UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

INTERAGENCY REPORT NASA-142

ANALYSIS OF MULTISENSOR DATA

(Interim Report IR1-3311)

by

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November 1968

Prepared by the Geological Survey for the National Aeronautics and Space Administration (NASA) under Contract No. W-12,589, Task No. 160-75-01-32-10. Work performed under USGS/Geographic Applications Program Contract No. 14-08-0001-11505 with Autometric Operation, Raytheon Company.

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ABSTRACT

This report represents the preliminary results achieved in the analysis of multisensor data acquired by NASA aircraft missions flown for the Geographic Applications Program of the USGS. While the principal analysis effort was concentrated on imagery taken during Mission #73 over test sites in Southern California, records acquired on missions over test sites at Phoenix, Chicago, Ashville, and New Orleans were also studied. The objectives of the analysis were: 1) to determine the relative capability of ten remote sensors in identifying the elements of information necessary in conducting geographic investigations in urban problems, land use, surface energy budget, and soil moisture; 2) to devise a format by means of which the cost effectiveness of the sensors used by the Principal Investigators can be derived; and 3) to analyse the multisensor imagery taken over test sites operated by the Office of Emergency Planning in order to determine the level of interpretable detail, to locate unique spectral signatures, to determine the applicability of each sensor to structural and functional analysis, and to determine the utility of the sensors in the analysis of man-made or natural disasters. Among the principal results achieved thus far are: 1) the development of Sensor Capability Matrices and approximately 50% completion of urban and land use analysis; 2) the completion of a prototype cost effectiveness format; and 3) completion of the OEP imagery analysis.

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1. INTRODUCTION

1.1 Purpose

The purpose of this report is to present the findings and preliminary conclusions thus far reached in the analysis of the Mission #73 multi-sensor data, and to outline the course of research planned for the future. The results herein presented are current to 31 October, at which time the analysis phase was approximately 40%, and the cost effectiveness phase 85%, complete.

1.2 General Approach

1.2.1 Urban Problems and Land Use

For these two portions of the analysis, detailed lists were drawn up of the elements of information that would have to be identified on the sensor records in order to carry out geographic studies. In a study of housing quality, for example, elements of information would include such things as the presence of litter, street lighting, building density, and others. These elements were placed in the column dimension of a two-dimensional matrix, and the ten sensors most used by the Principal Investigators were placed in the row dimension. The object of analysis, then, has been to determine which sensor or combination of sensors best provides the information needed. During this stage of the program, each analyst searched the imagery and records of each sensor at each scale and recorded whether it: 1) can identify; 2) cannot identify; or 3) can identify sometimes, in part, or relatively, each element of information. At the end of the analysis, the sensors will be ranked as to which is best, 2nd best, 3rd best, etc., by a consensus of the analysts.

It has been found in the course of the investigation that it is a useful heuristic procedure to actually conduct a study, such as housing quality determination, rather than to search the imagery at random. This method serves to limit and direct the search and to reveal, empirically, elements of information that may have been overlooked when the lists of elements were compiled.

1.2.2 Soil Moisture and Surface Energy Budget

In this phase of the analysis, efforts have so far been limited to determining the relations between soil moisture and temperature, and between moisture and land use.

1.2.3 Cost Effectiveness

A draft of a cost effectiveness format has been prepared which, though independently arrived at, bears a marked resemblance to the Sensor Capability Matrices compiled for urban analysis and land use. In completing this format, the Principal Investigators will be requested to attach weights both to the information elements they use and to the capability of the sensors to identify those elements.

1.2.4 Analysis of Office of Emergency Planning Imagery

This analysis has been completed, and since it will be published as a separate document, only the conclusions are included in this report.

2. DATA ANALYSIS

2.1 Urban Analysis

2.1.1 Objectives

Three objectives have been pursued in the course of analysis thus far: to investigate the utility of ten remote sensors for the identification of those geographic elements of information necessary for carrying out urban studies; to determine the relative merits of color and color IR film in studies of housing quality; and to determine the value of these two emulsions in detecting diseased and dying vegetation.

2.1.2 Approach to First Objective

Table I, The Sensor Capability Matrix for Urban Analysis, shows the ability of ten sensors to identify the elements of information needed in urban analysis. All of the imagery from Mission #73 was studied, as well as were selected records from NASA missions over Phoenix and Chicago, and imagery from the Autometric data bank. As can be seen in the Table, the sensors have so far been rated only as to whether they: 1) can identify; 2) cannot identify; or 3) can identify sometimes, in part, or relatively. Before the study has been completed, however, a consensus of the views of the analysts working with the records will rate them as to relative capability, listing them on a numerical scale from one to ten.

Following is a description of the results obtained using imagery flown on February 15, 1966, during Mission #19. The imagery described consists of two rolls of color infrared (8443) and two of color Ektachrome (8442), all at a scale of 1:6000.

Transportation Net

Identification of route types was easily accomplished on this imagery. Frequency of use could be determined with repetitive coverage, and a basic pavement condition survey would be possible. Determination of curbing condition was quite difficult, as was the plotting of all traffic light locations. Road and lane markings were easily discernible.

Traffic Congestion

All types and sizes of vehicles were identified on this imagery. Parking lot saturation studies were completed and ground speeds calculated for moving vehicles. Traffic flow patterns could be deduced.

TABLE I

SENSOR CAPABILITY MATRIX FOR
URBAN ANALYSIS

✓ = Can Identify
0 = Cannot Identify
X = Can Identify Sometimes, in Part
or Relatively

object size? photo-image scale?

GEOGRAPHIC STUDY AND INFORMATION ELEMENT	SENSOR									
	B&W	Col	CIR	SLR	Scat	Pass Mcrw Imag	UV	Ab. Spec	TV	IR
TRANSPORTATION NET										
kind of route (road, railroad, water)	✓	✓	✓	✓	0		X	0		X
number of channels (ship)	✓	✓	✓	✓	0		X	0		✓
tracks (count, not location)	✓	✓	✓	X	0	0	0	0		0
lanes	✓	✓	✓	X	0	0	X	0		X
access (frequency of)	✓	✓	✓	X	0		✓	0		✓
signal light	✓	✓	✓	0	0	0	0	0		0
pavement condition	✓	✓	✓	0	0	0	0	0		0
TRAFFIC CONGESTION										
vehicles	✓	✓	✓	X	0	0	0	0		X
automobiles	✓	✓	✓	X	0	0	0	0		0
trucks	✓	✓	✓	X	0	0	0	0		0
busses	✓	✓	✓	X	0	0	0	0		0
AIR AND WATER POLLUTION										
source of pollution										
chemical	X	✓	✓	0	0	0				
thermal				0						✓
extent of pollution										
chemical	X	✓	✓	0	0	0		✓		
thermal	X			0						✓

TABLE I (Cont'd.)

GEOGRAPHIC STUDY AND INFORMATION ELEMENT	SENSOR									
	B&W	Col.	CIR	SLR	Scat	Pass mcrw Imag	UV	Ab Spec	TV	IR
kind of pollution										
chemical	X	✓	✓	0	0	0		✓		X
thermal				0	0			0		✓
HOUSING QUALITY/SOCIO-ECONOMY										
dwelling type (single vs. multi-unit)	✓	✓	✓	0	0	0	0	0		0
vegetation (landscaping)	✓	✓	✓	0	0	0	0	0		X
litter	✓			0	0	0	0	0		0
lot size	✓	✓	✓	X		0	0	0		0
home size	✓	✓	✓	0		0	0	0		0
building density (roof area/total area	✓	✓	✓	X		0	0	0		0
vacant land	✓	✓	✓	X		0	X	0		✓
street condition	✓	✓	✓	0	0	0	0	0		0
street width	✓	✓	✓	X	0	0		0		✓
street pattern	✓	✓	✓	✓	0		✓		0	✓
street lighting	✓	✓	✓	0	0	0	0	0		0
traffic	✓	✓	✓	X	0	0	0	0		0
sidewalks & curbs	✓	✓	✓	0	0	0	0	0		0
community facilities	✓	✓	✓	X	0	0	0	0		X
pools and patios	✓	✓	✓	0	0	0	0	0		0
railroads	✓	✓	✓	✓	0			0		X
accessory buildings	✓	✓	✓	X	0	0	0	0		X
SUSCEPTIBILITY TO FIRE										
construction material	✓			0	0	0	0	0		
building density	✓	✓	✓	X			X	0		X

GEOGRAPHIC STUDY AND INFORMATION ELEMENT	SENSOR									
	B&W	Col.	CIR	SLR	Scat	Pass mcrw Imag	UV	Ab. Spec	TV	IR
SUSCEPTIBILITY TO FLOOD								0		
BARRIERS TO GROWTH										
transportation	✓	✓	✓	✓	0		✓	0		✓
river	✓	✓	✓	✓			✓	0		✓
lake	✓	✓	✓	✓			✓			✓
swamp	✓	✓	✓	✓				0		✓
topography	✓	✓	✓	✓				0		
zonal interfaces (urban terms)	✓	✓	✓	✓				0		✓
SHOPPING-INTENSITY & PATTERN										
vehicles in parking lot (no. of)	✓	✓	✓	X	0	0	0	0		0
people	✓	✓	✓	0	0	0	0	0		0
CENSUS UPDATING										
housing units	X	X	X	0	0	0	0	0		0
TIME/DISTRIBUTION OF POPULATION										
vehicles	✓	✓	✓	X	0	0	0	0		✓
people	✓	✓	✓	0	0	0	0	0		0
URBAN-RURAL INTERFACE	✓	✓	✓	✓		✓	✓	0		✓

Air and Water Pollution

Two factors limit detection of both classes of pollutants on this imagery. First, there are relatively few processing industries in Phoenix that produce air pollution, and no smoke plumes were detected. Secondly, the imagery shows evidence of recent rain, and the water in all streams and canals is heavily silt-laden, masking any pollution that might be present. Thus only a few effluents were detected, and these could not be traced for more than several feet. One pass covered the Phoenix sewage treatment plant, which has many evaporation ponds. Comparative analysis revealed little information differences between the two emulsions. The plant is adjacent to the Great Salt River, which was dry except for ground water lying in excavation holes. It appears that the discharge water and/or overflow materials from the sewage plant are allowed to stagnate in these channels, representing a health hazard. Flow rates and time periods would have to be checked before further conclusions could be reached. There is also one area along Central Street and the river that provides an excellent example of the way in which dry land-fill garbage can be eroded away and contaminate a stream.

Housing Quality/Socio-Economy

All of the elements listed in the included matrix were evident on this imagery. Again, however, determination of curb condition was sometimes questionable, as was street lighting. Litter such as paper and household garbage could not be seen, but abandoned cars, junk, lumber, and toys, were readily identified. Identification of garbage cans was only possible in a few isolated cases, but the general condition of alleys could be determined. Community facilities, pools, patios, etc., were all easily identifiable.

Susceptibility to Fire

Although the determination of construction materials was possible in many isolated cases, the distinction between flammable and non-flammable materials in small structures is usually difficult, unreliable, and based largely on inference.

Barriers to Growth

All barriers to the expansion of urban components can be identified on this imagery. The zonal interfaces are clearly defined, and accurate land use and housing category maps could be made.

Shopping-Intensity & Pattern

Shopping center vehicle counts and parking lot saturation studies can be accomplished on this imagery. Repetitive daily or seasonal coverage would be needed, however, in order to properly map the shopping patterns. People were imaged on both film types but were more readily resolved on the color IR (8443).

Census Updating

Census updating of housing units could accurately be accomplished on this imagery.

Time/Distribution of Population

All of the elements of information necessary for such a study were identified. To execute such a study, holiday, week end, and day and night coverage would be needed.

2.1.3 Approach to Second Objective

Urban Geographers working on the USGS/NASA program have been requesting and analyzing color infrared imagery of urban centers to determine if there is a correlative relationship between housing quality and lawn quality. It has been suggested that lawn vigor and condition would be a good indication of housing quality.

To check this, as well as other housing quality factors, three sections of single-family housing were selected for study. They include four blocks of high income housing, a nine-block, middle income development, and a five-block area of low income housing in the middle city.

The elements of information that were considered fall into three categories: the first comprises the number of houses, the additions to each home, the roof color and any additional buildings located on the property; the second embraces lawn care, landscaping and fencing; and the third is simply a count of luxury items, such as swimming pools, tennis courts, stables, etc.

The color Ektachrome (8442) imagery was interpreted first and the color IR next. Percentages were calculated for each element of information, following which the percent deviation between the elements found on the two emulsions was computed. These figures appear in Tables II through VII.

2.1.4 Approach to Third Objective

The first step in this analysis was to determine the individual condition of the trees in an orange orchard (Citrus Sinensis) in the Phoenix area. The orchard was selected on the basis of its showing a variety of tones and tone changes. Each tree was categorized as either good, partially diseased, totally diseased/dead, and removed. The subjective nature of this determination could not be avoided since ground truth was not available. The results of the interpretation are shown in Figure 1.

TABLE II

ANALYSIS OF HIGH INCOME HOUSING
COLOR

TEST SITE #29 (Phoenix)
MISSION #19
FILM TYPE: 8442
FRAMES: #6230-6232

ELEMENTS OF INFORMATION	BLOCK A	BLOCK B	BLOCK C	BLOCK D	TOTALS	PERCENTAGE
No. of Homes	16	8	8	6	38	-----
No. with Additions	5	1	2	1	9	23.6%
No. of Different Roof Colors	13	4	6	3	26	68.4%
No. with Outbuildings/Sheds	8	5	2	4	19	50 %
No. without Any Landscaping	0	0	0	0	0	-----
No. with Well Kept Front Lawns	8	3	1	4	16	42.1%
No. with Well Kept Back Lawns	4	2	0	3	9	23.6%
No. with Littered Appearances	0	0	0	0	0	-----
No. with Fencing and/or Hedges	16	8	8	6	38	100 %
No. with Swimming Pools	8	4	3	3	18	47.4%
No. with Above Ground Pools	0	0	0	0	0	-----
No. with Tennis/Handball/Basketball Courts	1	3	0	0	4	10.5%
No. with Stables	1	0	0	0	1	.26%

TABLE III

ANALYSIS OF HIGH INCOME HOUSING
COLOR IR

TEST SITE #29 (Phoenix)
MISSION #19
FILM TYPE: 8443
FRAMES: 6395-6397

ELEMENTS OF INFORMATION	BLOCK A	BLOCK B	BLOCK C	BLOCK D	PERCENTAGE	PERCENTAGE DIFFERENCE FROM COLOR
No. of Homes	16	8	8	6	-----	
No. with Additions	5	1	1	2	23.6%	SAME
No. of Different Roof Colors	13	5	8	4	79 %	+10.6%
No. with Outbuildings/Sheds	7	5	3	3	47.4%	- 2.6%
No. without Any Landscaping	0	0	0	0	-----	SAME
No. with Well Kept Front Lawns	6	3	1	4	36.8%	- 5.3%
No. with Well Kept Back Lawns	3	1	0	2	15.8%	- 7.8%
No with Littered Appearances	0	0	0	0	-----	SAME
No. with Fencing and/or Hedges	16	8	8	6	100 %	SAME
No. with Swimming Pools	8	4	3	3	47.4%	SAME
No. with Above Ground Pools	0	0	0	0	-----	SAME
No. with Tennis or Basketball/Handball	1	3	0	0	10.5%	SAME
No. with Stables	1	0	0	0	.26%	SAME

TABLE IV

TEST SITE #29 (Phoenix)
MISSION #19
FILM TYPE: 8442
FRAMES: #6216-6218

ANALYSIS OF MIDDLE INCOME HOUSING
COLOR

ELEMENTS OF INFORMATION	BLOCK A	BLOCK B	BLOCK C	BLOCK D	BLOCK E	BLOCK F	BLOCK G	BLOCK H	BLOCK I	TOTALS	PERCENTAGE
No. of Homes	9	26	17	32	41	44	45	48	33	295	-----
No. with Additions	5	9	2	2	16*	8	8	14	9	73	24.8%
No. of Different Roof Colors	1	4	1	0	2	2	0	0	0	10	3.4%
No. with Outbuildings/Sheds	0	2	1	8	3	6	6	10	3	39	13.4%
No. without Any Landscaping	0	0	1	0	1	0	0	1	0	3	1.1%
No. with Well Kept Front Lawns	3	7	4	6	3	10	11	5	5	54	18.3%
No. with Well Kept Back Lawns	1	2	3	4	4	6	5	3	4	32	10.8%
No. with Littered Appearances	1	0	0	0	0	2	1	0	1	5	1.7%
No. with Fencing/Hedging	9	18	15	27	31	43	39	39	26	247	83.8%
No. with Swimming Pools	1	2	2	2	0	5	2	0	3	17	5.8%
No. with Above Ground Pools	0	1	0	1	1	0	1	2	0	6	2.0%

*2 Being Built

TABLE V

ANALYSIS OF MIDDLE INCOME HOUSING
COLOR IR

TEST SITE #29 (Phoenix)
MISSION #19
FILM TYPE: 8443
FRAMES: 6384-6386

ELEMENTS OF INFORMATION	BLOCK A	BLOCK B	BLOCK C	BLOCK D	BLOCK E	BLOCK F	BLOCK G	BLOCK H	TOTALS	PERCENTAGE	PERCENTAGE DIFFERENCE FROM COLOR
No. of Homes	9	26	17	32	41	44	48	33	295	-----	
No. with Additions	7	8	2	8	14*	14	12	14	88	29.8%	+5. %
No. of Different Roof Colors	1	4	1	0	1	1	0	0	9	3. %	- .4%
No. with Outbuildings/Sheds	0	5	2	6	2	2	5	4	28	9.5%	-3.9%
No. without Any Landscaping	0	0	0	0	0	1	0	1	2	.67%	-.43%
No. with Well Kept Front Lawns	1	7	1	4*	2	3	3	4	35	11.9%	-6.4%
No. with Well Kept Back Lawns	2	2	1	4	4	4	3	4	28	9.5%	-1.3%
No. with Littered Appearances	1	0	0	1	0	2	0	1	5	1.7%	SAME
No. with Fencing and/or Hedges	7	18	13	26	34	42	32	24	234	79.5%	-4.3%
No. with Swimming Pools	1	2	2	2	0	5	0	3	17	5.8%	SAME
No. with Above Ground Pools	0	1	0	1	1	0	2	0	6	2. %	SAME

TEST SITE #29 (Phoenix)
MISSION #19
FILM TYPE: 8442
FRAMES: #6188-6190

TABLE VI

ANALYSIS OF LOW INCOME HOUSING COLOR

ELEMENTS OF INFORMATION	BLOCK A	BLOCK B	BLOCK C	BLOCK D	BLOCK E	TOTALS	PERCENTAGE
No. of Homes	21	19	25	26	21	112	14.3%
No. with Additions	5	4	3	2	2	16	53.5%
No. of Different Roof Colors	15	9	13	15	8	60	46.8%
No. with Outbuildings/Sheds	12	8	11	12	9	52	
No. without Any Landscaping	5	4	3	3	3	18	16.1%
No. with Well Kept Front Lawns	4	0	0	2	1	7	6.2%
No. with Well Kept Back Lawns	1	0	0	0	0	1	.89%
No. with Littered Appearances	10	8	5	2	3	28	25.2%
No. with Fencing and/or Hedges	15	13	19	12	10	69	62 %
No. with Swimming Pools	0	0	0	0	0	0	-----
No. with Above Ground Pools	0	0	0	0	0	0	-----

TABLE VII

TEST SITE #29 (Phoenix)
MISSION #19
FILM TYPE: 8443
FRAMES: #6357-6358

ANALYSIS OF LOW INCOME HOUSING
COLOR IR

ELEMENTS OF INFORMATION	BLOCK A	BLOCK B	BLOCK C	BLOCK D	BLOCK E	TOTALS	PERCENTAGE	PERCENTAGE DIFFERENCE FROM COLOR
No. of Homes	21	18	23	26	20	108	-----	
No. with Additions	4	3	3	6	2	18	16.6%	+ 2.3 %
No. of Different Roof Colors	*	--	--	--	--	--	-----	-------
No. with Outbuildings/Sheds	10	9	14	12	11	56	51.8%	+ 5.0 %
No. without Any Landscaping	4	5	2	0	5	16	14.8%	- 1.3 %
No. with Well Kept Front Lawns	1	1	0	2	0	4	3.7%	- 2.5 %
No. with Well Kept Back Lawns	0	1	1	1	0	3	2.8%	+ 1.91%
No. with Littered Appearances	13	10	6	5	7	41	37.9%	+12.7 %
No. with Fencing and/or Hedges	10	7	17	15	9	58	53.6%	- 8.4 %
No. with Swimming Pools	0	0	0	0	0	0	-----	
No. with Above Ground Pools	0	0	0	0	0	0	-----	

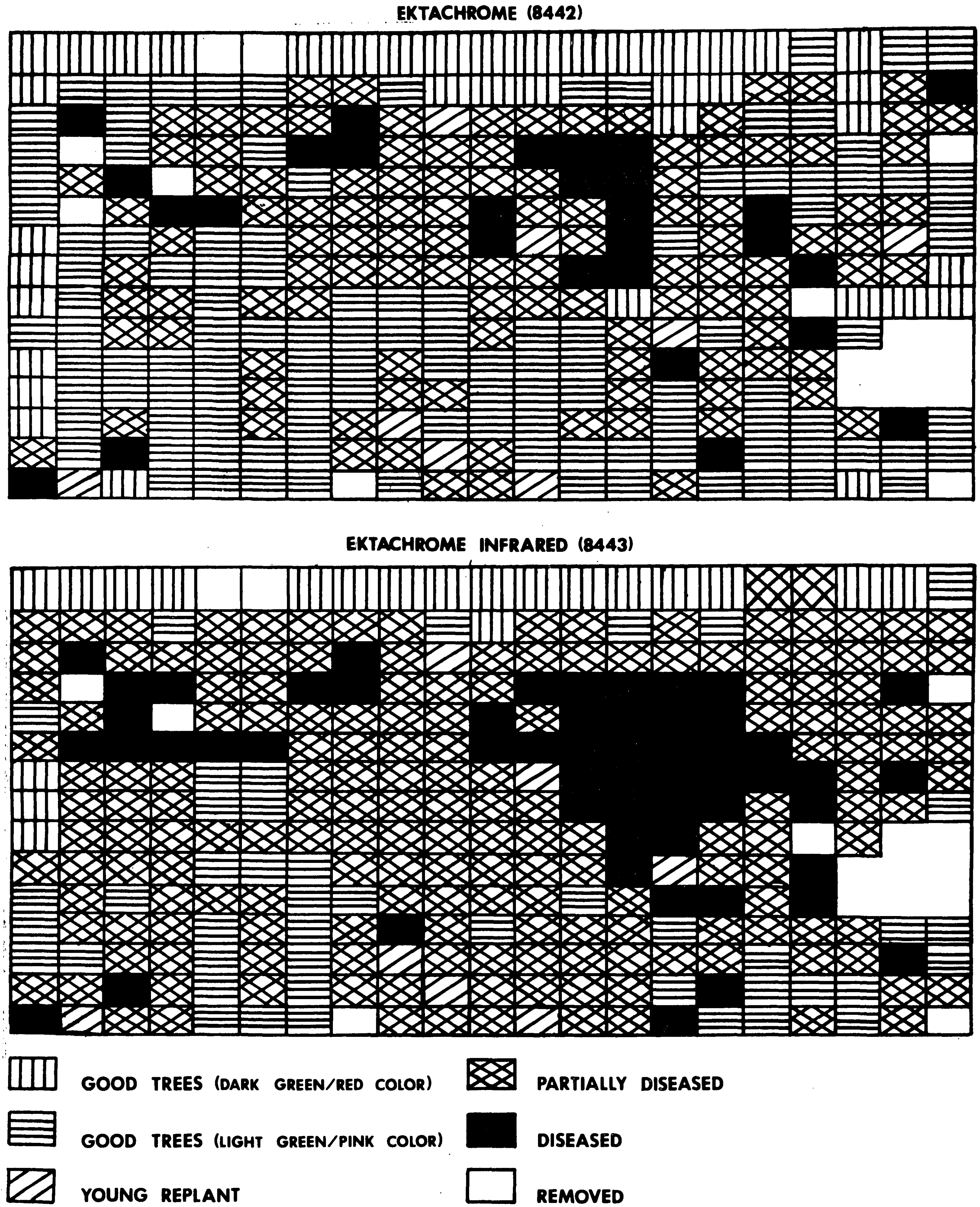

FIGURE 1 COMPARATIVE ANALYSIS OF A CITRUS GROVE UNDER STRESS

It was found by visual examination that the IR did have a definite advantage over color in the detection of tree disease. Diseased trees that were not readily apparent on the color imagery were easily detectable on the IR. Below is a summary of Figure 1.

	Tree Class	Apparent Tone	Total	Percent of Total*
Color	Good	Dark Green	36	11.8
	Good	Light Green	113	37.3
	Partially Diseased	Brownish Yellow	110	36.2
	Completely Diseased/Dead	Brown	28	9.2
	Removed		9	2.9
	Young Replant	Light Green	8	2.6
IR	Good	Red	20	6.6
	Good	Pink	42	13.8
	Partially Diseased	Brownish Pink	172	57.0
	Completely Diseased/Dead	Brown	55	16.5
	Removed		8	2.6
	Young Replant	Pink	7	2.5

*Percentage based on 304 trees. Trees covered by shadows on one emulsion or the other were not counted.

IR photography shows a significant increase in the number of partially diseased trees which were classified as good on the color photography. Measurements were made with the microdensitometer, and Figure 2 shows representative densitometric traces of a row of trees. The density of each tree classification was determined and statistically analyzed. The results are summarized in Figure 3.

The spectral sensitivities of the film types used are given in Figure 4. Color film is filtered to eliminate wavelengths below approximately .4 microns. Color infrared film is exposed through a Wratten 12 filter which cuts off wavelengths below approximately .5 microns. The transfer of color information by these films is given below.

	Spectral Region	Blue	Green	Red	Infrared
Kodak Ektachrome Aero Film	Normal Color film sensitivities	Blue	Green	Red	
	Color of the Dye Layers	Yellow	Magenta	Cyan	
	Resulting Color in Photograph	Blue	Green	Red	
Kodak Ektachrome Infrared Aero Film	Sensitivities with Yellow Filter		Green	Red	Infrared
	Color of the Dye Layers		Yellow	Magenta	Cyan
	Resulting Color in Photograph		Blue	Green	Red

Figure 5 shows the reflectance properties of healthy green vegetation. Note that the reflectance is greatest in the infrared, where about 40% of the energy is reflected, compared to the reflectance within the spectral band of panchromatic photography (with haze filter .52- .65 microns), where only about 10% of the total reflectance occurs. For diseased and dying vegetation spectral reflectance changes drastically in the infrared. After a branch is cut or becomes diseased, the reduction of transpiration of water from the leaves immediately reduces the reflectance in the infrared.* The visible reflectance changes much later.

It was noticed in the course of this study that, by viewing the IR imagery through a Wratten 15 (minus blue) filter, red tone discrimination was enhanced and overall viewing appeared to improve. This is partly explained by the fact that, by eliminating the blue, the overall tone of the photograph is shifted to a region where the human eye operates more efficiently. This was corroborated by densitometric measurements which showed that density differences were enhanced by using a yellow filter. However, there was an increase in the overall density level.

2.2 Land Use

2.2.1 Objective

The objective was to determine the capability of the ten sensors in identifying the elements of information needed in land use studies.

2.2.2 Approach

The sensor records were searched by the analysts for the information elements, and, as was done for urban problems, were rated as to their capability to identify, not identify, or to identify sometimes, in part, or relatively. The current status of the results is shown in Table VIII, The

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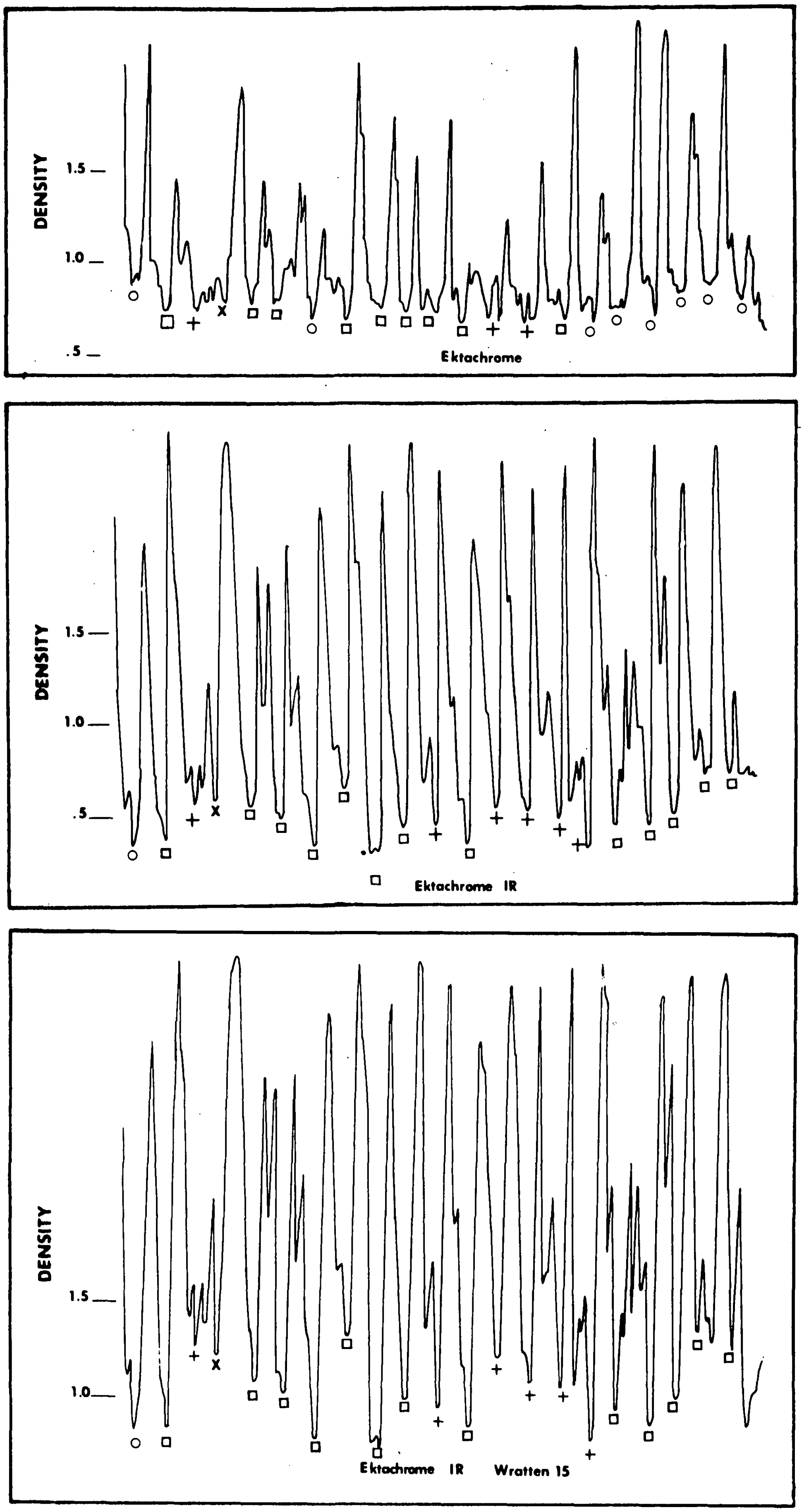
*Jensen, N., 1968, Optical and Photographic Reconnaissance Systems: John Wiley and Sons, Inc., New York, p. 70.



These traces were made across the fifth row (from the top) of citrus trees depicted in Figure 1.

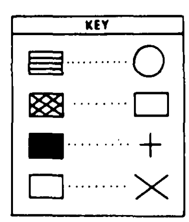


FIGURE 2 REPRESENTATIVE DENSITOMETRIC TRACES ACROSS A ROW OF CITRUS TREES

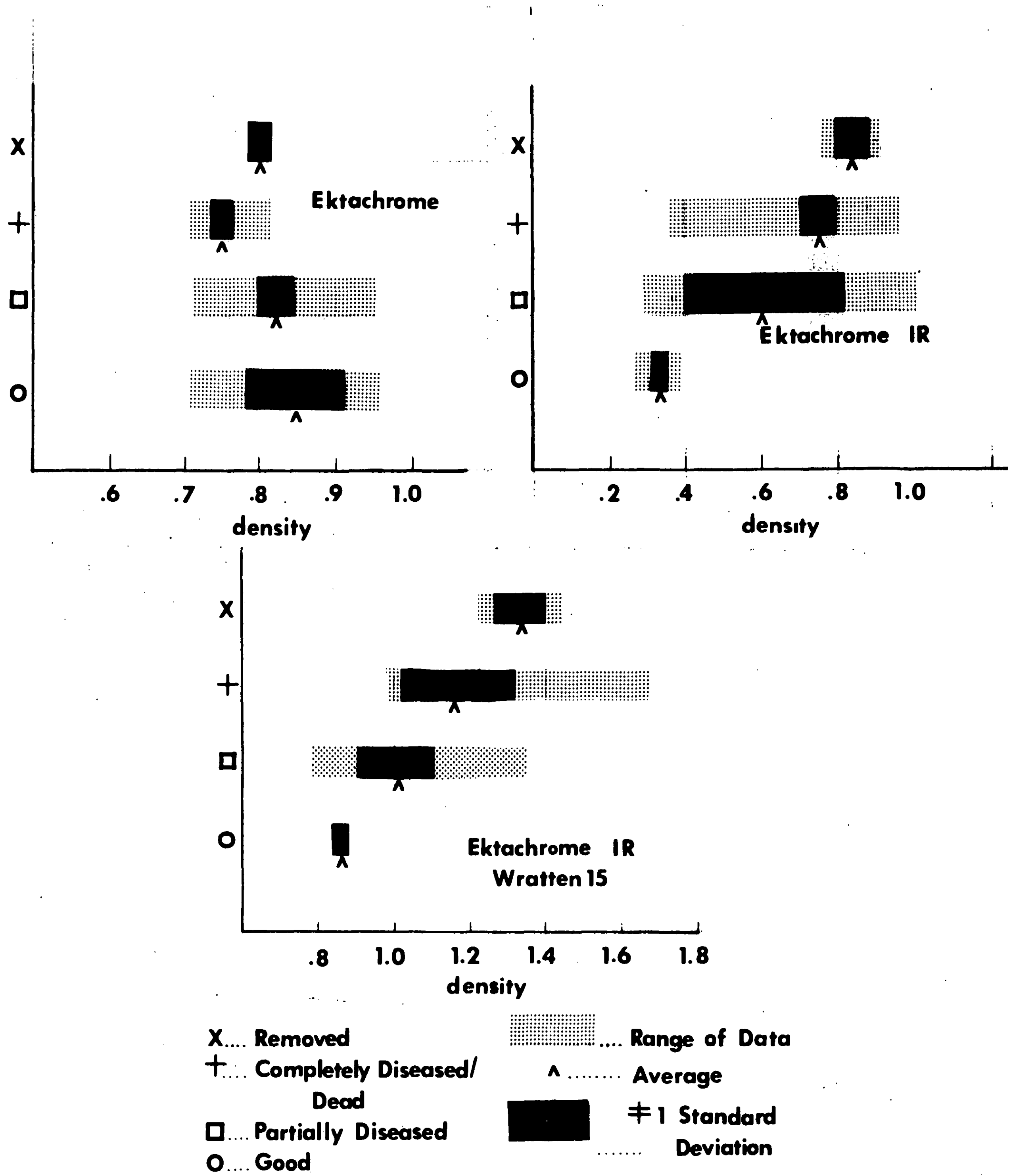


FIGURE 3 DISTRIBUTION OF DENSITY READINGS OVER ORCHARD

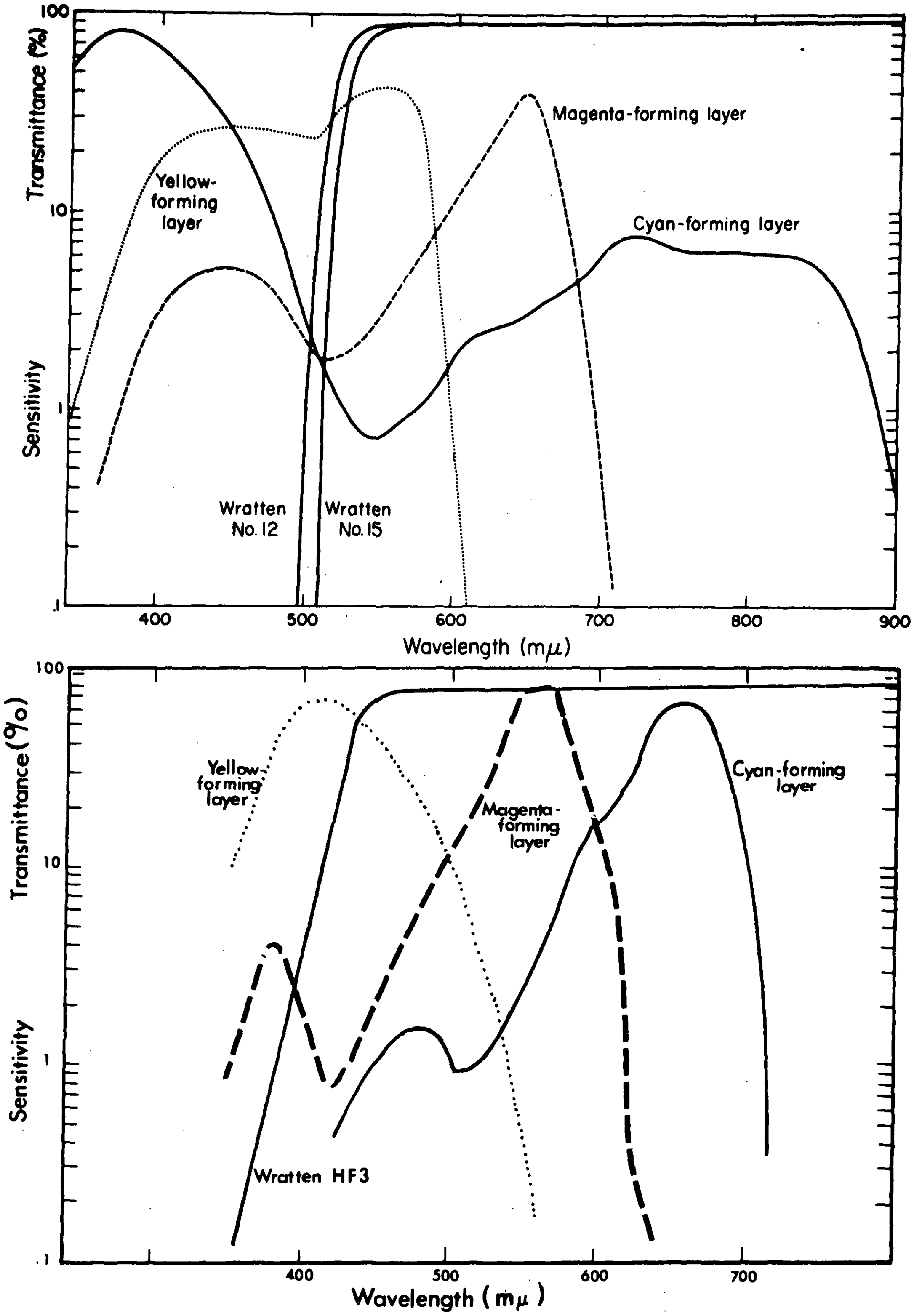


FIGURE 4 SPECTRAL SENSITIVITIES OF FILM TYPES USED

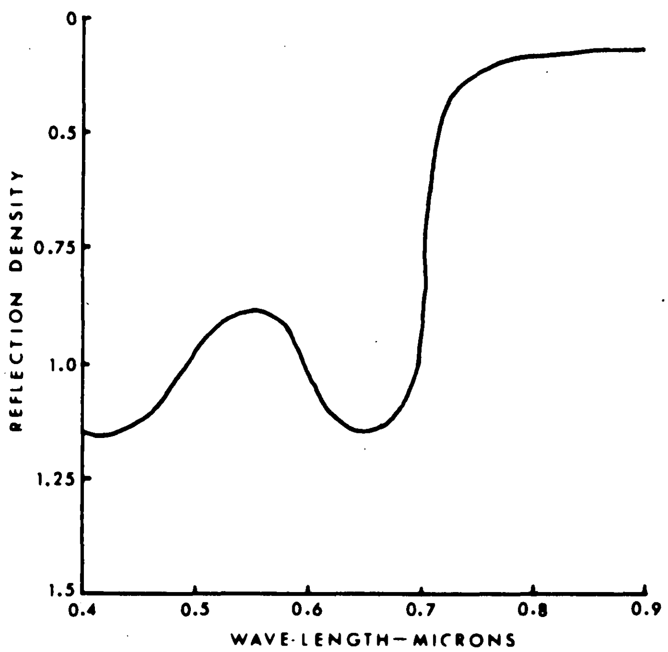


FIGURE 5 REFLECTANCE PROPERTIES OF HEALTHY GREEN VEGETATION

TABLE VIII

SENSOR CAPABILITY MATRIX
FOR LAND USE

√ = Can Identify
0 = Cannot Identify
X = Can Identify Sometimes, in Part
or Relatively

INFORMATION ELEMENT	SENSOR									
	B&W	Col.	CIR	SLR	Scat	Pass mcrw Imag	UV	Ab. Spec	TV	IR
AGRICULTURE	√	√	√	√			√			√
Orchards, Includes DTP & CTR, ETC	√	√	√				0			√
Vineyards	√	√	√				0			X
Horticulture or Floriculture (CTR)	√	√	√				0			X
High-Intensity Cropland	√	√	√				0			X
Cropland & Cropland Pasture	√	√	√				0			X
Cattle Feed Lot	√	√	√							
Permanent Pasture	√	√	√							
Inactive Agric. Lands	√	√	√				0			0
Specialty Farms	X	X	X							
Dairy Operations	√	√	√							
Poultry Operations	√	√	√							
Active Farmsteads	X	X	X							
Irrigation Canals	√	√	√				0			√
Abandoned Irrigation Canals	X	X	X				0			X
FOREST LAND	√	√	√	√			√			√
Forest Brushland & Brush Pasture	√	√	√				X			√
Forest Lands	√	√	√							
Plantations	√	√	√							
WATER	√	√	√	√			√			√

TABLE VIII (Cont'd.)

INFORMATION ELEMENT	SENSORS								
	B&W	Col.	CIR	SLR	Scat	Pass mcrw Imag	UV	Ab. Spec	TV	IR
Natural Ponds & Lakes	✓	✓	✓	✓						✓
Artificial Ponds, Lakes & Constructed Reservoirs	✓	✓	✓	✓			X			✓
Streams & Rivers	✓	✓	✓	✓			X			✓
Meadows, Marshes, Shrub Wetlands, & Bogs	✓	✓	✓	X						X
Wooded Wetlands	✓	✓	✓	0						✓
Marine Lakes, Rivers, & Seas	✓	✓	✓	✓						✓
URBAN	✓	✓	✓	✓		X	✓			✓
Tending Toward Intensive Use	✓	✓	✓				0			X
Intensive Use Under Construction	✓	✓	✓	0						
RESIDENTIAL	✓	✓	✓	✓			✓			✓
High Density	✓	✓	✓	X			X			✓
Medium Density	✓	✓	✓	X			X			✓
Low Density	✓	✓	✓	X			0			X
Residential Estates	✓	✓	✓	X						0
Strip Development	✓	✓	✓	X			0			X
Rural Hamlet	✓	✓	✓	X			X			✓
Farm Labor Camp	X	X	X							
Cottages & Vacation Homes (Along Lakes & Rivers)	✓	✓	✓	X						X
Apartment Buildings	✓	✓	✓	0			0			0
Trailer Parks	✓	✓	✓	X			0			0
Rural Non-Farm Res. - Prev. Used as Farm Headquarters	X	X	X	0			0			0
Rural Non-Farm Res. - Prev. Used as Farm Headquarters	X	X	X	0			0			0
COMMERCIAL & INDUSTRIAL	✓	✓	✓	✓			✓			✓
Urban (Central Business Section)	✓	✓	✓	X			✓			✓

TABLE VIII (Cont'd.)

INFORMATION ELEMENT	SENSORS									
	B&W	Col.	CIR	SLR	Scat	Pass mcrw Imag	UV	Ab. Spec	TV	IR
Shopping Centers	✓	✓	✓	X						X
Strip Development	✓	✓	✓	X			X			X
Commercial Resorts	X	X	X	X						0
Light Mfg. & Industrial Parks	✓	✓	✓	X			0			X
Heavy Mfg.	✓	✓	✓	X			0			X
OUTDOOR RECREATION	✓	✓	✓	X			X			X
Golf Courses	✓	✓	✓	X			0			✓
Ski Areas & Other Winter Sports	✓	✓	✓	X						
Pub. & Coml. Swimming Pools & Developed Beaches	✓	✓	✓	X						X
Marinas, Yacht Clubs, & Boat Launching Sites	✓	✓	✓	X						X
Campgrounds	X	X	X							
Stadiums, Drive-In Theaters, Coml. Race Tracks, Amusement Parks,				✓						
Museums	✓	✓	✓	0			0			X
Fairgrounds	✓	✓	✓	X			0			0
Pub. Parks - City, Town & State	✓	✓	✓	X						✓
Rifle, Skeet Shooting & Archery	✓	✓	✓	0			0			0
Other Recreational Facilities										
EXTRACTIVE INDUSTRY	✓	✓	✓	X			X			✓
Stone Quarries	✓	✓	✓	X						X
Sand & Gravel Pits	✓	✓	✓	X						X
Metallic Mineral Extraction	X	X	X	X						
Oil & Gas	X	X	X	X						0
Salt	X	X	X							
Other										

TABLE VIII (Cont'd.)

INFORMATION ELEMENT	SENSORS									
	B&W	Col.	CIR	SLR	Scat	Pass mcrw Imag	UV	Ab. Spec	TV	IR
Categories -										
Unimproved, Gravel, & Minor Paved Roads	✓	✓	✓	0			0			X
2-Lane Hwy. & 3-Lane Hwy.	✓	✓	✓	X			0			X
4-Lane Hwy.	✓	✓	✓	X			0			X
Divided Hwy., Usually 4 Lanes (With Access)	✓	✓	✓	X			0			X
Limited Access Hwy.	✓	✓	✓	X						✓
Limited Access Hwy. Interchange	✓	✓	✓	X						✓
Urban Street	✓	✓	✓	X			X			✓
Railway -	✓	✓	✓	✓			X			X
Abandoned R-O-W	X	X	X	0						X
Active Track	✓	✓	✓	0			0			X
Switching Yards	✓	✓	✓	X						✓
Stations & Structures	✓	✓	✓	X						X
Spurs	✓	✓	✓	X			0			X
Airport -	✓	✓	✓	✓			X			X
Personal & Flying Farmer	X	X	X							
Non-Commercial	✓	✓	✓	X						X
Coml. Fixed-Base Operator; Charter, Etc.	✓	✓	✓	X						✓
Airline, Scheduled	✓	✓	✓	✓						✓
Military	✓	✓	✓	X						✓
Heliport	✓	✓	✓	✓						X
Seaplane Base	✓	✓	✓	X						0
Barge Canal -	✓	✓	✓	X						X
Channel	✓	✓	✓	X						✓

TABLE VIII (Cont'd.)

INFORMATION ELEMENT	SENSORS									
	B&W	Col.	CIR	SLR	Scat	Pass mcrw Imag	UV	Ab. Spec	TV	IR
Abandoned	X	X	X	0						X
PUBLIC AND SEMI-PUBLIC										
Educational Inst.	✓	✓	✓	X			0			X
Religious Inst.	X	X	X	0			0			0
Health Inst.	X	X	X	0			0			0
Military Bases & Armories	✓	✓	✓	X			0			X
Solid Waste Disposal	✓	✓	✓	0						X
Water Supply Treatment Facilities	✓	✓	✓	0						X
Sewage Treatment Plants	✓	✓	✓	0						X
Cemeteries	✓	✓	✓	0						X
Flood Control Structures	✓	✓	✓	X						✓
Correctional Inst.	X	X	X	0						0
Road Equip. Centers	X	X	X	0						0
Forest Fire Towers	X	X	X	0						0
Urban Fire Stations	✓	✓	✓	0			0			0
Rural Fire Stations	✓	✓	✓	0						
State Agency Facilities	X	X	X	0						0
Welfare Centers, County Farms	X	X	X	0						0
TRANSPORTATION	✓	✓	✓	X			X			X
Highway -	✓	✓	✓	X			X			X
Interchanges	✓		✓	X						✓
Limited Access R-O-W	✓		✓	X						✓
Service & Terminal Facilities	✓		✓	X			0			0
Other Areas Connected with Hwy.	✓		✓	X			0			X
Bus, Motor Freight, & Auto Parking	✓		✓	X			0			X

TABLE VIII (Cont'd.)

INFORMATION ELEMENT	SENSORS									
	B&W	Col.	CIR	SLR	Scat	Pass mcrw Imag	UV	Ab. Spec	TV	IR
Lock & Water Control Structures	✓	✓	✓	✓						X
Abandoned Channel	✓	✓	✓	0						X
Marine Shipping (Ocean, Great Lakes, Seaway) -	✓		✓	✓			X			✓
Port or Dock Facilities	✓	✓	✓	✓						✓
Shipyards & Dry Docks	✓	✓	✓	✓						✓
Locks & Water Control Structures	✓	✓	✓	X						X
COMMUNICATIONS & UTILITIES	✓	✓	✓	X			X			X
Pumping Stations: Electrical Substations	✓	✓	✓	X						X
TV-Radio Tower	✓	✓	✓	0						0
Microwave: LF Navigation	X	X	X							
Gas & Oil - Long Distance Transmission (Pipe)	✓	✓	✓	0						X
Electric Power - Long Distance Transmission	✓	✓	✓	X			0			0
Water - Long Distance Transmission	X	X	X	0			0			0
Telephone - Long Distance	X	X	X	0						
NONPRODUCTIVE LAND	✓	✓	✓	X			X			X
Sand	✓		✓	X			X			X
Rock	✓		✓	X			X			X

Sensor Capability Matrix For Land Use. As the analysis phase progresses, entries will continue to be made in the matrix until it has been completed. It is not expected that all of the elements of information will be found in the Mission #73 area, so, as was done with the Urban Analysis Matrix, records from previous NASA missions and from Autometric's data bank will be used. In the final form of the matrix, sensor capability will be rated on a one-to-ten basis.

2.3 Soil Moisture and Surface Energy Budget

2.3.1 Objective

The objective, in the case of soil moisture, was to establish the relationship between ground measurements of soil moisture and image color and density. In the case of surface energy budget, the objective was to compare the ground measurements of temperature, reflectivity, and emissivity with image color and density.

2.3.2 Approach

Lacking as yet a diapositive of the thermal IR imagery or prints of the imaging passive microwave radiometer, the approach to this portion of the study has thus far been limited to determining the percentile distribution of soil moisture content, establishing the correlation between soil moisture and soil temperature, and relating soil moisture to land use. The subjective relationship of moisture, temperature, emissivity, and reflectivity to image color and density has not yet been undertaken.

2.3.3 Percentile Distribution of Soil Moisture

The distribution of moisture content in the seventy-one soil samples taken in the Jackson Street and Niland-Calipatria areas is shown in Table IX and Figure 6. In both of these illustrations the extreme aridity of the great bulk of the samples is brought out, as well as is the very high moisture content of a small number of samples. Figure 6 exhibits a surprisingly smooth curve, interrupted only in the 20-25% range.

TABLE IX

PERCENTILE DISTRIBUTION OF SOIL MOISTURE

Moisture Content	No. Samples	% Samples
<1%	36	50.7
≤1<5	16	22.5
>5≤10	8	11.2
>10≤15	2	2.8
>15≤20	1	1.4
>20≤25	5	7.4
>25≤30	1	1.4
>30≤35	1	1.4
>35≤40	1	1.4
TOTALS	71	100.2

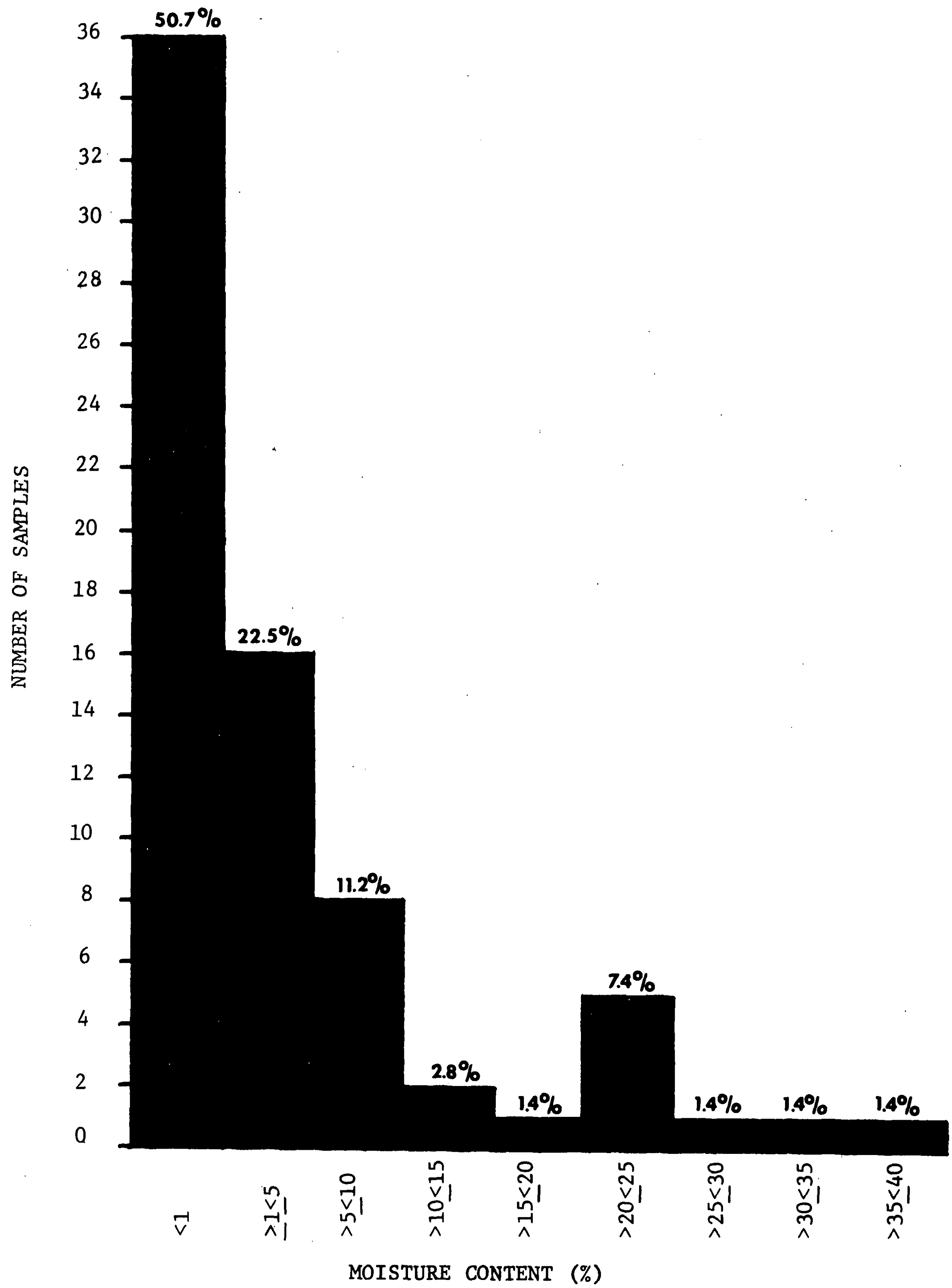


FIGURE 6 HISTOGRAM OF PERCENTILE DISTRIBUTION OF MOISTURE

2.3.4 Correlation Between Soil Moisture and Soil Temperature

Temperatures were taken at the sites of thirty-five of the seventy-one soil samples. They were taken with bulb thermometers at a depth of 1/4 inch below the surface. There is no uniformity among these samples as to conditions of illuminance, since in some areas, such as plowed fields, there was no shade, while in others, such as date palm groves, there was no sun. Even so, a general correlation was found to obtain, as is shown in Figure 7. These measurements were taken between 11:00 and 12:00 a.m. local time. It would be expected that, later in the afternoon, after peak temperatures have been reached, the migratory response of moisture to temperature would be more complete and the correlation between the two somewhat better.

2.3.5 Correlation Between Soil Moisture and Land Use

Except that the land use categories of mesquite and weeds are very dry (0.10% average), and date palm groves are very moist (19.3% average), there is no good correlation between soil moisture and land use. This is to be expected in irrigated areas, where the soils under most crops vary from fully saturated to moderately dry on a regular basis.

2.4 Cost Effectiveness

2.4.1 Objective

The objective of this portion of the study was to design a format into which the data thus far acquired for the Principal Investigators could be placed in order to arrive at a quantitative economic measure of the utility of selected remote sensors in providing data useful to geographers.

2.4.2 Approach

The approach taken was to compare the costs of alternate methods of assessing information elements relevant to specific geographic studies with the effectiveness of each method in supplying the information elements.

For each information element, the Principal Investigator will be asked to assess the effectiveness of each sensor or sensor combination in imaging that element. The overall effectiveness of the sensor is then calculated from the individual effectivenesses as follows:

$$E_{jk} = \sum_i w_i e_{ijk}$$

where

E_{jk} = Effectiveness of the k^{th} sensor or sensor combination in providing data at resolution level j

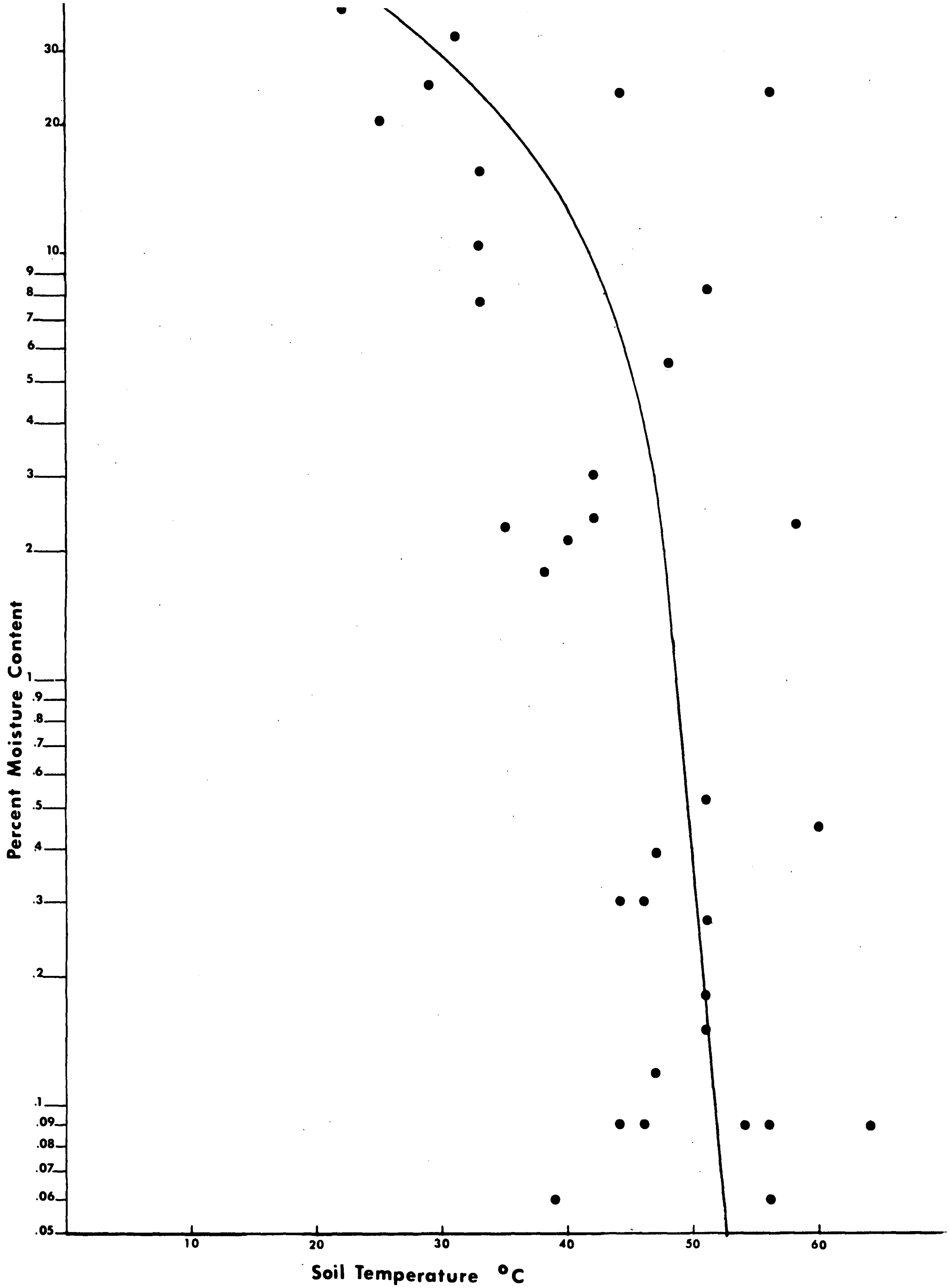


FIGURE 7 CORRELATION BETWEEN SOIL TEMPERATURE AND SOIL MOISTURE

w_i = Relative importance of the i^{th} information element. The sum of the relative importance of all the information elements is made to equal 1. $(\sum_i w_i = 1)$

e_{ijk} = Effectiveness of the k^{th} sensor or sensor combination in providing the i^{th} information element at resolution level j.

A cost effectiveness comparison can be made if the cost of each sensor alternative is known. This cost includes the procurement of the sensor and film, the operational costs incurred in obtaining the imagery or other recording medium, the processing, and any other costs incidental to acquiring the finished product in the form desired by the Principal Investigator.

2.4.3 Use of Format

A sample of the format is shown in Figure 8. In use, the Principal Investigator would determine the relative importance of each information element to his study and enter that value in the column headed w_i. A check would then be made to assure that the sum of all these values equals 1. $(\sum_i w_i = 1)$.

The Principal Investigator would then list, in the row under SENSOR, those sensors and sensor combinations he has used.

For each sensor alternative, the Investigator would next determine the value(s) of R_{jk}, the theoretical resolution of the sensor, and enter these values in the row R_{jk}. As many resolutions as have been used may be entered.

The effectiveness (e_{ijk}) of each alternative jk is then entered in the column below that jk. e_{ijk} may be determined either qualitatively or quantitatively. An approach recommended where applicable is to count the number of information elements (vehicles, homes, roads, etc.) that can be identified in the imagery and compare those observed data with the ground truth or other reference data. The measure of effectiveness would then be:

$$e_{ijk} = \frac{\text{number of objects observed}}{\text{actual number of objects}}$$

This procedure would be continued for each column.

From these data E_{jk} can be calculated, and, if the costs of obtaining the data are known, the cost effectiveness of each sensor or sensor combination can be computed.

Resolution

Identifier of resolution and sensor set

INFORMATION ELEMENT		SENSORS															
		Ground Truth		9" Camera B&W			9" Camera CIR				70mm Camera B&W		9" B&W + SLR			
	R_{jk}			.5	2	15	.5	2	5	15	2	15	2	5	50	
	w_i \ jk	101	201	102	202	302	103	203	303	403	104	204	105	205	305	
Water																
Salt																
Brackish																
Fresh																
…																
	…															
	E_{jk}															
	C_{jk}															
	E/C															

NOTE:

C_{jk} = Cost to obtain each jk

E/C = Cost effectiveness

R_{jk} = Resolution in feet

jk = Identifier number of resolution/sensor set

FIGURE 8 SAMPLE OF COST EFFECTIVENESS FORMAT

2.5 Analysis of Office of Emergency Planning Imagery

Multisensor imagery provided by the Office of Emergency Planning covered the following test sites: The Alaskan earthquake area around and including Anchorage, the Michoud Assembly Facility, the Slidell Computer Facility, the Mississippi Test Facility, and the city of New Orleans.

2.5.1 Objective

The overall objective of the study was to determine the capability of the five remote sensors* to acquire imagery meeting OEP reconnaissance information requirements. In accomplishing this, analysis efforts were directed into four specific channels: determination of the level of detail interpretable from the sensor records; examination of the imagery for unique spectral signatures; determination of each sensor's usefulness in functional, structural, and material analyses, and the determination of the sensors' capability in the portrayal of earthquake damage.

Since this analysis has been completed, and since the final report, detailing the methods used and the results obtained, will be published concomitantly with the present report, only the results will be given here. These can be found in Section 3, General Conclusions.

3. GENERAL CONCLUSIONS

3.1 Geographic Applications Program Imagery

The most important of the preliminary conclusions derived from this analysis include:

1) In urban analysis, the 8443 identified litter, house additions and roof color much better than did the 8442. Microdensitometer edge traces indicated that the 8443 had better resolution, and this could account for the litter and addition variance. This emulsion also cuts down the glare and is thus a better recorder of roof color.

2) The determination of lawn quality was more complete on the color than on the IR. All lawns that were less than 95% red or pink on the IR were considered to be not well kept. On the color film, however, the more subtle tones of green were interpreted as well kept, living lawn, while the same lawn appeared grey or blue,that is, dead, on the IR.

3) Except in the case of lawn quality, the color IR was, as expected, the sensor best able to detect diseased or dead vegetation. However, no instance has yet been discovered in which vegetation identified as dead or dying on the color IR could not also be identified as such on the color and the black-and-white imagery, albeit less readily.

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*Black-and-white photography, color photography, color infrared photography, 9-channel multiband photography, and thermal IR imagery.

4) Based on the statistical data and the second conclusion mentioned above, the information content of the 8442 appears to be slightly better than that of the 8443, even though the 8443 has better resolution. Coupling this with the fact that the cost of film and processing is higher for the 8443, it appears that the 8442 color Ektachrome imagery would better serve the needs of the urban geographer. (More data is needed, however, to verify this conclusion, and samples in other cities will be analyzed.)

3.2 Office of Emergency Planning Imagery

The most important of the final conclusions are as follows:

1) The level of detail, and therefore the identification of structural, functional and material types, and the extent of structural damage, is a function of image quality and scale alone. Good resolution, acuity, and tonal rendition are the most important image parameters. To this kind of interpretation, color contributed nothing and color IR little, its use being limited to the location of water pollution. Thus the multi-band imagery was the most useful because of its large scale and good resolution, rather than for the differences in spectral reflectance it brought out. The thermal IR, with all its capability in indicating the on-off state of industrial activity, pipeline use, and the level of storage in POL tanks and grain elevators, also contributed nothing to the present study other than the detection of some thermal pollution from the thermal power plant near the Michoud Assembly facility. This was almost certainly due to its small scale and poor quality.

2) No spectral signatures were found.

3) Oblique photography is an excellent adjunct to vertical photographs in the interpretation of subtle damage to structures. Many examples were found of earthquake damage to buildings, readily visible on oblique photography but undetectable on the vertical photos.

4) Interpretation of roofing material types is extremely difficult. The discrimination between these materials by means of microdensitometer traces showed promise, however, but was hampered by lack of ground truth.

4. RESEARCH PLANNED

4.1 Urban Problems and Land Use

In these two areas of analysis, the work planned is simply a continuation of that already in progress - extending the number of information elements and determining by rank the capability of the sensors to identify them. In the future, as at present, imagery from missions other than Mission #73 will also be examined, and, in those cases where information elements were not identified simply because they were not present, we will utilize the imagery in the Autometric data bank.

4.2 Soil Moisture and Surface Energy Budget

The principal effort in respect to soil moisture will be to make and analyze microdensitraces on positive transparencies of the thermal IR imagery. In addition, the attempt will be made to isolate, on the records of each applicable sensor, those tones and colors indicative of higher or lower moisture content.

The microdensitraces will also be used in the study of surface energy budget. The passive microwave imagery of the Imperial Valley will be compared with a detailed land-use map of the same area, and an attempt will be made to correlate brightness temperature with land use.

4.3 Cost Effectiveness

Samples of the cost effectiveness forms will be sent to the Principal Investigators along with instructions for their use. The Investigators will add any information elements that may have been omitted, will fill out the forms, and will evaluate them. The forms will then be revised to remedy any shortcomings and to accommodate any unforeseen needs.

4.4 Analysis of Office of Emergency Planning Imagery

The imagery originally provided by the Office of Emergency Planning has been analyzed and a draft copy of the final report prepared. Publication of the report is being delayed pending receipt of imagery acquired on 11 October over New Orleans. Selected portions of this imagery will be interpreted and new or augmented results will be added to the report.

4.5 Analysis of Scatterometer Data

The capability of the scatterometer to identify land use will be determined.

4.6 Analysis of Television Camera Imagery

The television imagery held by East Tennessee State University will be studied over a one or two day period with the primary objective of determining its utility in identifying the information elements in the land use and urban problems matrices.

4.7 Feasibility from Spacecraft

Using empirical and hypothetical data, the reduction in resolution due to the constraints imposed by geometry and atmospheric attenuation will be computed for each sensor. Based on the resolutions obtained, sensor capability matrices will be drawn up to show the expected utility of each sensor to detect geographic elements of information from orbital altitudes.