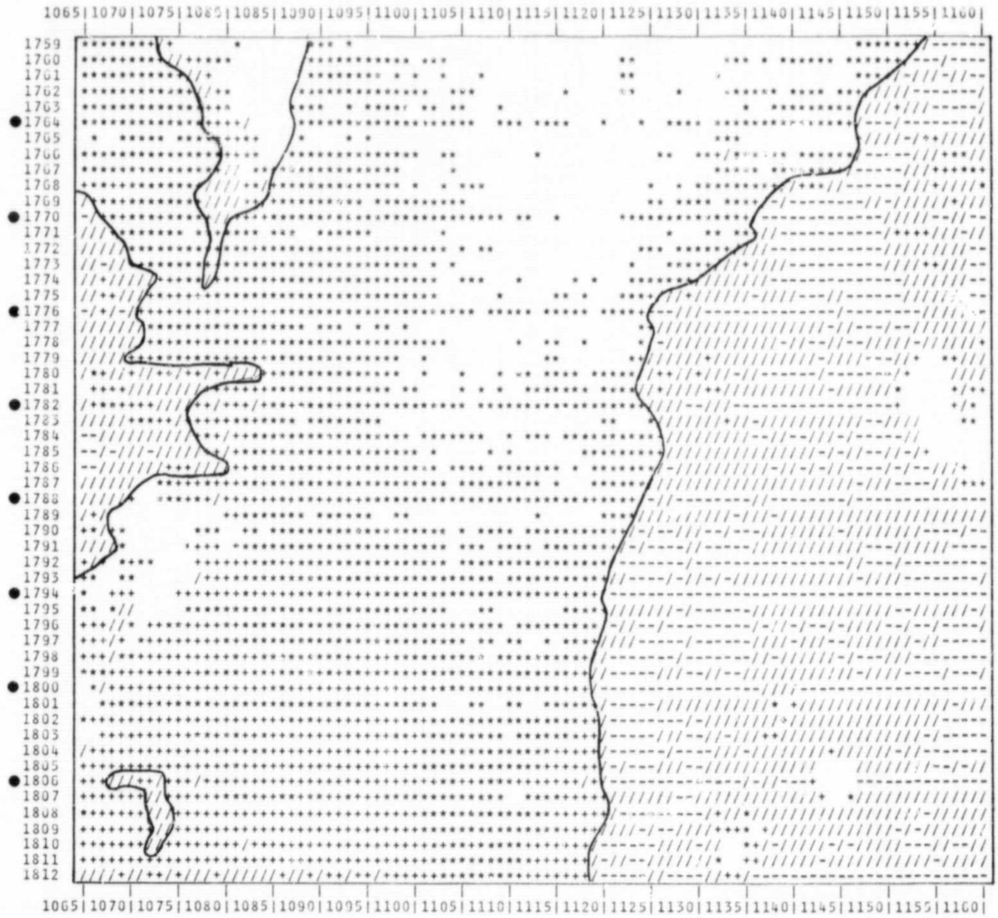


FIGURE B-8
QUANTICO, MITRE's CHANNEL 4
INTENSITY MAP, IMPROVED TAPES

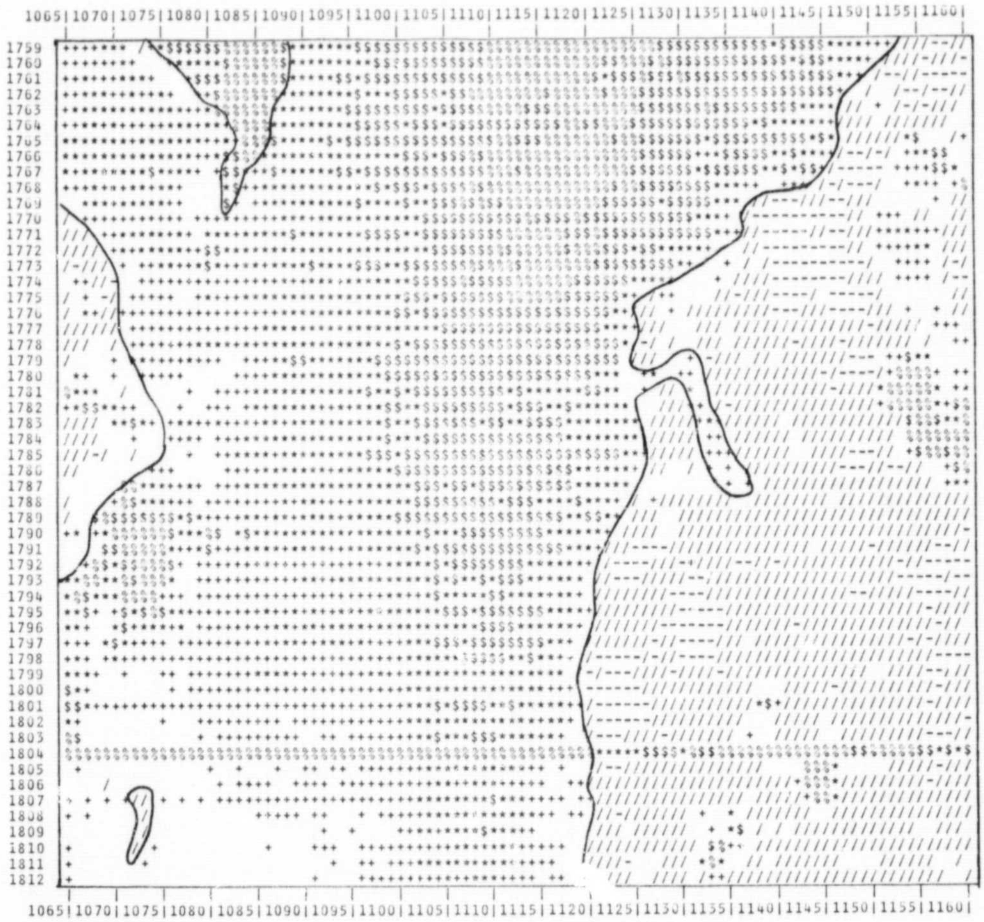


FIGURE B-9
QUANTICO, MITRE's CHANNEL 5
INTENSITY MAP, IMPROVED TAPES

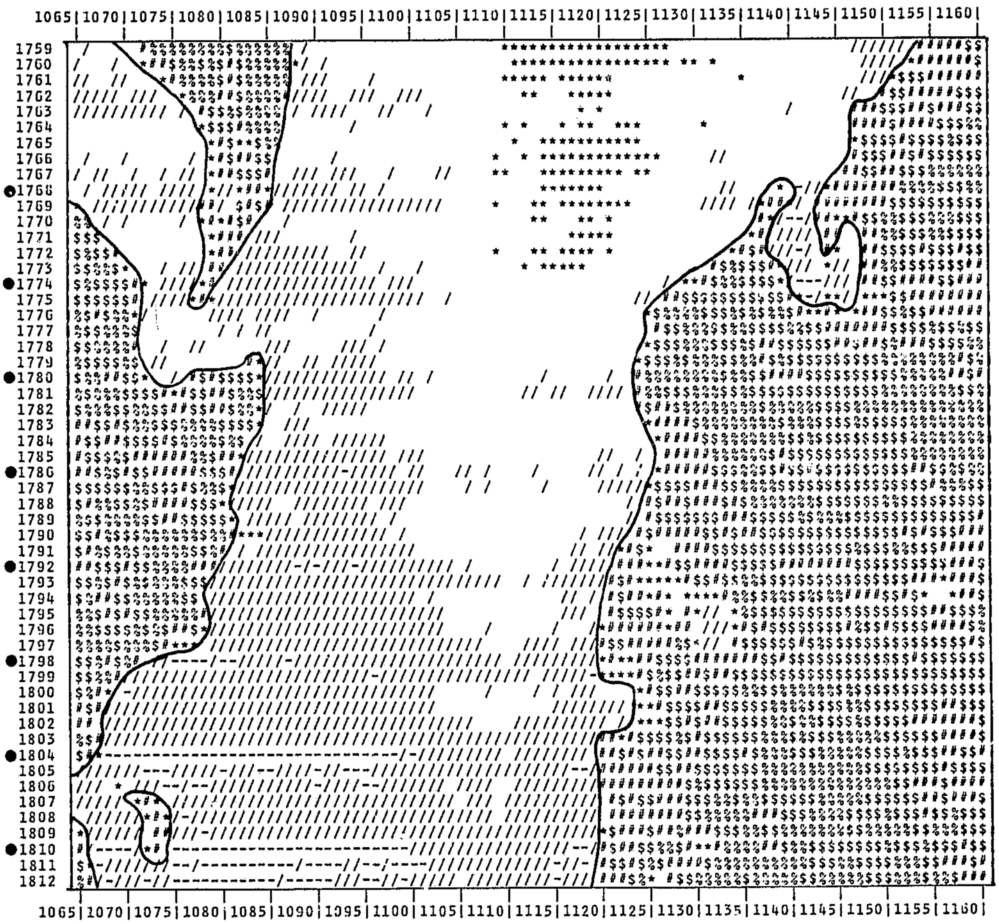


FIGURE B-10
QUANTICO, MITRE's CHANNEL 6
INTENSITY MAP, IMPROVED TAPES

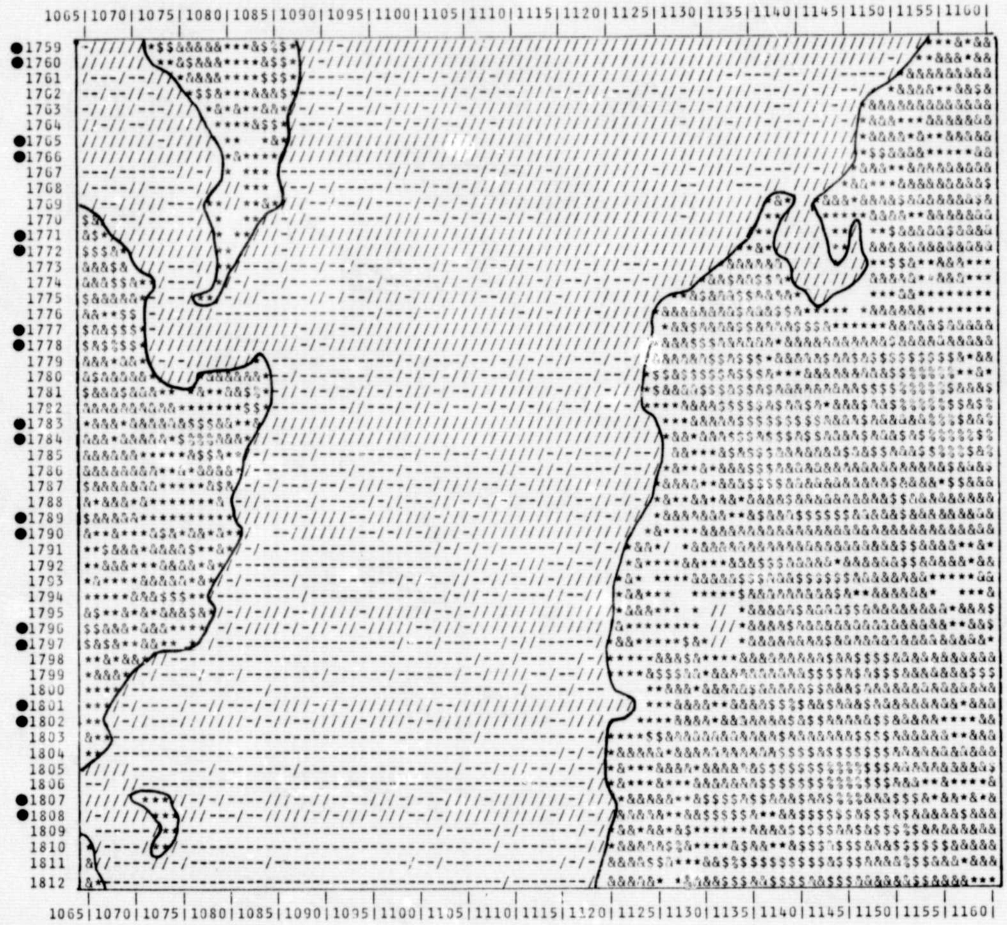


FIGURE B-11
QUANTICO, MITRE's CHANNEL 7
INTENSITY MAP, IMPROVED TAPES

C-5

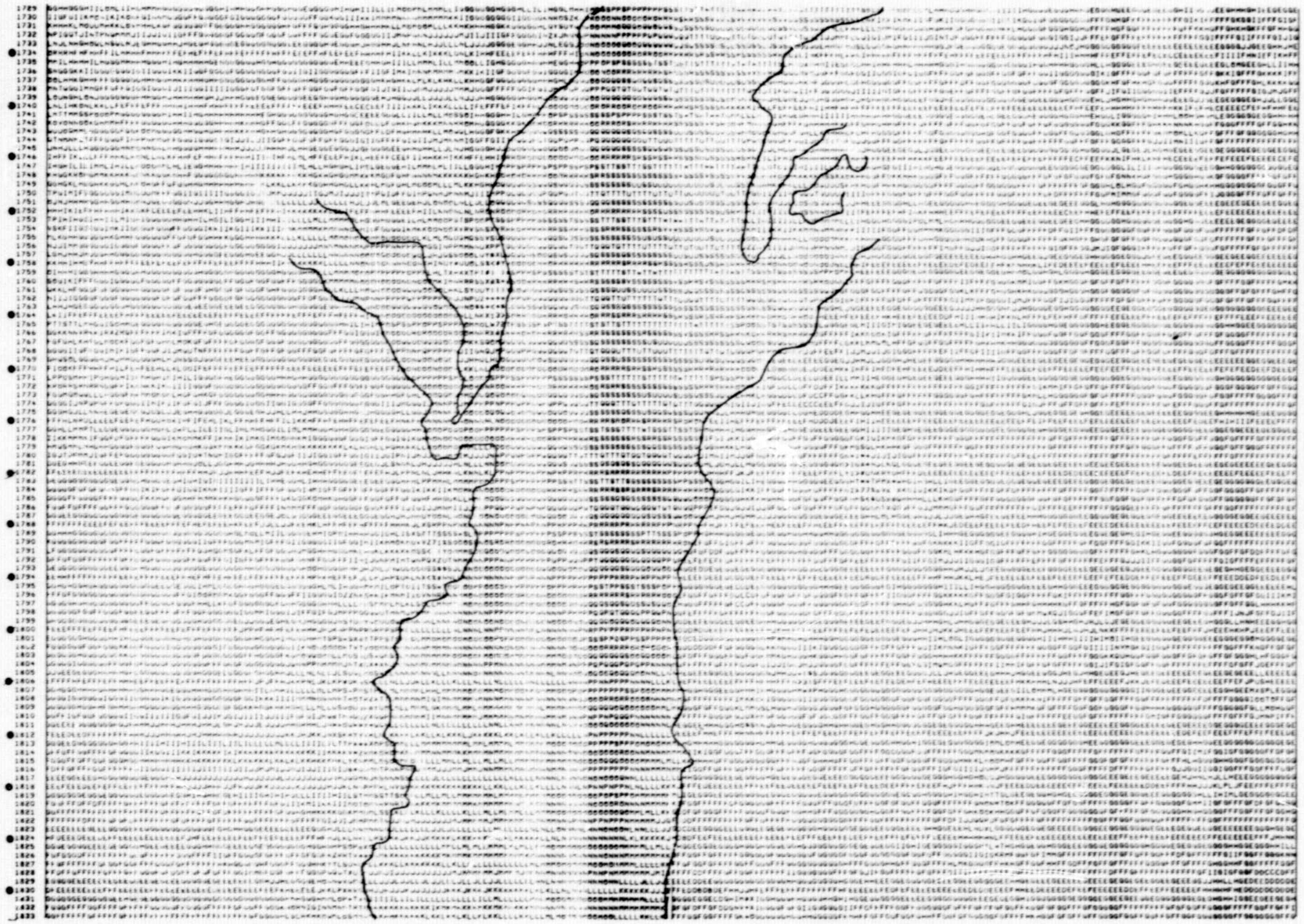


FIGURE B-12
QUANTICO, GE's CHANNEL 4
INTENSITY MAP, IMPROVED TAPES

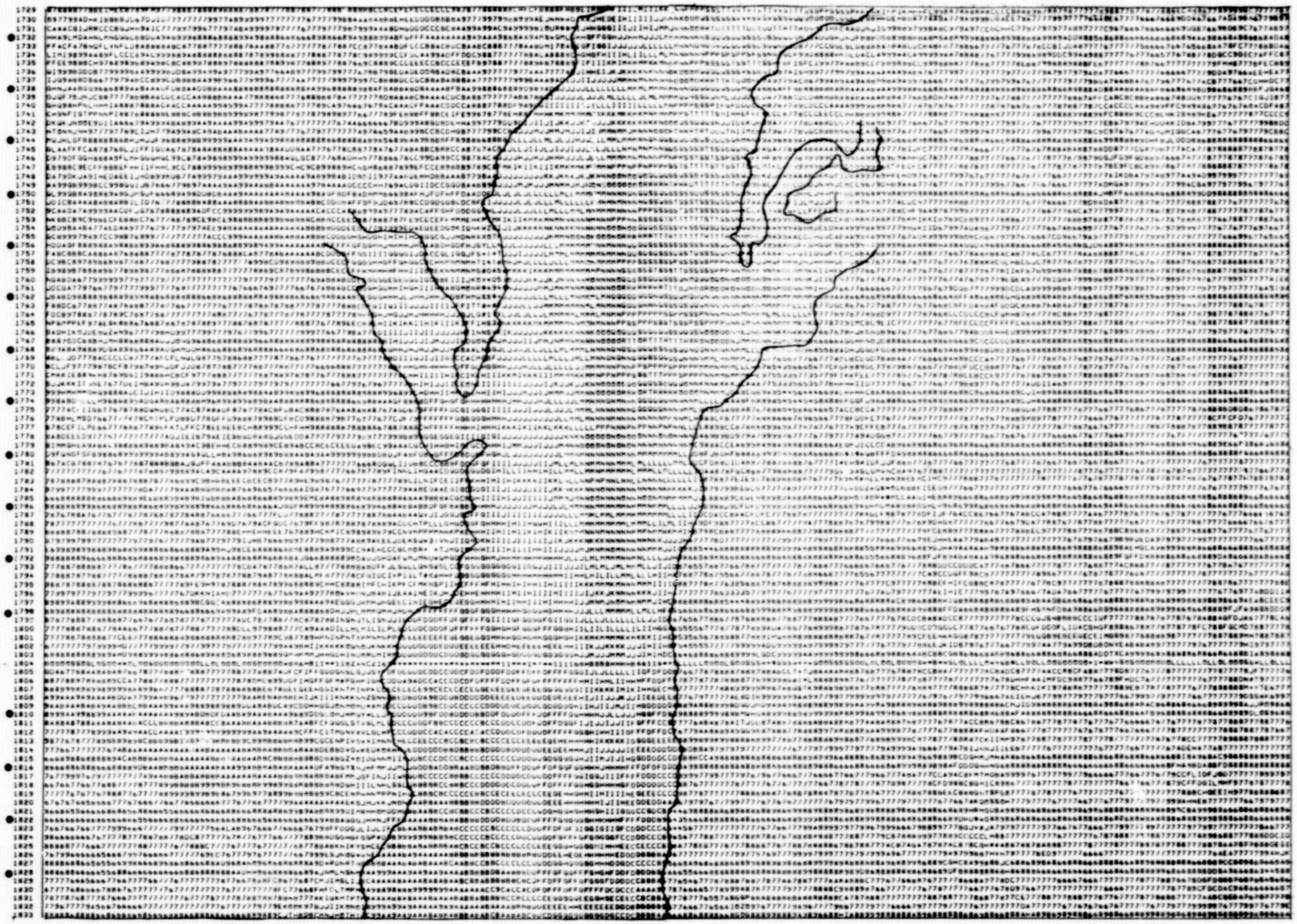


FIGURE B-13
QUANTICO, GE's CHANNEL 5
INTENSITY MAP, IMPROVED TAPES

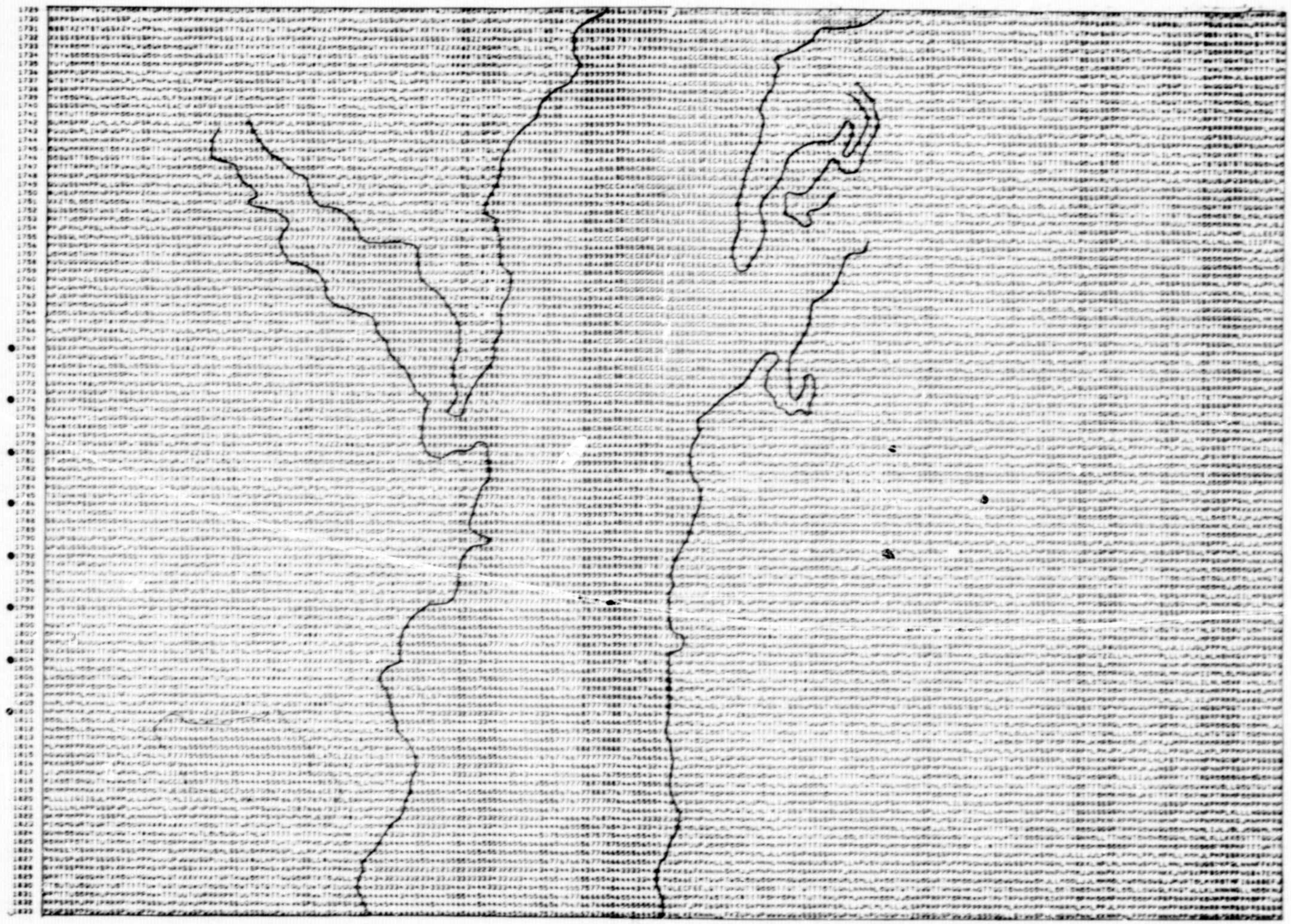


FIGURE B-14
QUANTICO, GE's CHANNEL 6
INTENSITY MAP, IMPROVED TAPES

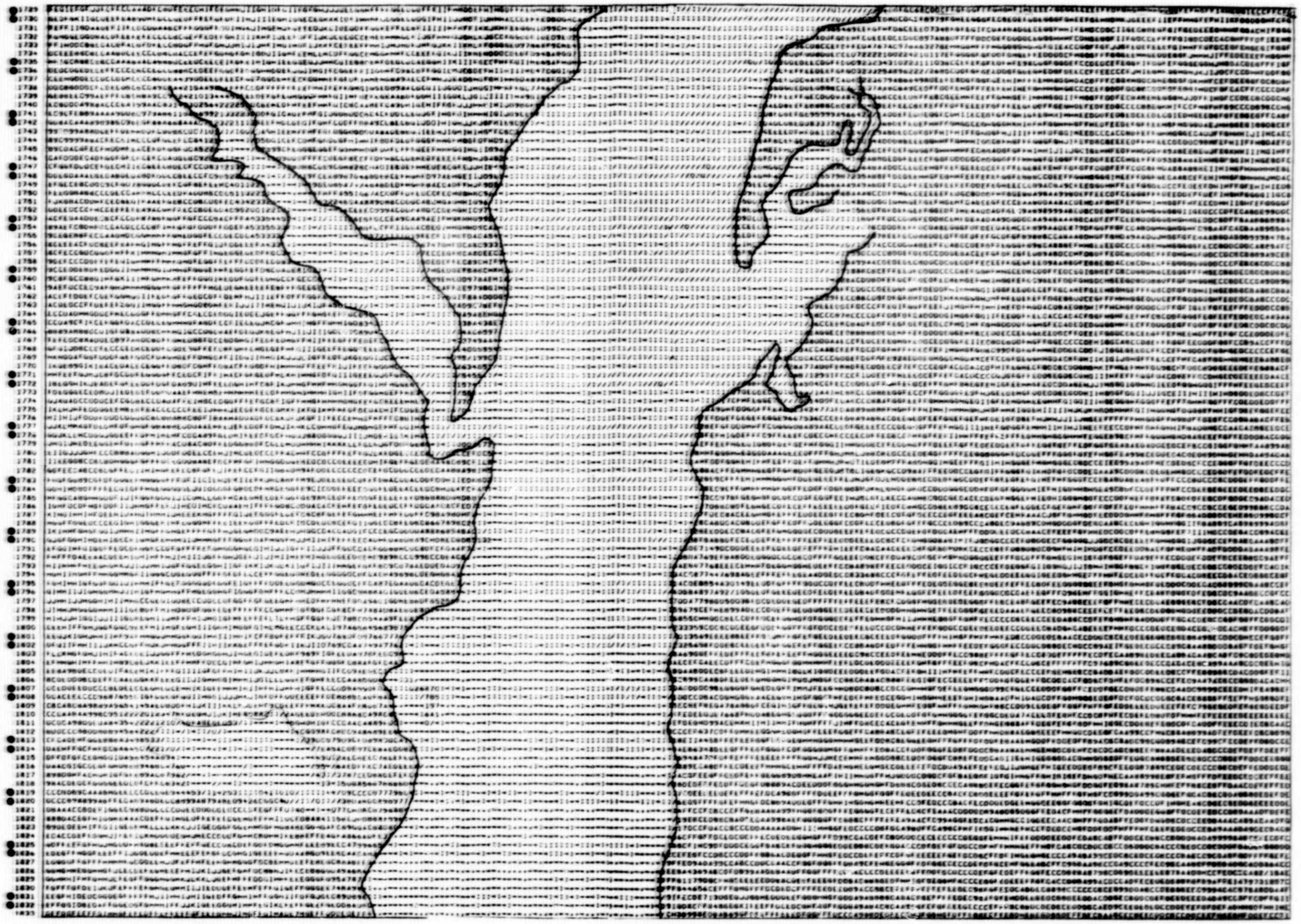


FIGURE B-15
QUANTICO, GE's CHANNEL 7
INTENSITY MAP, IMPROVED TAPES