37 37

WAVEFORM AND COMPUTER ANALYSIS OF GEOGRAPHY PHENOMENA REPORTED ON COLOR AND COLOR IR MULTI-SPECTRAL IMAGERY FROM AERIAL AND ORBITAL ALTITUDES

by

G. Lennis Berlin

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WAVEFORM AND COMPUTER ANALYSIS OF GEOGRAPHIC PHENOMENA RECORDED ON COLOR AND COLOR INFRARED MULTISPECTRAL IMAGERY FROM AERIAL AND ORBITAL ALTITUDES

by

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ABSTRACT

This investigation is a part of a continuing research program studying the potential of television-waveform instrumentation in identifying, analyzing, and mapping geographic phenomena recorded in aerial and space imagery. Research objectives included: (1) Effectiveness of converting aerial color and color infrared imagery to electronic scanning returns with an ultimate goal of providing a graphic and quantitative method for analyzing the geographic data recorded on the above two imagery types; (2) Effectiveness of manually transposing waveform information recorded from a systematic sampling by scan traverse lines into representative numbers (expressed as percentages) that reveal geographic phenomena and developing a computer program to manipulate the geographic data in several ways; and (3) To reveal new facets of research that could be an outgrowth of this investigation, and to evaluate the study as a contribution to geography.

Results indicated that the television-waveform system offers positive potential for the quantitative analysis of geographic distributions found on aerial color and color infrared photography. Phenomena colors were segregated on both the above film types, but identifying waveforms extracted from the former type offered optimum results. Waveform results from high altitude (15,000 feet) and orbital color photography also indicated positive results in the identification of geographic distributants. A direct correlation, however, does exist - as the scale of the photography decreases the degree of categorization becomes more generalized.

With geographic information in the form of digits (graytone percentages) a computer program was developed to identify, analyze, and map the coded information. Computer analysis of graytone digital data revealed very positive findings. Additional discussion noted equipment additions which could be incorporated into the television-waveform system to more fully automate computer input information.

PREFACE

A time-series of seasonally-spaced multisensor missions was accomplished over NASA Earth Resources Test Site Number 164 in 1968 and 1969. The data resulting provided our investigators with the opportunity to apply a previously developed television scanning and waveform analysis interpretation system to directly comparable color and color infrared imagery. Coordinated acquisition of "ground truth" by field survey teams strengthened interpretation verification, since seasonal variations in cultural and physical environmental parameters are significant modifiers of the imagery characteristics. This report is one of a series on the instrumented detection and analysis of geographic phenomena recorded in imagery of various types.

Geographic land use analysis is concerned with the patterns of phenomena distribution as indicators of the spatial relationships between man and his environment. It is usually concerned with locating and bounding the cropland rather than the crop, the commercial district rather than the commercial building, or the residential neighborhood rather than the residence. It needs to identify the specific only to the degree necessary to establish the category of land use present. A principal advantage of the electronic scanning and waveform analysis system is its inherent generalizing of the detailed density fluctuations in imagery into useful categories derived from phenomena occurrences. This capability contributes to the efficient extraction of geographic patterns which must be achieved if the vast quantities of data becoming available are to be processed and integrated into geographic analyses

A list of some of the other technical reports produced by the Florida Atlantic University Remote Sensing and Interpretation Laboratory is included at the back of this report.

James P. Latham
Principal Investigator

ACKNOWLEDGMENTS

The author wishes to express his appreciation to the many colleagues who aided in the completion of this investigation. Special thanks are accorded Principal Investigator Dr. James P. Latham, Dissertation Supervisor Dr. Sidney Jumper, and Laboratory Supervisor William H. Kuyper for their constructive suggestions and guidance. Graduate Assistant Dillard Larson provided artistic illustrations, and Mrs. Anita Becker rendered valuable secretarial assistance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

CHAPTER I

REMOTE SENSING

A. Introduction

Defining the Term

Some of the most recent research systems made available to the earth sciences are a group of "information-gathering devices"[1] known collectively as remote sensors. For decades conventional aerial photography has been the mainstay of remote sensing, but with the development and subsequent declassification of various other sensing devices scientists are now able to extract data from the environment which was previously denied them.

In its broadest application remote sensing refers to any system collecting information not in direct contact with the subject in question. By this definition, the human sensors of hearing and smell have to be added to sight. Remote sensors utilized by earth scientists are, however, somewhat more restricted. Again they are gathering devices but they collect information via airborne or spaceborne platforms and the data collected are confined to various energy regions of electromagnetic spectrum (Figure 1).

By developing remote sensors sensitive to different wavelengths of energy, an increasing amount of environmental data is being

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[1]John E. Estes, "Some Applications of Aerial Infrared Imagery," _Annals of the Association of American Geographers_, 56 (December, 1966), 673.

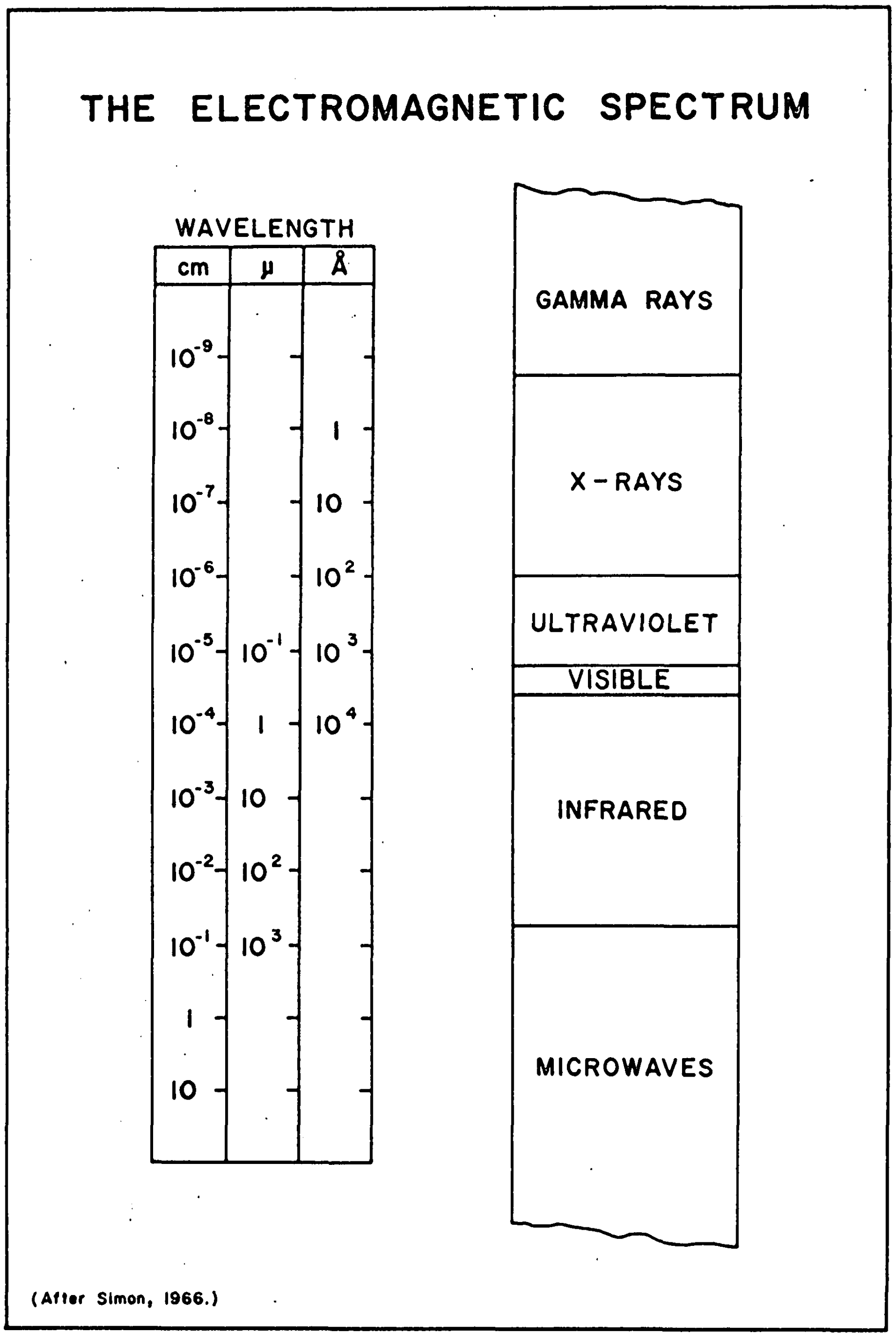
THE ELECTROMAGNETIC SPECTRUM
WAVELENGTH
cm
μ
Å
10^-9
10^-8
10^-7
10^-6
10^-5
10^-4
10^-3
10^-2
10^-1
1
10
10^-1
1
10
10^2
10^3
1
10
10^2
10^3
10^4
GAMMA RAYS
X-RAYS
ULTRAVIOLET
VISIBLE
INFRARED
MICROWAVES
(After Simon, 1966.)

Figure 1.

collected from spectral regions invisible to the human eye. Energy distribution levels for all environmental phenomena resulting from reflection, absorption, and emissitivity, can be detected by various remote sensors operating in wavelength bands where these energy levels are present.[2] It is impossible, however, for any one sensor to operate in several energy bands of the electromagnetic spectrum.

Electromagnetic Remote Sensors

Remote sensors showing the most promise in geographic science include: aerial photography, thermal infrared (IR)[3] scanning radiometers, radar, passive microwave scanning radiometers, multispectral/multiband, and television. Each has its own spectral region of operation. For example, radar systems cannot detect visible light; aerial films cannot detect thermal IR radiation; and microwaves are invisible to thermal IR scanners.[4] A second category of aerial remote sensors are measuring gravitational and magnetic field forces, but advantages are not presently applicable to geographic investigations.[5]

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[2]Jane Lancaster, "Geographers and Remote Sensing," Journal of Geography, LXII (May, 1968), 301.

[3]Throughout this dissertation IR will refer to infrared.

[4]T. Eugene Avery, Interpretation of Aerial Photographs (2nd ed. rev.; Minneapolis: Burgess Publishing Company, 1968), p. 141.

[5]Dana Parker, "Some Basic Considerations Related to the Problem of Remote Sensing," Proceedings of the First Symposium on Remote Sensing of Environment (2nd ed. rev.; Ann Arbor: University of Michigan, 1964), p. 17.

Electromagnetic sensors are usually classified as either active or passive. Active sensing involves the artifical illumination of the object under investigation "with radiation of a particular wavelength and then sampling the portion reflected back to the radiation sensors."[6] Radar and night photography are examples of active sensors. Passive sensors measure "emitted and reflected radiation from a source."[7] Passive systems include passive microwave radiometers and thermal IR scanners.

Daytime photography does not fit well into either category and Smith has classified it as a "semi-active" sensor.[8] In this example illumination is received from the sun making an object visible in reflected light. Daylight photography is the only system presently classified by some as semi-active.

Remote Sensing and Military Restrictions

World War II research was responsible for a new trend in systems development involving new photographic films and intelligence gathering devices. Because of their intelligence capabilities the military has until quite recently maintained strict security on sensor use among various disciplines of the scientific world. Further complications were also encountered when university personnel attempted to secure imagery generated by the sensing systems.

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[6] *Ibid.*, p. 9.

[7] *Ibid.*

[8] Newbern Smith, "Radar Technology and Remote Sensing," *Proceedings of the First Symposium on Remote Sensing of Environment* (2nd ed. rev.; Ann Arbor: University of Michigan, 1964), p. 27.

At the first symposium on remote sensing of environment (1962), the military influence was quite apparent. This meeting was sponsored by a committee of the National Academy of Science - National Research Council and cooperatively funded by Army, Navy, and Air Force research agencies. One primary objective of the symposium was to examine the potentials of new sensors in advancing research in the earth sciences. After several days of discussion scientists concluded that although sensor potentials appeared unlimited, security restrictions would make it "very difficult to make any progress outside of immediate military application."[9]

Since the conclusion of the first symposium considerable progress has been made and as Bailey has stated "the military is taking bold steps to get its house in order."[10] There now appears to be a much better communication channel between the military and scientific world. One example of the military willingness to review security restrictions was made when the Director of Classification Management established the Committee on Remote Sensing of Environment. It is comprised of six members representing the Army, Navy, Air Force, Office of Director of Defense Research and Engineering, Defense Intelligence Agency, and the Joint Chiefs of Staff.[11] According to Bailey the Committee has two functions most

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[9]Lawrence H. Lattman, "Keynote Address," Proceedings of the Second Symposium on Remote Sensing of Environment (Ann Arbor: University of Michigan, 1963), p. 1.

[10]Walter H. Bailey, "The National Academy of Sciences - National Research Council Committee on Remote Sensing of Environment," Proceedings of the Third Symposium on Remote Sensing of Environment (2nd ed. rev.; Ann Arbor: University of Michigan, 1965), p. 6.

[11]Ibid., pp. 6-7.

pertinent to remote sensing investigations:

> One is to revise the regulations, to revise the miserable regulations, that now exist and to issue a new manual on classification procedures of remote sensors and related data.... A second function...will be to formulate and establish efficient procedures for obtaining classification reviews.[12]

Tremendous strides have been accomplished since the first symposium was held in 1962. Adequate amounts of imagery have been declassified and are presently available to the scientific world. It is apparent, without argument, certain imagery will have to remain classified not for the coverage *per se* but for equipment parameters such as altitudes and resolutions involved in recording the imagery. Perhaps the most important factor is the military's awareness of the value of environmental sensing. The growing awareness is revealed by the ever-increasing imagery and equipment declassifications.

Historical Development of Remote Sensing

Although the term remote sensing was used for the first time in 1961[13] the science of data collection by sensing is quite ancient. It began when human systems were used in sensing information from the surrounding environment; the first use of a mechanical sensing system was introduced by astronomers - the telescope.[14] The greatest strides in remote sensing occurred with the introduction of ballooning and photography.

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[12] *Ibid.*, p. 7.

[13] Lancaster, *op. cit.*, pp. 304 - 305.

[14] A. G. Norman, "Welcome and Introduction," *Proceedings of the Fifth Symposium on Remote Sensing of Environment* (Ann Arbor: University of Michigan, 1968) , p. 1.

> Through the science of ballooning, man was able to occupy a point in space from which he could command a highly advantageous view...of the terrain in which he was interested. Through the sciences of photography, he was able to acquire a permanent unbiased record of that terrain. By measuring and interpreting these aerial photographs, he could better obtain certain kinds of information regarding his environment than he could possibly have obtained either by visual observation from the same station or by direct on-the-ground study of the area.[15]

With a lack of maneuverability inherent in ballooning a navigable platform had to be provided for cameras before aerial photography could become widely adaptable. The first imagery recorded from an airplane occurred on April 24, 1909 by Wilbur Wright who photographed an area centering on Centocelli, Italy.[16] With technical advancements in aircraft, cameras, and films aerial photography made steady progress and mushroomed with the beginning of World War II.

During the war years the military realized the many advantages of aerial photography, although earth scientists had arrived at many of the same conclusions several years prior to the war. It was the scientific group who developed most of the aerial systems used in World War II.

Research did not decline after the war and instead if anything the pace has increased. Today we are sensing information originating

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[15]Robert N. Colwell, "Uses and Limitations of Multispectral Remote Sensing," Proceedings of the Fourth Symposium on Remote Sensing of Environment (Ann Arbor: University of Michigan, 1966), pp. 71 - 72.

[16]Robert S. Quackenbush, Arthur C. Lundahl and Edward Monsour, "Development of Photo Interpretation," Manual of Photographic Interpretation, ed. Robert N. Colwell, (Falls Church, Va.: American Society of Photogrammetry, 1960), p. 5.

from many parts of the electromagnetic spectrum; refinements are continually being made in sensor systems; new sensors are continually being introduced to environmental sensing studies; and new and improved films are steadily finding their way to commercial markets. Concluding, although remote sensing is as old as man it is one of the "youngest" scientific disciplines with an apparently unlimited future.

B. REMOTE SENSORS

Introduction to Aerial Photographic Sensing

The type of sensing systems limited to the visible, and near infrared spectrum are referred to as photographic sensors. With research into new film types the limits of photographic sensors are expanding into spectrum bands where it was once impossible to record energy directly onto photographic film.

Concerning the visible band of the spectrum (400 - 700 millimicrons), conventional photography detects and records the distribution of visible reflected light; (Figure 2), whereas, in the photographic near infrared (700 - 900 millimicrons) invisible infrared radiation can be recorded directly onto film because emulsions have been sensitized to this type of invisible reflection. Presently both color and black and white infrared films are commercially available.

Panchromatic and Color Sensing

Panchromatic photography, also referred to as black and white, minus-blue, or conventional, has been the mainstay of all photographic

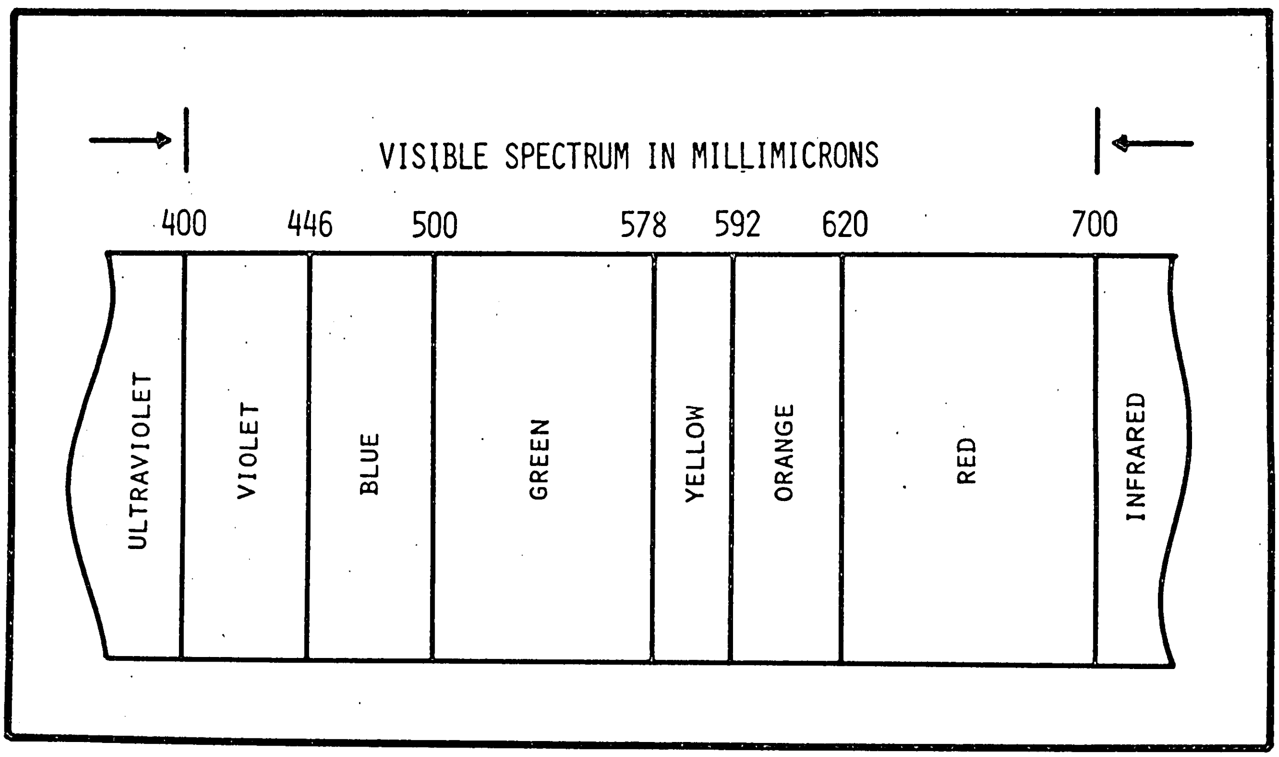

Figure 2. Visible Sector of the electromagnetic spectrum.

Source: T. Eugene Avery, Interpretation of Aerial Photographs (2nd ed. revised; Minneapolis: Burgess Publishing Company, 1968), p. 87.

sensors. It was the first sensor to sample and record a segment of the electromagnetic spectrum and is still the most widely used system among all sensors.

The film is sensitive to all wavelengths of visible light, but the blue band of the spectrum is usually filtered out. Therefore, panchromatic film actually records only a segment of the visible spectrum (Figure 3). Blue light is filtered because it has a tendency to obscure ground detail when it is scattered by atmospheric haze.[17] Objects recorded on panchromatic photos are reproduced in various shades of gray "with each tone comparable to the density of an object's color as seen by the human eye."[18]

The introduction of aerial color films to remote sensing has been a recent addition. During the 1930's there were many attempts to develop suitable color films but success was not experienced until World War II. Color films rendering acceptable colors were used during the war mainly as support media for panchromatic photography since metric stability was erratic. Through the 1950's and 1960's improved versions have been introduced; these films "have increased the confidence in color materials and stimulated an interest in the use of color aerial photography as a direct photogrammetric mapping medium."[19]

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[17]Lawrence H. Lattman and Richard G. Ray, Aerial Photographs in Field Geology (New York: Holt, Rinehart, and Winston, 1965), p. 18.

[18]Avery, op. cit., p. 89.

[19]Gary W. Schallock, "Metric Tests for Color Photography," Photogrammetric Engineering, XXXIV (October, 1968), p. 1063.

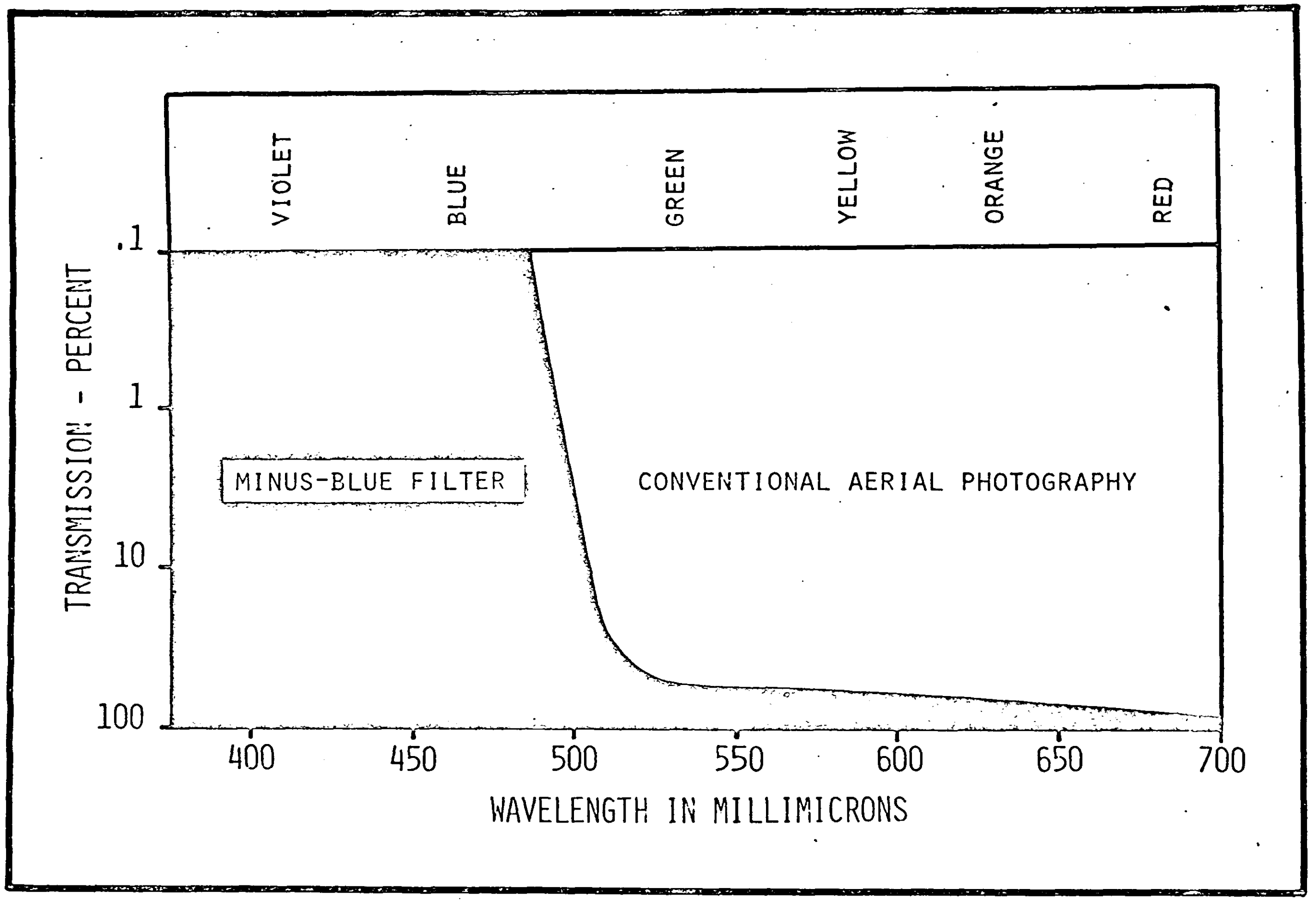
VIOLET
BLUE
GREEN
YELLOW
ORANGE
RED
MINUS-BLUE FILTER
CONVENTIONAL AERIAL PHOTOGRAPHY
TRANSMISSION - PERCENT
.1
1
10
100
400
450
500
550
600
650
700
WAVELENGTH IN MILLIMICRONS

Figure 3.

Two aspects of color films are similar to those of panchromatic. First, color films are sensitive to all wavelengths comprising the visible band of the electromagnetic spectrum, and secondly an optical filter is utilized to absorb blue light.

A color photo has a distinct advantage over a panchromatic one because the former more closely resembles the original scene. The approximate number of graytones differentiated on a black and white print approaches 200; whereas, a color system differentiates the same number of color shades (200) every 20 millimicrons.[20] Therefore, a second advantage is realized - an interpreter can more easily discriminate phenomena. On a panchromatic photo these differences are often obliterated in the comparatively smaller tonal range.[21]

Black and White and Color Infrared Sensing

As previously mentioned both black and white and color infrared films are primarily sensitive to the 700 to 900 millimicrons or near infrared band of the electromagnetic spectrum. Because the wavelengths between 700 and 900 millimicrons can be recorded directly onto infrared sensitive films, both are referred to as "photographic infrared."[22]

These films have been especially important in remote sensing

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[20]Manfred Duddek, "Wild Mapping Cameras for Color," Manual of Color Aerial Photography, ed. John T. Smith (Falls Church, Va.: American Society of Photogrammetry, 1968), p. 154.

[21]Carl H. Strandberg, "The Language of Color," Manual of Color Aerial Photography, ed. John T. Smith (Falls Church, Va.: American Society of Photogrammetry, 1968), p. 3.

[22]Floyd F. Sabins, Jr., "Thermal Infrared Imagery and Its Application to Structual Mapping in Southern California," Geological Society of American Bulletin, 80 (March, 1969), p. 398.

studies treating distribution and vegetational health states. On color infrared photos healthy vegetation instead of appearing as shades of green is rendered in reds. Black and white infrared records in different graytones.

Thermal Infrared Sensing

Thermal infrared (heat) radiation has wavelengths ranging from 0.7 to approximately 800 microns. The intensity of thermal radiation is dependent upon two factors: the temperature of the material and the emissivity or radiating efficiency of the material. When any object absorbs insolation, temperatures increase and a portion of the energy is re-emitted back to the atmosphere via the infrared band of the electromagnetic spectrum.[23] Infrared sensors, therefore, are designed to record differences in emitted energy and not reflected radiation.

Unfortunately thermal infrared radiation cannot be detected and recorded throughout the entire length of the infrared band. In most wavelength areas a large percentage of thermal radiation is absorbed or scattered by such atmospheric components as water vapor, gases, and solid particles. But there are two major infrared "windows" where it is possible to intercept thermal radiation; these windows occur at 4.3 microns and from 8 to 14 microns.[24] (Figure 4). When sensors are sensitized to wavelengths included within these two windows it is possible to record thermal radiation

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[23]Estes, op. cit., p. 674.

[24]Lancaster, op. cit., p. 302.

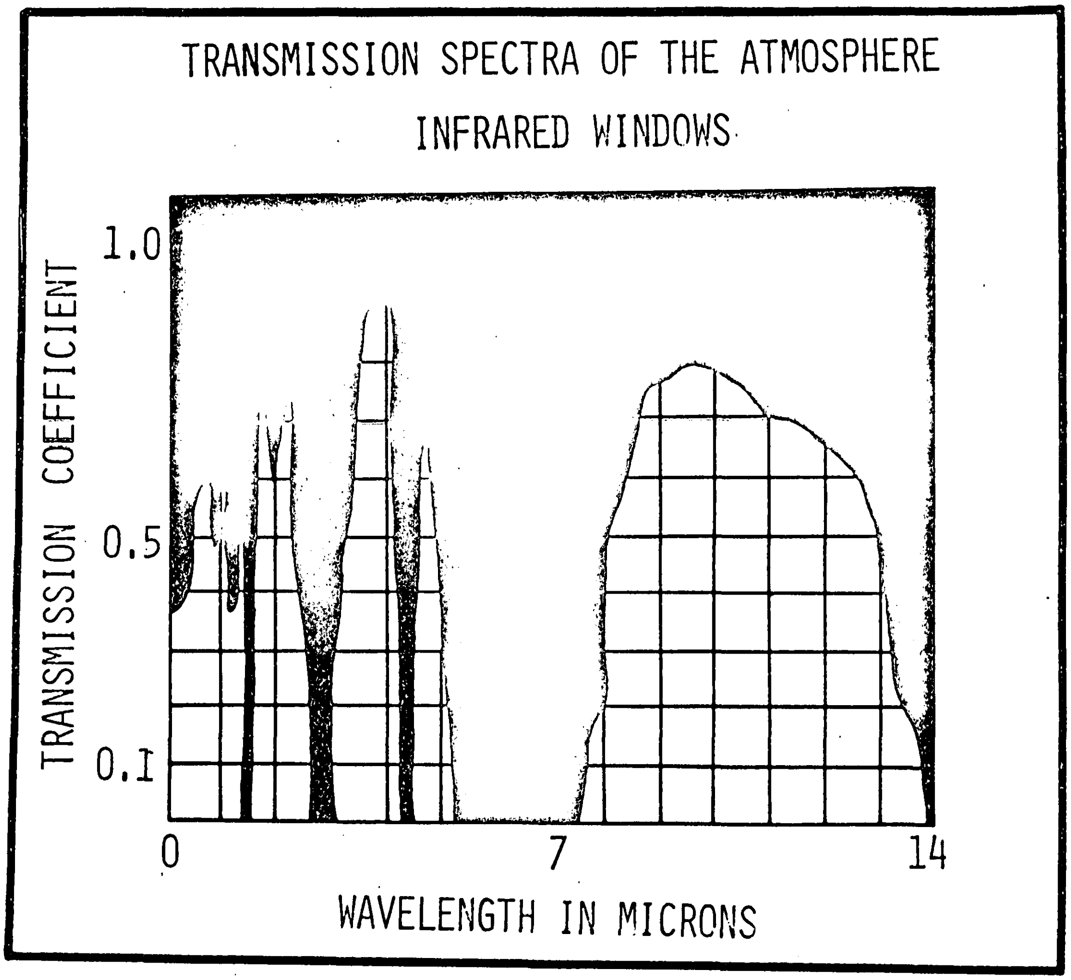
TRANSMISSION SPECTRA OF THE ATMOSPHERE
INFRARED WINDOWS
TRANSMISSION COEFFICIENT
1.0
0.5
0.1
0
7
14
WAVELENGTH IN MICRONS

Figure 4.

both during daylight and darkness and also through smoke and haze.[25]

Although thermal infrared radiation can be detected day and night there are two periods when an object's rate of heat emission coincides with the background. On resulting imagery both the object and the background would be rendered in the same graytone thus obscuring the object. The two periods of "crossover" usually occur during the morning and evening.[26] Poor results are also recorded during or immediately after a period of rainfall. Precipitation has a tendency to minimize temperature differences and most ground objects will not be recorded.

With thermal radiation being invisible conventional photographic methods are not operative. Instead an infrared telescope or radiometer, incorporating a rotating mirror, scans the ground in lines perpendicular to the flight path of the aircraft. The infrared scanning radiometer is classified as an optical scanner because it produces an image by scanning a scene one line at a time.[27] Thermal information is then usually transferred line by line onto photographic film in approximately the same manner as it was scanned; the scanning being "effectively endless" the term strip map is often used to describe the infrared imagery.[28]

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[25] Ibid., pp. 302 - 303.

[26] Estes, op. cit.

[27] D. S. Lowe, "Line Scan Devices and Why Use Them," Proceedings of the Fifth Symposium on Remote Sensing of Environment (Ann Arbor: University of Michigan, 1968), p. 79.

[28] Joseph Morgan, "Infrared Technology," Proceedings of the First Symposium on Remote Sensing of Environment (2nd ed. rev.; Ann Arbor: University of Michigan, 1964), p. 55.

In interpreting thermal images varying graytones result from differences in radiant temperature - the "hotter" an object the lighter the graytone on the resulting strip map.[29] With refinements in unclassified infrared scanners it is possible to measure thermal radiation variances resulting from temperature changes on the ground of approximately 0.5°F.

Passive Microwave Sensing

Microwave frequencies occupy the portion of the electromagnetic spectrum between $5X10^{-2}$ and 30 centimeter wavelengths,[30] thus comprising the longer bands of heat or thermal radiation. A microwave radiometer has subsequently been developed capable of measuring these frequencies.

Passive microwave sensing differs from those previously discussed because when measuring this type of natural emission a part of the energy originates from below the ground surface. Consequently, microwave energy:

> can originate from objects beneath an ice, snow, or soil cover, and radiate up through these materials into space to be detected by passive microwave sensors. Information or subsurface composition, condition, and temperature can thus be conveyed.[31]

Research conducted to date has revealed that microwave sensors have two advantages over visible and infrared systems: (1) ability

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[29] Peter C. Badgley, Leo Childs, and William L. Vest, "The Application of Remote Sensing Instruments in Earth Resource Surveys," Geophysics, XXXII (August, 1967), p. 591.

[30] A. T. Edgerton, "Engineering Applications of Microwave Radiometry," Proceedings of the Fifth Symposium on Remote Sensing of Environment (Ann Arbor: University of Michigan, 1968), p. 712.

[31] Lancaster, op. cit., p. 303.

to penetrate the ground surface revealing subsurface information and (2) propagation through inclement weather conditions.[32] With passive microwave sensing still in a lower state of development several limitations have been placed on it. Low resolution and slow scanning speeds are inherent in all systems. To the above has to be added the shortage of unclassified microwave imagery.[33]

Radar

Radar sensors utilize microwave energy, but with radar the energy is generated by the system and not from natural earth emissions. Sensing by radar is then restricted to "surfaces which are directly on a line-of-sight from the antenna. Surfaces not in this line received no energy and are recorded...as a shadow no-return."[34] Microwaves utilized by radar are extremely long, ranging from approximately one centimeter to three meters.[35]

Coming out of World War II research were two major types of radar: plan positive indicator (PPI) and side looking airborne radar (SLAR). Because of optimum resolution qualities side looking airborne radar has been the type receiving the most attention from earth scientists.[36] Side looking systems utilize twin radar beams

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[32] Weston E. Vivian, "Application of Passive Microwave Techniques in Terrain Analysis," Proceedings of the Second Symposium on Remote Sensing of Environment (Ann Arbor: University of Michigan, 1963), p. 119.

[33] Lancaster, op. cit., p. 304.

[34] Hubert O. Rydstrom, "Interpreting Local Geology from Radar Imagery," Proceedings of the Fourth Symposium on Remote Sensing of Environment (Ann Arbor: University of Michigan, 1966), p. 193.

[35] Avery, op. cit., p. 150.

[36] Ibid., p. 152.

each traversing the line of flight.

With radar being an active sensor, imagery can be obtained at all hours of the day and during adverse weather conditions. Of all spectrum sensors, radar offers optimum possibilities of generating useable imagery when the above factors are taken into consideration. An additional advantage is also inherent with the types of energy available. By utilizing different wavelengths, both surface and subsurface information can be obtained. When short wavelengths are used, data from surface phenomena are returned and long wavelengths have the ability to penetrate the surface on the order of feet.[37] Concerning the latter example, when subsurface data are wanted in an area covered by forest, a long wave pulse appears to completely "ignore" vegetation, and the resulting image reveals only geological data.

Terrain roughness plays an important part on radar images and can be a disadvantage in certain investigations. Any surface having a roughness of one-half or less the wavelength of the radar pulse results in a "smooth" image texture. Therefore, if radar is sensing with three centimeter wavelengths any terrain material with a roughness of one and one-half centimeters the image texture will be smooth. In the above example radar could not sense the presence of sand or gravel.

Presently the most advanced side looking airborne radar systems are classified. These of course offer the finest resolution, but

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[37] Dana C. Parker and Michael F. Wolff, "Remote Sensing," International Science and Technology, 43 (July, 1965), 27.

declassified systems have proven to be very benefical in many environmental studies.

Multispectral/Multiband Sensing

Multispectral or multiband sensing refers to a method of recording imagery of the same subject from different bands of the electromagnetic spectrum. More specifically the images are recorded simultaneously insuring environmental parameter control. Multispectral sensing is not limited solely to the visible and near-infrared bands of the spectrum; the most recent systems are capable of obtaining simultaneous data by extending their spectral limits into the thermal and microwave bands.

Multispectral sensing is becoming increasingly important mainly on account of the additional information that can be gained from observing the same object in different bands of the spectrum. By comparing the various images "we may learn something about the object we could not learn by studying the tonal values on just one photograph."[38]

Itek Corporation has developed the most complete photographic multispectral camera. It is composed of nine matched lenses, equipped with various filters, and is capable of obtaining simultaneous imagery from 400 to 900 millimicrons. One example of films used include two rolls of 70 mm panchromatic and one roll of 70 mm infrared; six exposures are on panchromatic and three on infrared.[39]

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[38] Ibid., p. 25.

[39] Carlton E. Molineux, "Aerial Reconnaissance of Surface Features with the Multiband Spectral System," Proceedings of the Third Symposium on Remote Sensing of Environment (2nd ed. rev.; Ann Arbor: University of Michigan, 1965), pp. 400 - 401.

A multispectral camera manufactured by the Fairchild Camera and Instrument Corporation has been introduced to remote sensing for taking photographs in the ultraviolet, visible, and near-IR spectral regions. The camera incorporates four matched-seven inch lenses for obtaining four spectral negatives.[40]

A six cluster Hasselblad has recently been installed in NASA's newly acquired RB-57 aircraft. Six individual cameras are mounted in such a manner to acquire simultaneous ground coverage. Each camera can have differentiated focal length and hence differentiated image scale. Although film and filter combinations vary, the following is an example of film types which Florida Atlantic University has requested for future overflights: Plus-X Aerecon (8401), Ektachrome Aero (8442), Infrared Aerographic (5424), and Ektachrome Infrared Aero (8443).

At the Institute of Science and Technology, University of Michigan, scientists have been using a multiband system comprised of an aerial camera, IR scanner, and side looking airborne radar. In conjunction, the system operates in the spectrum range of 0.3 to fourteen microns.[41]

Images used in this dissertation were derived from multispectral sensing. A matched-pair of Wild RC-8 cartographic cameras simul-

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[40]Edward Yost and Sandra Wenderoth, "Additive Color Aerial Photography," Manual of Color Aerial Photography, ed. John T. Smith (Falls Church, Va.: American Society of Photogrammetry, 1968), p. 451.

[41]R. R. Legault and F. C. Polcyn, "Investigations of Multi-Spectral Image Interpretation," Proceedings of the Third Symposium on Remote Sensing of Environment (2nd ed. rev.; Ann Arbor: University of Michigan, 1965), p. 813.

taneously photographed the same ground phenomena with color and color IR aerial films.

Television

Sensing by television cameras is presently being employed in all NASA space flights; coverage from television systems was at first only in black and white, but officals introduced a color camera on Apollo 10. In viewing the earth from hundreds of miles into space, television imagery loses much impact when presented in graytones.

Television coverage of the earth's surface from orbital altitudes has a distinct advantage over other sensors because the imagery can be electronically transmitted to ground station convertors. These convertors have the capability of reconstructing images in only a matter of seconds. By using this sensor "real time" capabilities are realized; whereas, other imagery has to be recovered and processed before the imagery can be examined.

Once color systems are perfected, television sensing will become an important component in analyzing global environmental phenomena. Sub-orbital altitudes may prove promising for television sensing, but very little research has been completed at this time.

C. Remote Sensing in Geographic Science

Introduction

The imagery output generated by remote sensors is perhaps better adapted to geographic science than to other environmental disciplines. With the breadth of geographic research being so diverse, high percentages of remote sensing images, regardless of type, have possibilities in problem solving. All previously discussed sensors have present applications and future potentials appear to be even more promising.

Detection of Geographic Phenomena with Remote Sensors

The introduction of various remote sensors in geographic science has made it possible to detect phenomena characteristics by isolating certain spectral bands of the electromagnetic spectrum. Aerial photography continues to be the most important sensor, but other devices are continually extending their applications. Figure 5 summarizes the detection potential of important geographic sensors.

Automation in Remote Sensing Data Extraction

A group of geographers who have followed the evolution of remote sensing are concerned with a twofold problem. With the tremendous amounts of sensing being generated there is a growing store of backlogged imagery which is exceeding present interpretation capabilities, and secondly a large percentage of the imagery being used by geographers has not been applied to its maximum potential. As a solution several geographers have directed their attention to instrumentation research in an effort to solve the growing problem. The research of this dissertation is one such example.

Such an automatic solution (s) will especially be pertinent in geography because of the huge quantities of geographic data

DETECTING GEOGRAPHIC PHENOMENA WITH REMOTE SENSORS*

TIME CAPABILITIES: DAY - O, DAY AND LIMITED NIGHT POSSIBILITIES - Φ, DAY AND NIGHT - ◑, DAY, NIGHT, AND ALL WEATHER - ⊕.

GEOGRAPHIC PHENOMENA	SENSORS					
	AERIAL CAMERA	INFRARED SCANNER	RADAR	MAGNETOMETER	PASSIVE MICROWAVE	TELEVISION
LAND - WATER DISTRIBUTION	Φ	◑	⊕		⊕	O
LAND FORMS (SIZE, SHAPE, RELIEF)	Φ	◑	⊕		⊕	O
MINERAL RESOURCES						
SURFACE LOCATION	O	◑	⊕	⊕	⊕	O
SUBSURFACE LOCATION		◑	⊕	⊕	⊕	
SOIL CATEGORIES	O	◑	⊕			
SOIL MOISTURE	O	◑	⊕		⊕	
SUBSURFACE WATER		◑			⊕	
WATER CURRENTS		◑			⊕	
WATER POLLUTION		◑			⊕	
ICE - GLACIAL OR SEA	Φ	◑	⊕		⊕	O
ICE CREVASSES	Φ	◑	⊕		⊕	
SUBICE PHENOMENA				⊕	⊕	
VEGETATION						
IDENTIFICATION	O	◑	⊕		⊕	O
MOISTURE STATE	O	◑	⊕			
HEALTH	O	◑			⊕	
CLOUD PATTERNS	Φ	◑	⊕		⊕	O
STRUCTURES						
SIZE, SHAPE, RELIEF	Φ	◑	⊕		⊕	O
MATERIALS	Φ	◑	⊕	⊕	⊕	
CONTENTS		◑		⊕	⊕	
HIGHWAYS	Φ	◑	⊕		⊕	O
RAILROADS	Φ	◑	⊕	⊕		O
PIPELINES	O		⊕			O
TRAFFIC FLOW - VEHICLES	Φ		⊕			O
- THERMAL INDICATION		◑			⊕	
- OFF - ROAD PATHMAKING	Φ					
INDUSTRIAL ACTIVITY (THERMAL INDICATION)		◑			⊕	
FIRES						
SURFACE	Φ	◑			⊕	O
SUBSURFACE		◑			⊕	

*DEVELOPED FROM PROCEEDINGS OF THE FIRST SYMPOSIUM ON REMOTE SENSING OF ENVIRONMENT.

Figure 5.

Source: Latham, James P., "Electronic Measurement and Analysis of Geographic Phenomena," Final Report, Contract Nonr 3004(01). (Washington: Office of Naval Research, June 1964), p. 18.

recorded on remote sensor imagery. As Simonett has stated:

> The environment we sense is extremely complex. For example, for sensing to be successful in describing the environment, vast quantities of information received from sensors must be analyzed.... It seems obvious therefore that automation of some type must play a large role in analyzing these data.[42]

Regardless of the system devised the computer will be a vital component. Computer applications enable vast amounts of data to be stored in such a manner that they can be manipulated and retrieved in a time span numbering in seconds. It is also possible to program a computer to map geographic distributants which have been extracted from remote sensing imagery.

Waveform and Computer Analysis[43]

Waveform and computer analysis is one example of an attempt to automate the extraction, manipulation, and mapping of geographic phenomena recorded on color and color IR multispectral imagery. A television camera and waveform analyzer in conjunction served as the system for extracting quantified data from the imagery and a computer for manipulating and mapping the data.

By the use of the above systems the writer envisioned that once the methodological research was completed it would have the following potential geographic applications: (1) identification of general land use types, (2) identification of specific crop types, (3) method for quantifying geographic dispersants, (4) recording

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[42]David S. Simonett, "Present and Future Needs of Remote Sensing in Geography," Proceedings of the Fourth Symposium on Remote Sensing of Environment (Ann Arbor: University of Michigan, 1966), p. 42.

[43]Chapter 2 describes instrumentation procedures involving waveform and computer analysis.

quantified geographic data in such a manner to estimate areas and to estimate percentages of total area occupied by any one dispersant, and (5) computer land use mapping. Evaluations of these potentials are evaluated in Chapters 4, 5, and 6.

D. Research Objectives

Intensive research commencing in the 1960's revealed the possibilities for utilizing television-waveform analysis as an instrumented technique for comparing and quantitatively analyzing geographic phenomena recorded on certain types of photography. Continuing experiments, conducted in the Department of Geography's Remote Sensing and Interpretation Laboratory, Florida Atlantic University, have demonstrated the technique to be a promising photointerpretation approach. The results have stimulated this writer to investigate the following concepts for instrumenting the analysis of geographic phenomena recorded on color and color IR multispectral imagery:

1. Effectiveness of converting aerial color and color IR imagery to electronic scanning returns with an ultimate goal of providing a graphic and quantitative method for identifying and analyzing the geographic data recorded on these two imagery types.
2. Effectiveness of manually transposing waveform information recorded from a systematic sampling by scan or traverse lines into representative numbers (expressed as percentages)

that actually reveal geographic phenomena and developing a computer program to manipulate the data in various ways.

3. To reveal new facets of research that could be an outgrowth of this investigation and to evaluate the study as a contribution to geographic science.

Concerning the first research objective, color and color IR images were chosen as the research base for one specific reason. Their main value in photointerpretation has been in their reproduction of earth phenomena in colors rather than graytones. But what if digitized data could be extracted utilizing a graytone television system? The extraction of digitized data would reinforce the value of these two films because additional interpretation data would be made available to photointerpreters.

The first experiments centered on establishing quantified values for the colors determinable on the images which had been selected for waveform analysis. The results are discussed in Chapter 4.

Once graytone percentages were determined, the second objective was to manually record graytone data from a sampling of television scan lines which actually revealed (segregated) geographic phenomena. By extracting digitized data it was possible to utilize a computer in analyzing these graytone percentages. Computer application provided a method for extracting a maximum amount of geographic information from the aerial imagery in the shortest time possible.

Such an instrumentation approach to geographic analysis also contributed to a program whereby electronic waveforms rendered "signature" characteristics that discriminated many types of geographic phenomena. Waveform and computer potentials are evaluated in Chapters 4, 5, and 6.

Since this investigation was based on a methodological approach, several research steps had to be completed manually. But the success of such procedures has waranted additional studies based on complete automation. The focus in Chapter 6 centers on equipment that has potential in a totally automated waveform and computer system for analyzing geographic phenomena recorded on remote sensing imagery.

CHAPTER II

RESEARCH OVERVIEW

A. Instrumentation Procedures

Waveform Analysis

In utilizing the waveform analysis technique, the arrangement of apparatus is similar to a normal television recording, but with the major emphasis upon the waveform analyzer rather than a receiving set. The waveform analyzer provides a graphic display of how a pattern of spatially distributed phenomena converted to electronic signals is being intercepted and transmitted to receiver systems, thereby providing a method for measurement and calibration.

For example a television camera scans[1] a specific test pattern, of which one sector is comprised of a series of different graytones. With proper calibration (camera blanking), the waveform analyzer can be adjusted to record white as 100% graytone and black as 0%. Other tones of gray fall into percentage categories somewhere between these two extremes (Figure 6).

When any scene is scanned by a television camera, it is intensely sampled with parallel traverse or scan lines which record differences

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[1]Since a television camera views a scene one line at a time, the method of viewing is referred to as scanning.

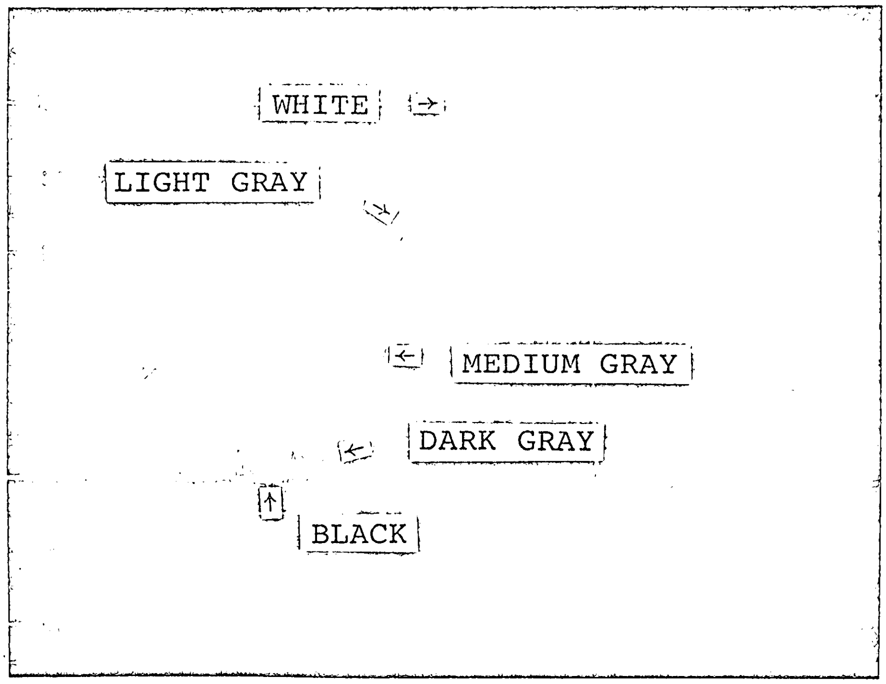

Figure 6. Waveform Analyzer recording various graytones comprising ICSS-NBS graytone value chips.

in the distribution of incident light.[2] The electron charge varies because the photocathode tube, when receiving an image, releases electrons in proportion to the intensity of light it receives. An electron beam then scans the inner-face of the tube, line by line, converting the image to a low frequency for transmission.[3]

Within a television receiver set, the electronic signal "is reconverted to a video signal which is used to modulate the intensity of the electron beam in the cathode ray tube.[4] The scanning beam operates in an identical manner as within the camera system, producing a graytone image of the original (Figure 7). Because the resulting image is constructed of parallel scan lines, it can be electronically dissected, line by line, utilizing the waveform analyzer[5] (Figure 8).

For commercial television in the United States, the beam scans the scene with 525 parallel lines. The number of scan lines varies from nation to nation, with a low of 405 lines in Great Britain and

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[2] James P. Latham, "Methodology for an Instrumented Geographic Analysis," Annals of the Association of American Geographers, 53 (June, 1963), p.194.

[3] Monroe Upton, Inside Electronics (New York: The New American Library, 1965), p. 114.

[4] Kam W. Wong, "Geometric Calibration of Television Systems for Photogrammetric Applications," Papers from the 34th Annual Meeting (Falls Church, Va.: American Society of Photogrammetry, 1968), p. 381.

[5] James P. Latham, Machine Evaluation of Images for Regionalization Problems, A Report to the International Geographical Union's Commission on Interpretation of Aerial Photographs (Ottawa, Canada: March 16, 1967).

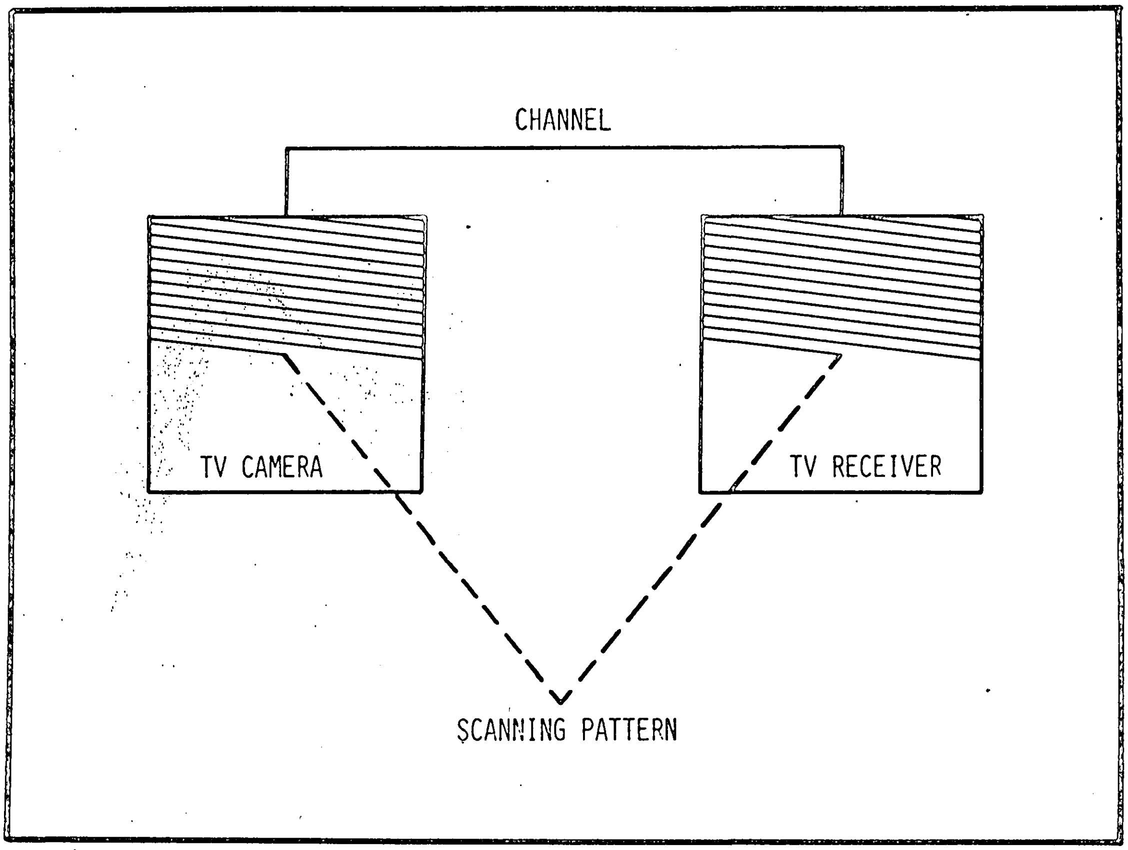

Figure 7. Television system utilizing parallel scan line construction.

Source: Kam W. Wong, "Geometric Calibration of Television Systems for Photogrammetric Applications," Papers from the 34th Annual Meeting. (Falls Church, Va.: American Society of Photogrammetry, 1968), p. 378.

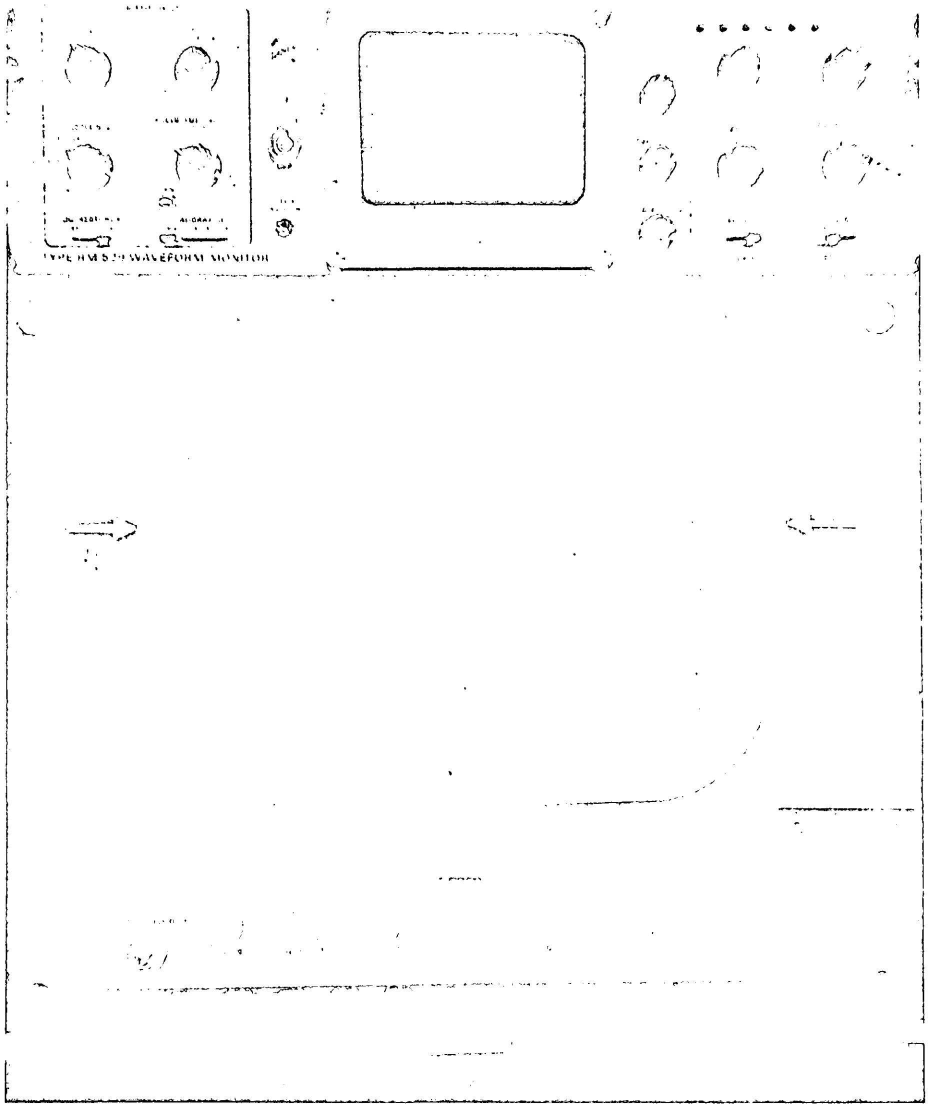

Figure 8. Example of imagery conversion to scan line waveforms at 5X magnification. Waveform depicts only central half of scan line seen on monitor at position indicated by arrows.

a high of 809 lines in France. For this study, a variable line television camera capable of utilizing a maximum of 945 scan lines was used (Figure 9). Four monitors were also available which individually incorporated 525, 729, 853, and 945 line systems.

In a closed circuit operation (Figure 10) where the electronic signal is converted to graytones within the monitor tube, a moveable trace visually locates any scan line on the televised image (Figure 8). Therefore, when all systems are in operation any scan line selected for investigation is revealed on the monitor face; a positional control on the analyzer enables the investigator to graphically display graytone intensities for any scan line he might select (Figure 8).

Latham was the first researcher to report on the possibilities of utilizing electronic devices such as densitometers for the quantitative measurement and analysis of geographic phenomena.[6] Rosenfeld, using the methodology introduced by Latham, later conducted research into the possibilities of using a flying spot scanner in identifying terrain types recorded on black and white aerial imagery.[7]

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[6]James P. Latham, Possible Applications of Electronic Scanning and Computer Devices to the Analysis of Geographic Phenomena, Report No. 1, NR 387-023 (Washington: Office of Naval Research, August, 1959).

[7]Azriel Rosenfeld, "Automatic Recognition of Basic Terrain Types from Aerial Photographs," Photogrammetric Engineering, XXVII (January, 1962), pp. 115-132.

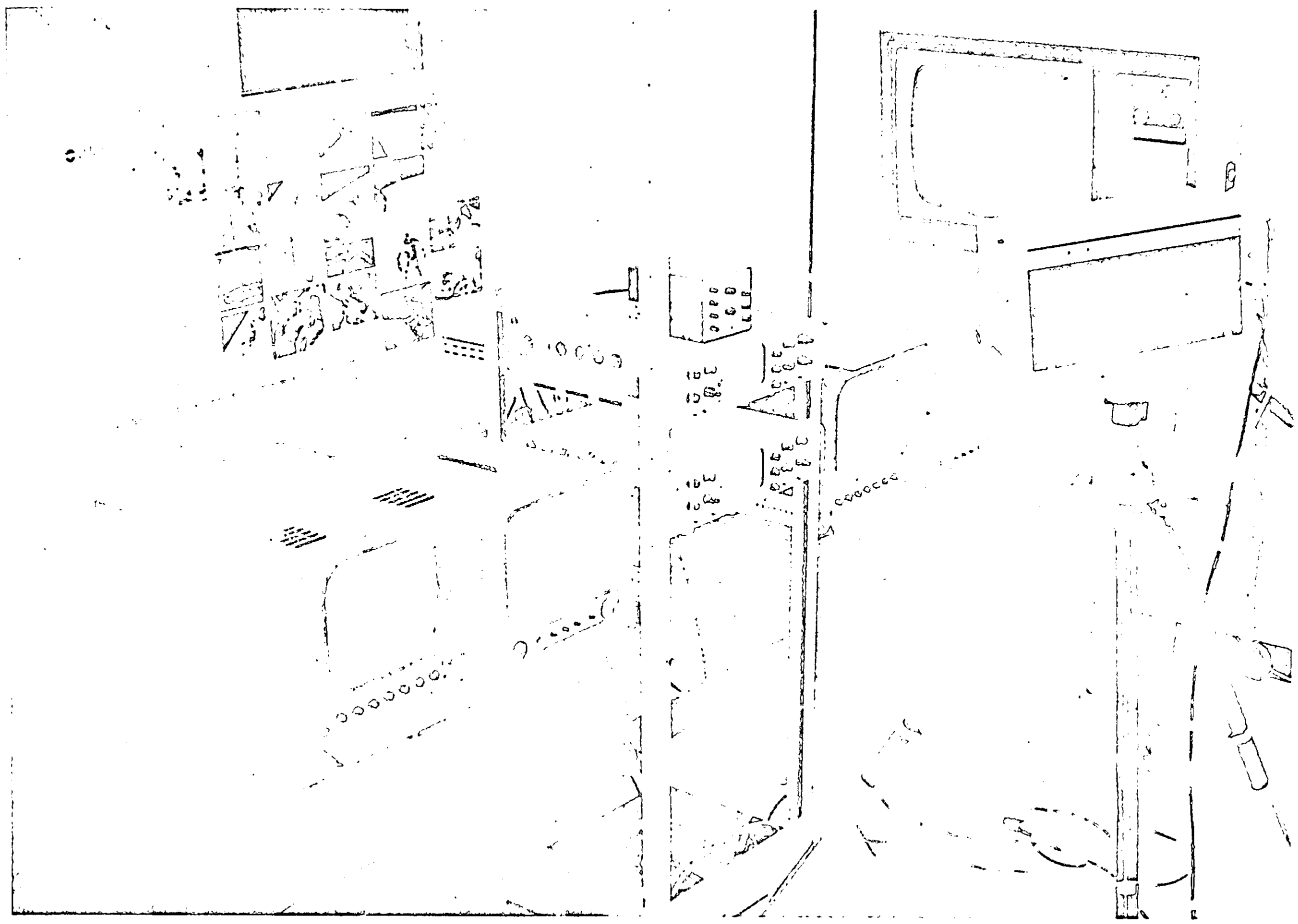

Figure 9. Department of Geography's (Florida Atlantic University) electronic instrumentation equipment.

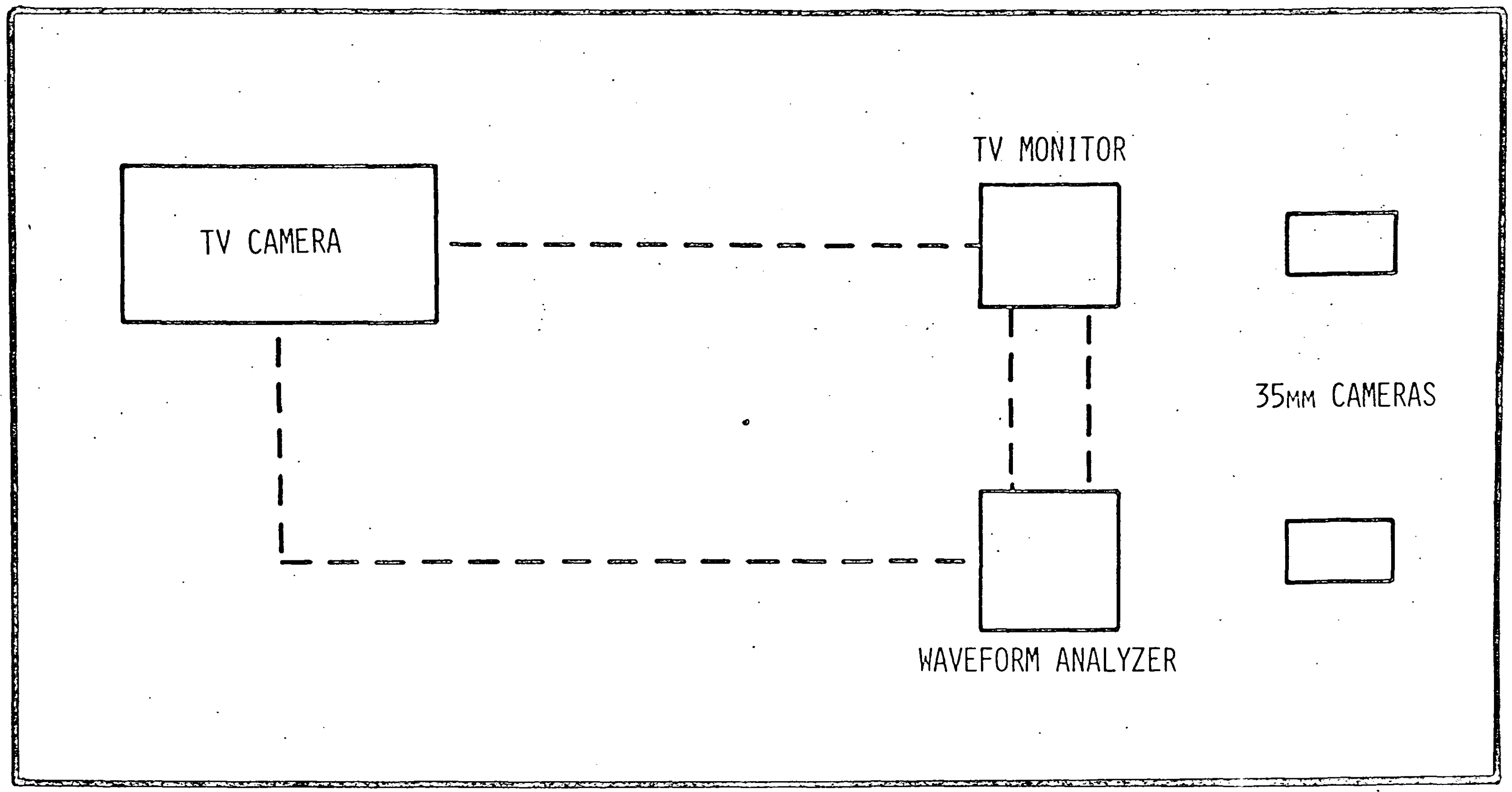

Figure 10. Closed circuit television operation with 35mm cameras to photograph "geographic" waveforms and scan lines visible on the television monitor.

The use of a television camera in geographic pattern analysis was also first reported on by Latham.[8]

The potential of the electronic instrumentation approach in geographic analysis has led to additional studies. With Latham, Witmer conducted research into a methodological framework for the application of the television-waveform system to the integrated analysis of panchromatic and thermal infrared imagery.[9] These studies demonstrated that when electronic waveforms, which distinguish geographic patterns in images from two different sensor systems, are interrelated in the analysis they actually segregate various geographic phenomena. In a 1968 report, Nunnally substantiated previous findings when he demonstrated the advantages (lower costs, rapid data accumulation, and ability to simultaneously see the location of the scan line being analyzed) of waveform over microdensitometry analysis.[10]

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[8] James P. Latham, Geographic Integration of Imagery Patterns, A Report to the Symposium on Remote Sensing of Environment at the Annual Meeting of the American Association for the Advancement of Science (Berkeley, California: December 28, 1965).

[9] James P. Latham and Richard E. Witmer, "Comparative Waveform Analysis of Multisensor Imagery," Photogrammetric Engineering, XXXIII (July, 1967), pp. 779-786; Richard E. Witmer, Waveform Analysis of Geographic Patterns Recorded on Visible and Infrared Imagery, Technical Report No. 4, NR 387-034 (Washington: Office of Naval Research, December, 1967).

[10] Nelson R. Nunnally, A Comparison of Microdensitometry and TV Waveform Analysis as Expressions of Observed Landscape Patterns on Radar, Technical Report No. 6, NR 389-151 (Washington: Office of Naval Research, August, 1968).

Computer Digitized Analysis

Latham also postulated that a measurement methodology utilizing a scanning densitometer had possibilities in recording quantitative measurements from land use maps in such a manner that would "permit the use of mechanical and/or electronic sorting and computing equipment for organizing and statistically evaluating the data."[11] It appears that a similar system utilizing color and color IR remote sensing imagery in place of maps, and the television camera to replace the flying spot scanner or microdensitometer, will lead to a procedure whereby multispectral imagery can be analyzed by computer methods.

With this application of the waveform analyzer, it is possible to accomplish the digitizing of imagery by the utilization of graytone values recorded from "geographic waveforms." Computer analysis of the resulting statistical parameters is possible once the analogue information has been transformed into digitized data.[12]

The waveform analyzer reveals graytone levels as one dimensional for individual scan lines. Two dimensions are easily achieved by extracting graytone data from a sampling of scan lines at equal distances from a predetermined point. Digital conversion is easily accomplished by recording graytone values or percentages at constant intervals along

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[11] James P. Latham, Possible Applications of Electronic Scanning and Computer Devices to the Analysis of Geographic Phenomena, op. cit.

[12] James P. Latham, Remote Sensing Papers at the AAAS-Impact and Implications, Technical Report No. 2, NR 387-034 (Washington: Office of Naval Research, June, 1967), p. 541.

each waveform. By calibrating a distance scale for the X axis, data collection is handled systematically.

Once the graytone percentages are collected from a certain number of scan lines, they can be recorded on either punch cards or magnetic tape and processed by a Fortran IV program. Any number of calculations could be performed by the computer in a matter of seconds.

Because geographic patterns will be represented by different graytone percentages, or a statistical evaluation of their occurrence, two of the most obvious calculations the computer could perform would be: (1) determining the surface area covered by each pattern or phenomenon and (2) the total area being analyzed in square miles. Concerning the former it would be possible to have the results either as a percentage figure, acres, or square miles. In Chapter VI these and other measurements are tested and evaluated for various land uses from both an agricultural and urban environment.

It is also possible for the computer to print out digital information in the form of letter coding which in effect constitutes land use mapping. For example if it was determined that the graytone percentages 45, 46, and 47 represented mature sugar cane, and it was decided that the letter C would indicate the above percentages, the computer would print this letter whenever the above numbers were contacted in the digital search; other letters might represent a variety of land use types.

B. Imagery Selection

The first research procedure involved selecting sets of color and color IR simultaneous images for the comparative waveform experiments.[13] In analyzing the positive transparencies it was felt that coverages from two major environments were adequate for the investigation. One set was of a coastal-intracoastal urban environment which centered on Boca Raton, Florida (Figure 11). The second set centered upon an intensive agricultural area east of Lake Okeechobee near the city of Belle Glade, Florida (Figure 12). These two examples exhibited a variety of surface features, vegetational types, and land uses. Another important reason for selecting imagery coverage from the two areas was that field teams simultaneously collected ground data during the imagery overflights to support photo evaluation and interpretation. Additional data were made available from the United States Weather Bureau-West Palm Beach and the Belle Glade Agricultural Experiment Station.

The images were recorded during three overflight missions: (September 11, 1968 - Mission No. 79; January 14, 1969 - Mission No. 85; and March 13, 1969 - Mission No. 90) by a NASA team which provided the camera systems as proposed by the Geography Department's contracts with the Geographic Applications Office of the U.S. Geological Survey. They

[13] Since this is the first waveform-computer study to utilize color and color IR photography, the characteristics of these films are fully discussed in Chapter III.

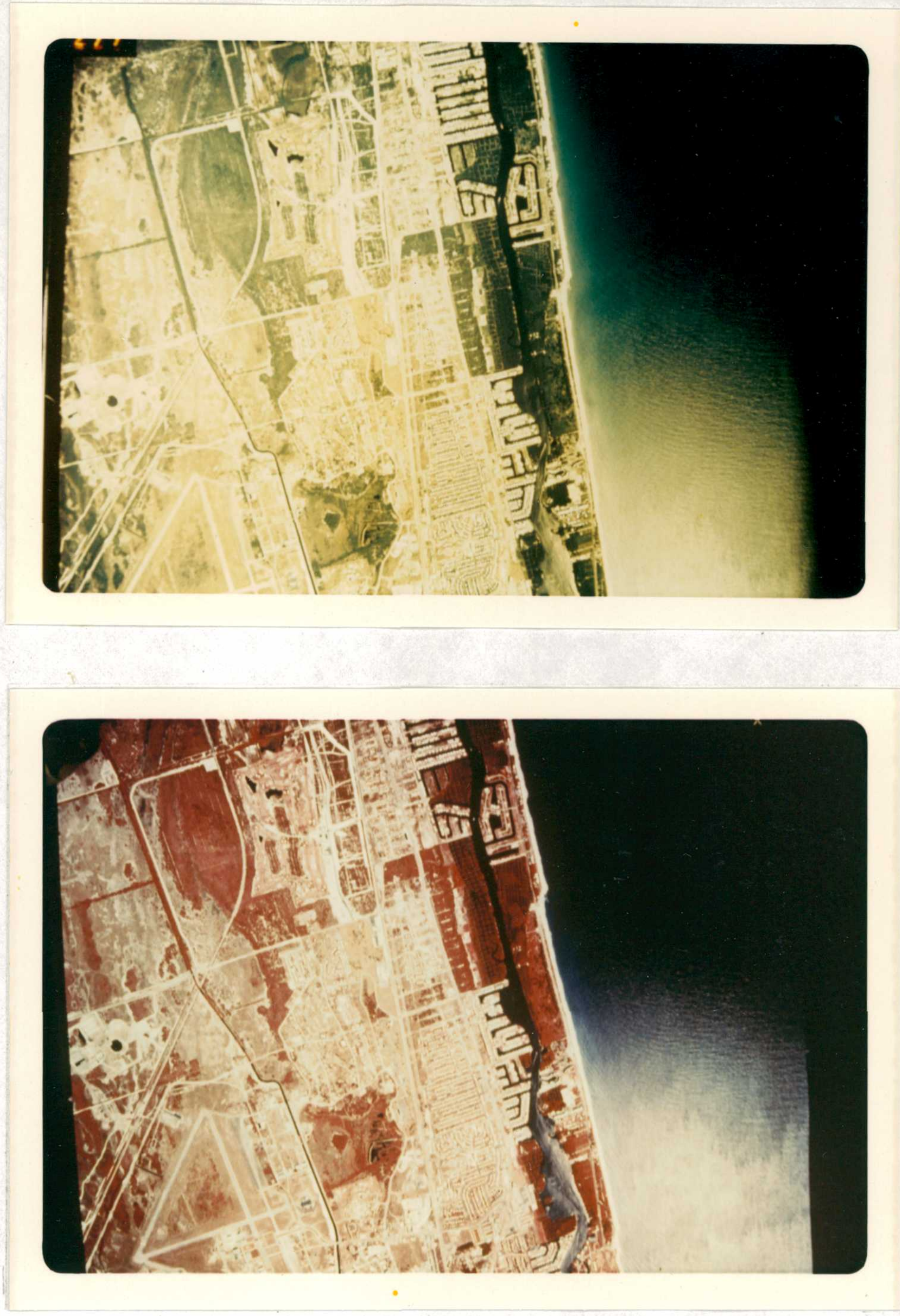

Figure 11. Color and color IR photographs of the Boca Raton area of NASA Test Site No. 164 operated by Florida Atlantic University.

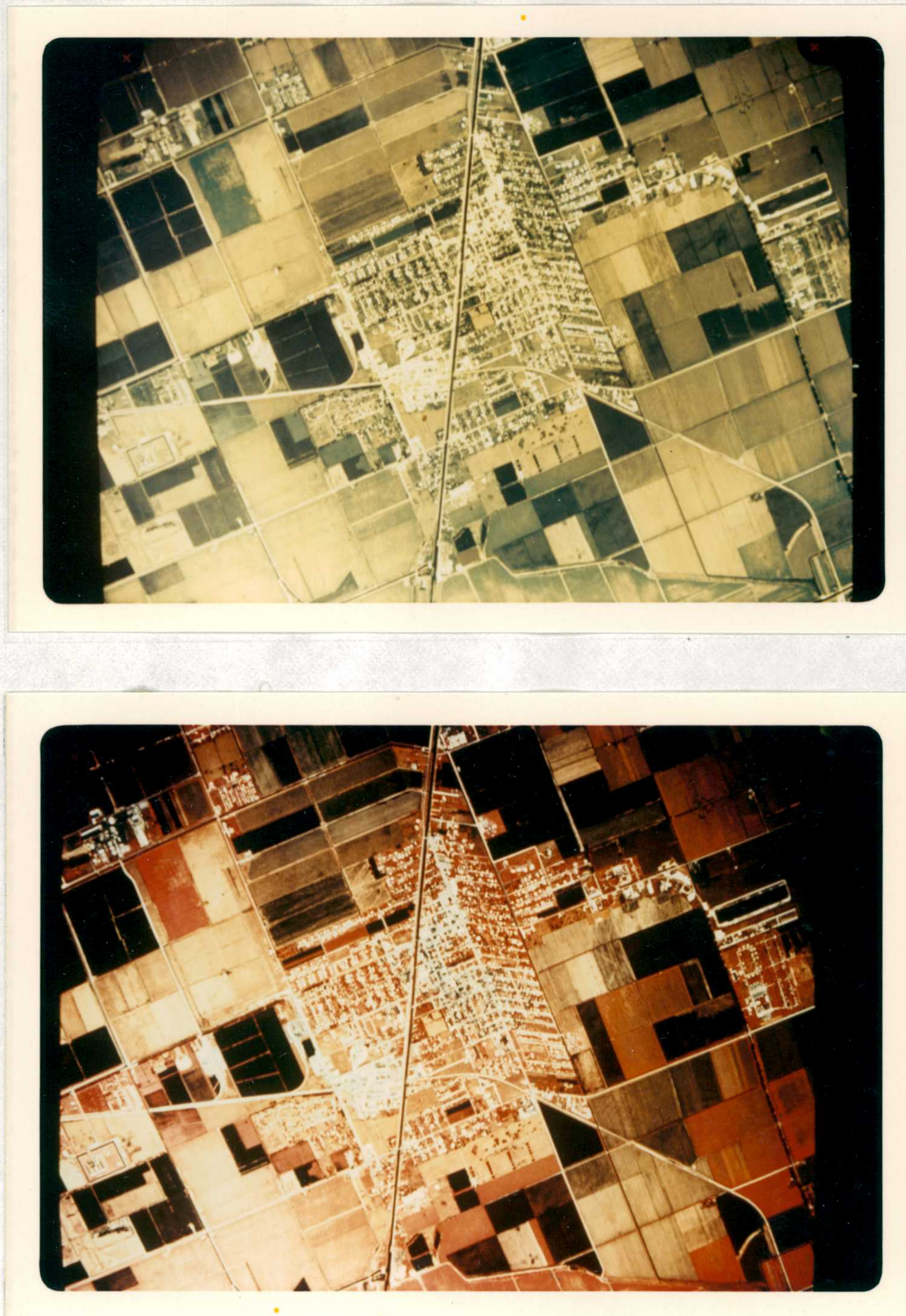

Figure 12. Color and color IR photographs of the Belle Glade area of NASA Test Site No. 164 operated by Florida Atlantic University.

were multisensor missions, as simultaneous color and color IR positive transparencies were recorded. Because of this feature, the following parameters remained constant: (1) scale, (2) light and sun conditions, (3) time of exposure, (4) atmospheric environment, and (5) state of ground phenomena. Wild RC-8 Cartographic Cameras were used, producing images that measured 9X9 inches. The images constituted simultaneous matched sets.

CHAPTER III

AERIAL COLOR AND COLOR IR MULTISPECTRAL IMAGERY

A. Aerial Color Photography

General Characteristics

To understand the characteristics of aerial color photography, one must first become aware of the premise that even the best films can never reproduce precisely all the colors present in a scene. Earlier color films failed to render acceptable colors because the emulsion was comprised of only a single layer. Later improvements involved a film constructed of three emulsion layers, each sensitive to various wavelengths of light within the visible spectrum (Figure 13). After additional refinements (e.g., dye stability) color films have been highly successful and are now receiving increasing utilization among all the earth sciences.

In almost all photointerpretation tasks, color aerial films afford a distinct advantage over panchromatic imagery in that color constituting the photography can contribute greatly to identification along with relative size, shape, and texture characteristics.[1] Color

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[1] Carl H. Strandberg, "The Language of Color," Manual of Color Aerial Photography, ed. John T. Smith (Falls Church, Va.: American Society of Photogrammetry, 1968), p. 4

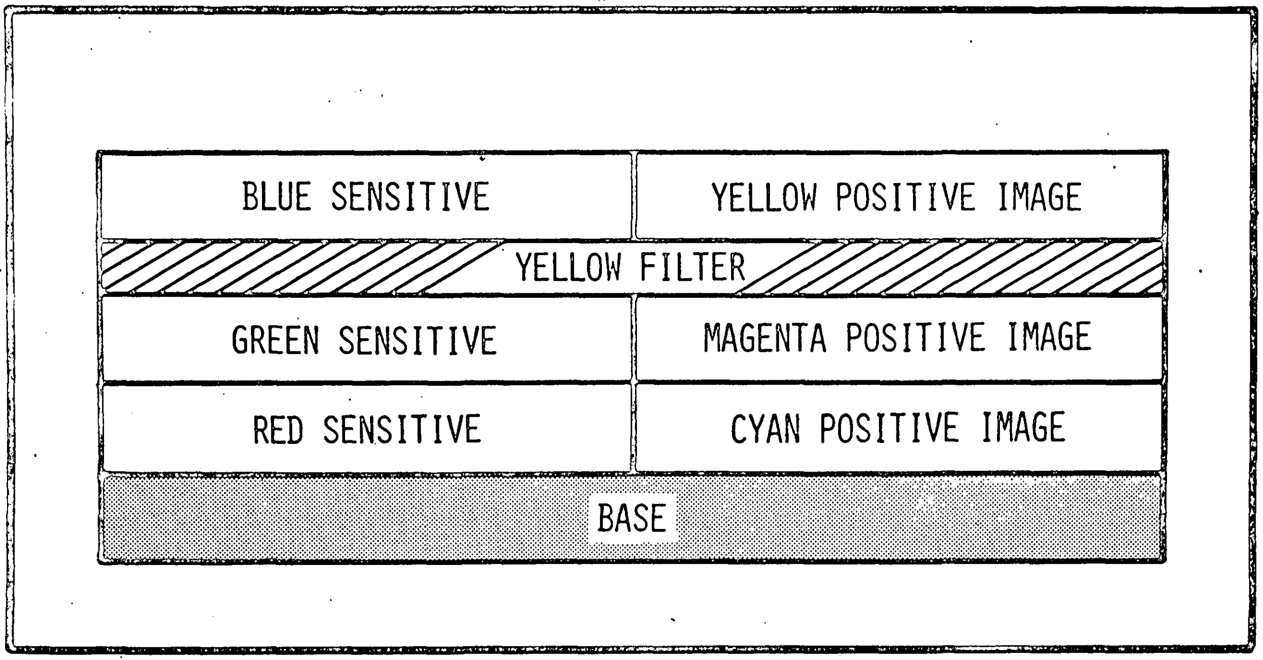

Figure 13. Multilayer color film.

Source: Raife G. Tarkington and Allan L. Sorem, "Color and False-Color Films for Serial Photography," Photogrammetric Engineering, XXIX (January, 1963), 88.

is indeed a most relevant interpretation factor in geographic science since the landscape is viewed in colors rather than graytones.

In the design of a reversal[2] color film, three principles govern the basis of design:

> (1) colors perceived by the human eye can be produced by mixtures of only three suitably chosen colors called primaries; (2) photographic emulsions can be made to respond selectively to each of these three colors; and (3) chemical reactions exist which can produce three individual colorants, each capable of absorbing essentially only one of the chosen primary colors.[3]

Therefore, a color reversal film is composed of three emulsion layers, each of which is sensitive to one of the three primary colors: (1) red, (2) green, or (3) blue (Figure 13). Through a dual development process positive dyes are produced in each layer: (1) yellow which is exposed by blue light; (2) magenta (mixture of blue and red) produced by green light; and (3) cyan (mixture of blue and green) responding to red light[4] (Figure 13).

When the layers of the processed positive are superimposed and

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[2]All Kodak Ektachrome films are designed for reversal processing. This procedure first involves developing the film as a negative material and then reversing the colors to form positive transparencies.

[3]Raife G. Tarkington and Allan L. Sorem, "Color and False-Color Films for Aerial Photography," Photogrammetric Engineering, XXIV (January, 1963), 88.

[4]Allan L. Sorem, "Principles of Aerial Color Photography," Photogrammetric Engineering, XXXIII (September, 1967), 1011.

viewed through a source of white light, they subtractively form colors closely approximating those of the original subject (Figure 14). It is impossible, however, to have perfect color renditions because of imperfect dyes. For example a theoretically pure cyan dye would absorb only red wavelengths, but the most ideal cyan dye also absorbs certain amounts of blue and green light. The same is also true for magenta dyes - some blue light is absorbed in addition to that of green light.[5] For this reason exact color reproductions will not be achieved.

When the film is illuminated by white light, the human eye sees the original colors of a scene through a subtractive process. Since all non-white subjects are represented by unequal amounts of dye in the emulsion layers, they combine to subtract the approximate quantities of red, green and blue light to form a color closely representing that of the original[6] (Figure 14). For example red is visible to the viewer when yellow and magenta dyes are present in their respective emulsion layers. The yellow positive dye absorbs blue light and magenta the green light, allowing red light to pass through. By the same principle blue light is produced by the subtraction process of magenta and cyan positive dyes. White light is present when none of the three dyes are present on the positive dye image,

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[5]Eastman Kodak Company, "Kodak Chemistry," <u>Manual of Color Aerial Photography</u>, ed. John T. Smith (Falls Church, Va.: American Society of Photogrammetry, 1968), p. 225.

[6]Sorem, "Principles of Aerial Color Photography," <u>op. cit</u>., p. 1012.

WHITE	RED	GREEN	BLUE	YELLOW	BLACK

A. COLORS OF SUBJECT PHOTOGRAPHED

YELLOW			YELLOW		
MAGENTA		MAGENTA		MAGENTA	
CYAN	CYAN			CYAN	

B. EMULSION LAYERS AFTER INITIAL EXPOSURE (NEGATIVE IMAGE)

	YELLOW	YELLOW		YELLOW	YELLOW
	MAGENTA		MAGENTA		MAGENTA
		CYAN	CYAN		CYAN

C. EMULSION LAYERS AFTER RE-EXPOSURE (POSITIVE DYE IMAGE)

WHITE	RED	GREEN	BLUE	YELLOW	BLACK

D. PROCESSED TRANSPARENCY VIEWED OVER SOURCE OF WHITE LIGHT

Figure 14. Stages in reversal color processing.

whereas the converse is true for black. In the latter example all three dyes are present, and once in conjunction they absorb all colors.[7]

To record acceptable colors one other component has to be added to the film format. In the historical film development program, after dye sensitive layers were included, the film still did not render acceptable colors; instead all photographs were dominated by a blue overcast. This problem was solved by placing a thin yellow filter within the film itself - between the yellow and magenta layers (Figure 13). A filter of this color cuts-off or absorbs blue light to which all layers are sensitive. A lens filter (e.g., Wratten Gelatin Filters HF-3, HF-4, or HF-5) is also used to absorb ultra-violet light. A filter of this type helps to reduce the excess bluishness caused by atmospheric haze.[8]

Kodak Ektachrome Aero Film, Type 8442.

This specific type of aerial color film, Kodacolor Aero Reversal, was first manufactured by the Eastman Kodak Company in 1942 for the Allied Forces.[9] A replacement offering several refinements was marketed in 1962. Three times faster, Kodak Ektachrome Aero Film, Type 8442,

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[7]Eastman Kodak Company, "Kodak Chemistry," op. cit.

[8]Eastman Kodak Company, Kodak Data for Aerial Photography (2nd ed. rev., Rochester, N.Y.: Eastman Kodak Company, 1969), p. 4.

[9]Tarkington and Sorem, op. cit.

incorporated increased definition, less granularity, it was a vast improvement over its predecessor.[10] Color images from the September (1968) overflight were produced from this film type.

Kodak Ektachrome MS Aerographic Film, Type 2448

By agreement between NASA and various chief investigators, Kodak Ektachrome Aero Film, Type 8442 was recently replaced with Kodak Ektachrome MS Aerographic Film, Type 2448. It has a definite advantage over 8442 since when it is processed to a color negative it forms the base for the Kodak Aero-Neg Color System. The following reproductions can then be made from the color negative: (1) color diapositive plates, (2) color paper prints, (3) color film transparencies, (4) black and white diapositive plates, and (5) black and white paper prints.[11] Type 2448 was the color medium used on the January and March (1969) overflights.

B. Color IR Photography

General Characteristics

Color IR film differs from normal color types because the resulting colors are "false" for the objects they are representing.

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[10] Ibid., p. 95.

[11] Eastman Kodak Company, "Kodak Color Films," ed. John T. Smith, Manual of Color Aerial Photography (Falls Church, Va.: American Society of Photogrammetry, 1968), pp. 204, 206.

First supplied to Allied Forces in 1942, it was originally known as Kodak Aero Film, Camouflage Detection.[12]

As the latter name implies, this film was designed primarily for detecting differences between living vegetation and various objects visually appearing to be live vegetation.

> Basically the film differentiated initially between (a) complex organic growing tissues containing chlorophyll and (b) non-living or non-organic objects, canvas, paint, rope nets, dead branches, and dead foliage used to camouflage military objects.[13]

Color IR film is sensitive to both the visible and near-infrared (700-900 millimicrons) portions of the electromagnetic spectrum (Figure 15). However, with a yellow lens filter, the film is sensitive to red, green, and infrared radiation instead of the usual blue, green, and red sensitivities of normal color film (Figure 15).

Upon dual exposure, identical positive dyes are produced in the three layers that also occur in color emulsions - yellow, magenta, and cyan. With color IR, however, these dyes are found in longer wavelength regions.[14] Once reversal processing is completed and the film is viewed through white light, the major colors recorded include blue, green and

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[12]Tarkington and Sorem, op. cit., p. 93.

[13]G. Ross Cochrane, "False-Color Film Fails in Practice: The Statement is Refuted," Photogrammetric Engineering, XXXIV (November,1968), 1143.

[14]Norman L. Fritz, "Optimum Methods for Using infrared-sensitive Color Films," Photogrammetric Engineering, XXXIII (October, 1967), 1129.

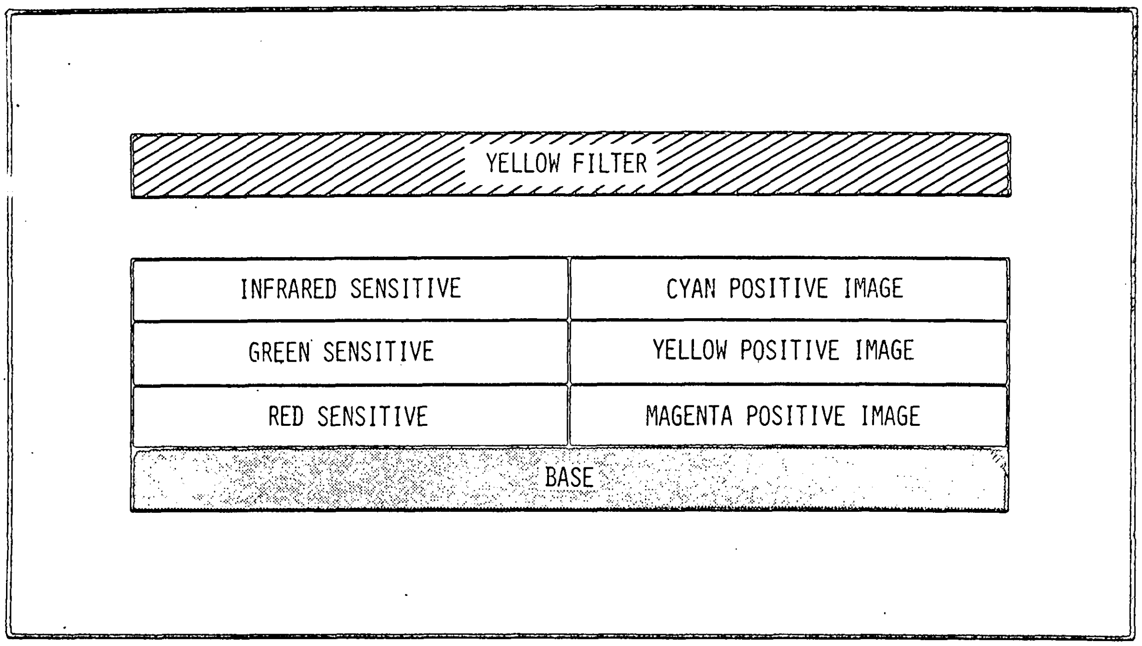

Figure 15. Kodak Ektachrome Infrared Aero Film, Type 8443.

Source: Norman L. Fritz, "Optimum Methods for Using Infrared-Sensitive Color Films," Photogrammetric Engineering, XXXIII (October, 1967), 1128.

red representing green, red and infrared sensitivities, respectively (Figure 16).

Living vegetation, because of the presence of spongy mesophyll, records in shades of red or magenta; infrared reflectance is very strong whenever this substance is encountered (Figure 17). For example in its initial use, healthy foliage would appear as red or magenta, whereas an object painted or camouflaged with an artificial covering would be rendered in shades of purple or blue.[15]

Because of the missing blue sensitive layer, the number of colors that can be recorded is more restricted for color IR than normal color film. However, this is not a disadvantage for this study. Color IR usefully generalizes some phenomena by recording them in one rather than several colors, and because of this electronic identifications are simplified. In addition, many remote sensing investigators have concluded that color IR photography is often the most useful type for analyzing geographic patterns. It sharply divides many boundaries, such as those between vegetational types or the contact between water and land surfaces.

Unlike color film, color IR has no filter incorporated within the emulsion layers. Instead, a yellow filter must always be placed over the camera lens to absorb blue light to which all layers are sensitive.

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[15]T. Eugene Avery, Interpretation of Aerial Photographs (2nd ed. rev.; Minneapolis: Burgess Publishing Company, 1968), p. 91.

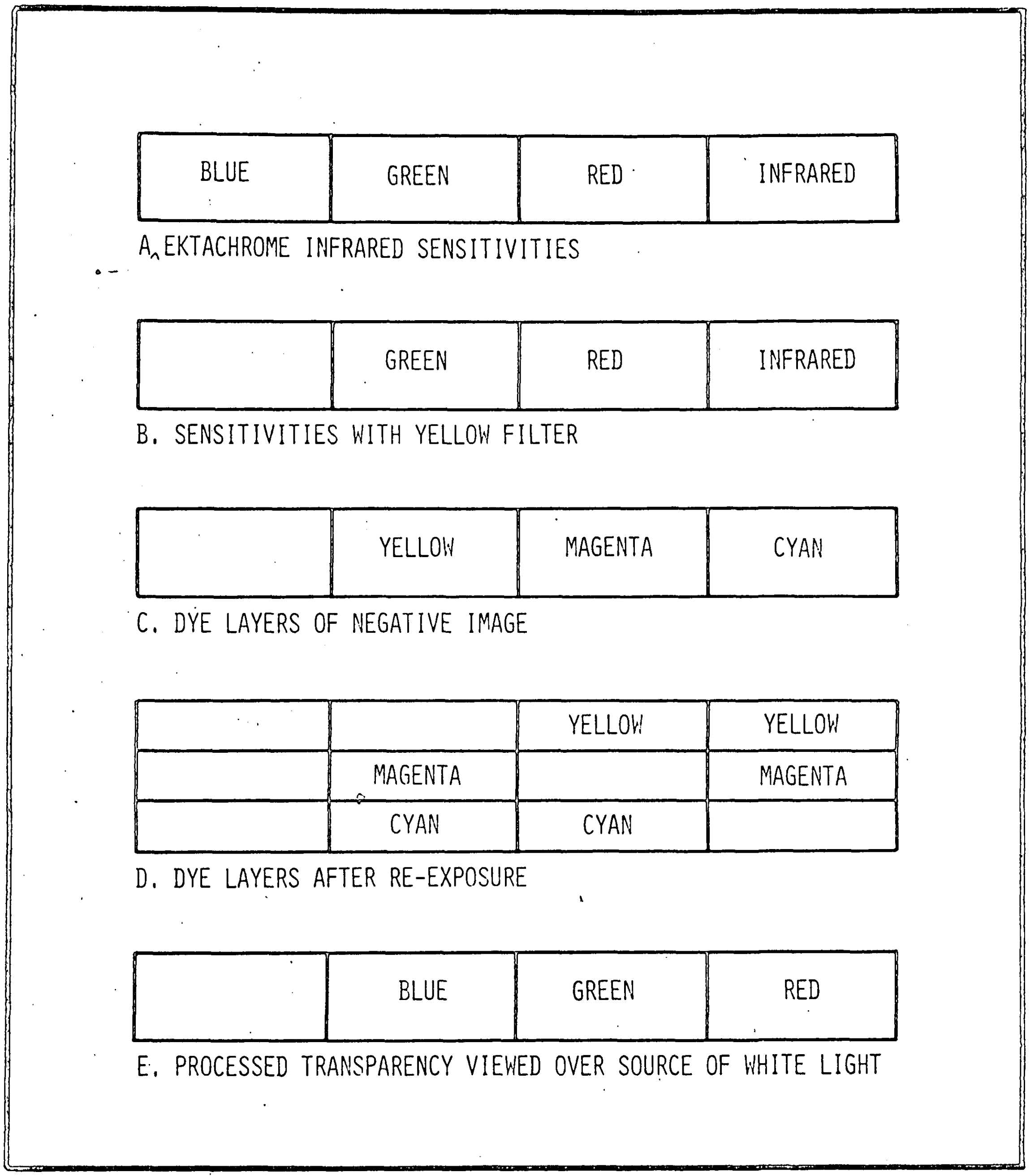

Figure 16. Stages in reversal processing for Kodak Ektachrome Infrared Aero Film, Type 8443.

Source: Norman L. Fritz, "Optimum Methods for Using Infrared Sensitive Color Films," Photogrammetric Engineering, XXXIII (October, 1967), 1129.

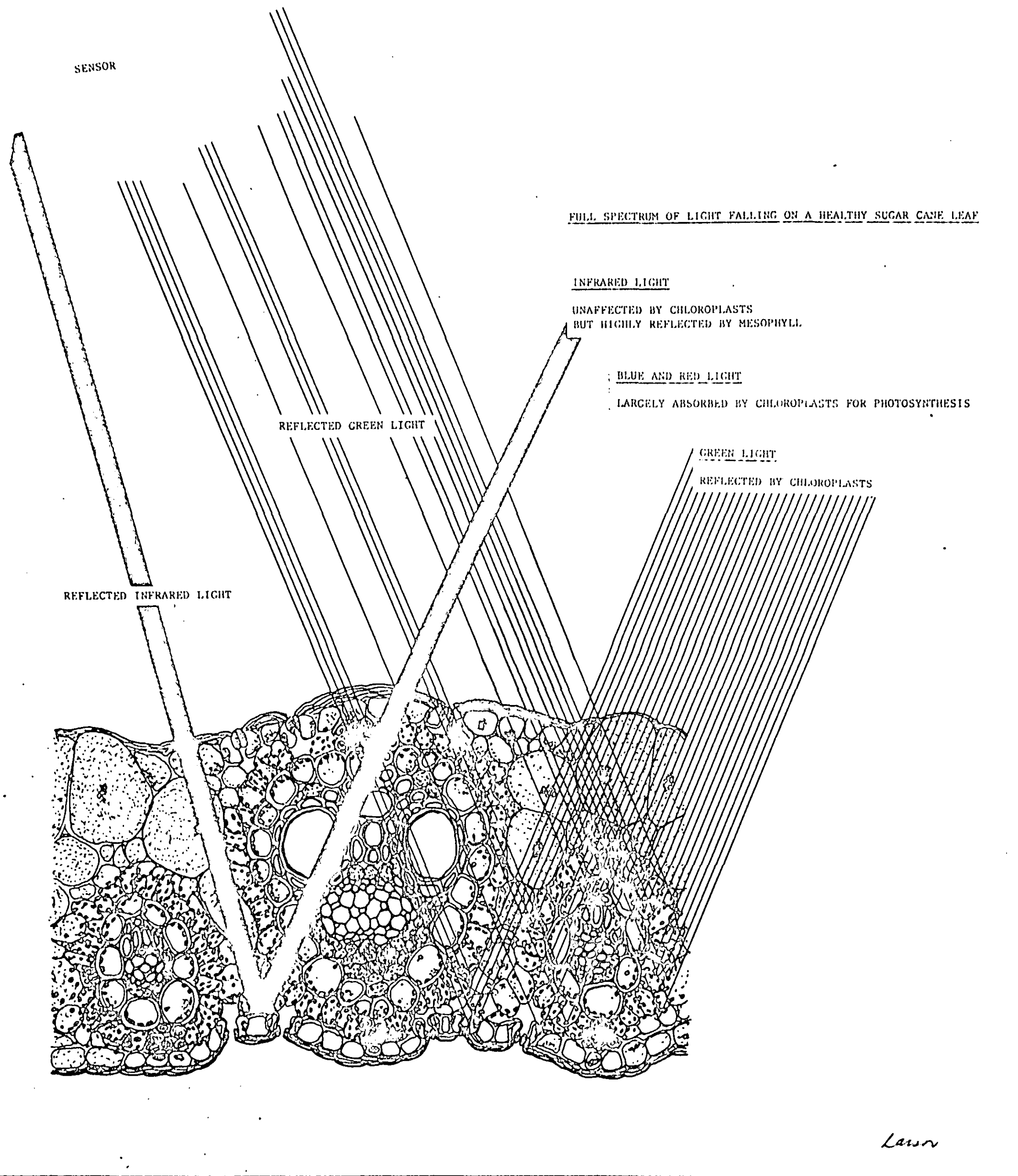

Figure 17. Illustration of how a sugar cane leaf reflects infrared radiation and absorbs certain other wavelengths.

With the presence of this filter, color IR film has a distinct advantage for obtaining good results on very hazy days. Definition is improved since the blue light produced by atmospheric haze is eliminated. The film also has a high gamma which tends to off-set degrading effects of haze in the green and red spectral regions.[16]

A Wratten 15 filter was recommended for the forerunner of this film, but the present type was designed especially for a Wratten 12 or minus-blue filter.[17] The latter absorbs the blue portion of the visible spectrum and a lesser amount of ultraviolet radiation. As evidenced in Figure 18, almost all of the green and red wavelengths pass through the Wratten 12 filter.

Kodak Ektachrome Infrared Aero Film, Type 8443

The color IR film used in this investigation is an improved version that was first used during World War II. The most recent replacement was introduced in 1962 under the trade name of Kodal Ektachrome Aero Film, Type 8443. As in the color film replacement, the color IR is also three times faster, has improved definition, and less granularity than the older product.[18] Designed for large format

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[16] Fritz, *op. cit.*, p. 1132.

[17] *Ibid.*, p. 1130.

[18] Tarkington and Sorem, *op. cit.*, p. 95.

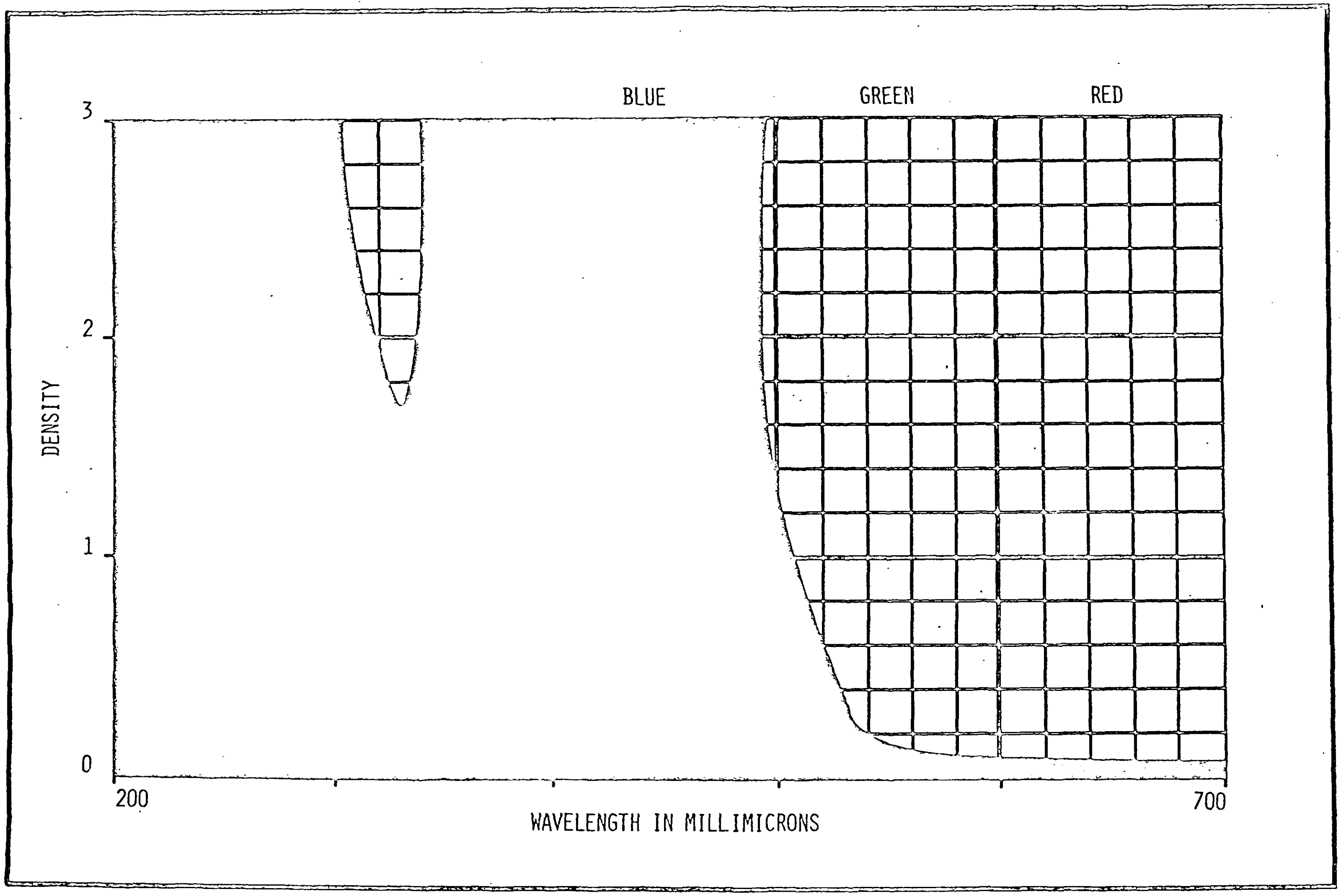

Figure 18. Kodak Wratten 12 Filter.

Source: Eastman Kodak Company, Kodak Data for Aerial Photography (Rochester, N.Y.: Eastman Kodak Company, 1969), p. 5.

cameras, it produces transparencies that measure 9X9 inches. All IR images from the four photo missions were recorded on Type 8443 film.

C. Color and Color IR Reliability

Metric Qualities

Formerly, aerial panchromatic film had a tremendous advantage over color and color IR types because of faultless metric qualities. Even after several refinements, which gave the latter certain advantages over black and white photography, metric stability could not be maintained. However, recent metric tests utilizing the latest film types have shown that color and color IR films now available equal or surpass aerial panchromatic imagery.[19]

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[19] Abraham Anson, "Developments in Aerial Color Photography," Photogrammetric Engineering, XXXIV (October, 1968), 1048 - 1057; Abraham Anson and J. Robert Quick, "Collection of Metric Color Photography of the Phoenix, Arizona Test Area," Manual of Color Aerial Photography, Ed. John T. Smith (Falls Church, Va.; American Society of Photogrammetry, 1968), pp. 334 - 341; Gary W. Schallock, "Metric Tests for Color Photography," Photogrammetric Engineering, XXXIV (October, 1968), 1063 - 1066; Gary W. Schallock, "Metric Tests of ASP-Phoenix Color Photography," Manual of Color Aerial Photography, ed. John T. Smith (Falls Church, Va.: American Society of Photogrammetry, 1968), pp. 342 - 364; William D. Harris, B. Frank Lampton, and Melvin J. Umbach, "Metric Quality of Color Serial Photography," Manual of Color Aerial Photography, ed. John T. Smith (Falls Church, Va.: American Society of Photogrammetry, 1968), pp. 324 - 333.

Additional refinements are possible when color transparencies are used instead of conventional print photos. Since one goal of this dissertation is to detect major and minor geographic occurrences, it is essential to have film types which reveal the greatest amount of information. Positive transparencies offer an advantage in this regard because of their slightly sharper images compared to those obtained from a reflection print. The reason for the sharper image centers on the principle of multiple internal light reflections which are trapped between the base and emulsion surface. The reflective interference factor tends to reduce definition on all photographic prints.[20]

Literature Overview

As previously mentioned, aerial color and color IR films are rapidly coming into a wider range of applications among the earth sciences. A review of the literature clearly indicates the growing amount of interest that has been directed towards these types of recording media. For reference purposes, a representative bibliography is included which lists a cross-section of significant works that have successfully utilized color and color IR photography.

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[20] R. Welch, "Film Transparencies vs. Paper Prints," Photogrammetric Engineering, XXXIV (May, 1968), 490 - 493.

CHAPTER IV

WAVEFORM ANALYSIS METHODOLOGY

A. Instrumentation Procedures

Introduction

In progressing to the stage of photographing electronic waveforms several instrumentation procedures were tested and evaluated. Also during the course of the experiments several parameters, which had not been anticipated, were encountered. Following sections center on a discussion of these factors.

Camera Calibration

A major problem curtailing many approaches to automatic photo-interpretation has been the reliance placed on absolute graytone values. Concerning previous television-waveform studies the procedure involved calibrating the camera while it was scanning a "stairstep" or commercial broadcast test pattern (Figure 19). By camera blanking the black segment of the pattern was recorded as 0% graytone and white as 100% graytone. These parameters were then maintained when the camera scanned all images regardless of type. Absolute graytone values were produced via electronic waveforms.

There are major drawbacks in using absolute values. They fail to take into account the many factors that vary on photographic emulsions. Several factors include: light and sun conditions, atmospheric environment, length of exposure, and processing variations. Latham suggested these factors inhibiting automatic interpretation

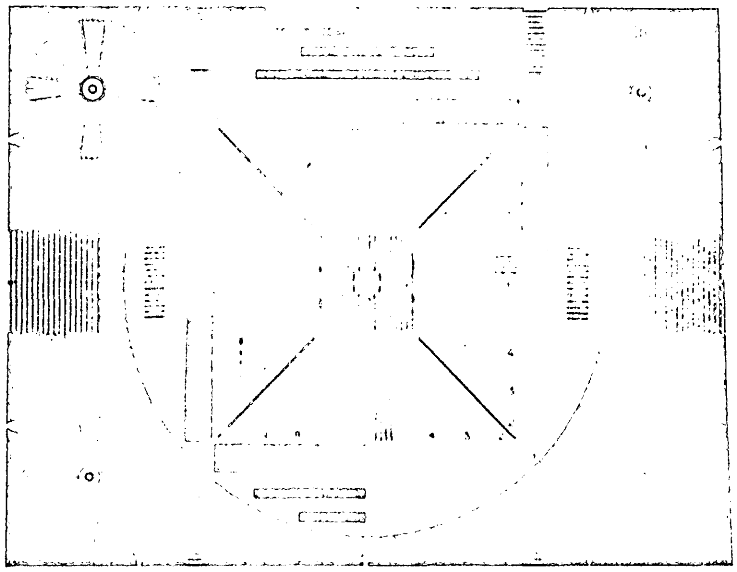

Figure 19. Commercial broadcast or "stairstep" test pattern.

might be overcome by adjusting percentage values to reflect the density range in each particular image.[1]

During initial tests the writer evaluated geographic identification capabilities using absolute values extracted from imagery exposed under extremely cloudy conditions. The absolute range between film densities was so limited geographic phenomena could not be segregated on electronic waveforms. (Figure 20). To the contrary, valid data extraction from the same imagery was realized when relative graytone values were extracted. These are percentage values for the range of densities detectable on each particular image.

The television camera plus waveform analyzer system is unique when compared to other scanning instruments. It has the capacity of extracting both absolute and relative graytone values. Only simple calibrations were required to insure relative graytone extraction. Concerning the microdensitometer, relative value extraction is possible only through an involved computer process that converts absolute graytone percentages to relative equivalents.

Because of the previously listed limitations, waveform results presented in this dissertation were based on relative values. The procedure involved camera calibration via the imagery to be scanned and not a test pattern. The camera blanking was such that the brightest pattern or object within each frame registered 100% graytone and the most dense 0% graytone. Once this step was completed

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[1]James P. Latham, "Instrumented Geographic Analysis of Multi-Sensor Imagery," Selected Papers of the 21st International Geographical Congress, New Delhi, India. (Paper presented December 5, 1968) To be published in 1969.

Figure 20. Geographic waveform based on absolute graytone values.

selected scan lines of an individual frame were evaluated.

Scanning and Recording Instrumentation

Before each waveform recording session, a "stairstep" test pattern was used as a medium to detect shape distortions of imagery reconstructed by the television camera (Figure 19). With the camera situated in such a manner to render a 1:1 scale relationship, calibration measurements were made on the test pattern and compared to identical areas on the reconstructed monitor test pattern. No additional calibrations were required after initial measurements were completed and the distortions removed from the system.

The second procedural step involved the actual imagery scanning and to insure proper orientation the television camera lens was aligned perpendicular to the film surface on all axes (Figure 21). With the camera and film correctly positioned they were not altered during laboratory sessions.

Concerning imagery scanning, a maximum of 20 minutes was alloted for photographing each of the waveforms selected for comparative analysis. Witmer discovered that when a television camera scanned a stationary subject exceeding 20 minutes the image was "burned" into the phosphor coating of the camera's principal cathode-ray tube.[2]

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[2]Richard E. Witmer, Waveform Analysis of Geographic Patterns Recorded on Visible and Infrared Imagery, Technical Report No. 4, NR 387-034 (Washington: Office of Naval Research, December, 1967), p. 55.

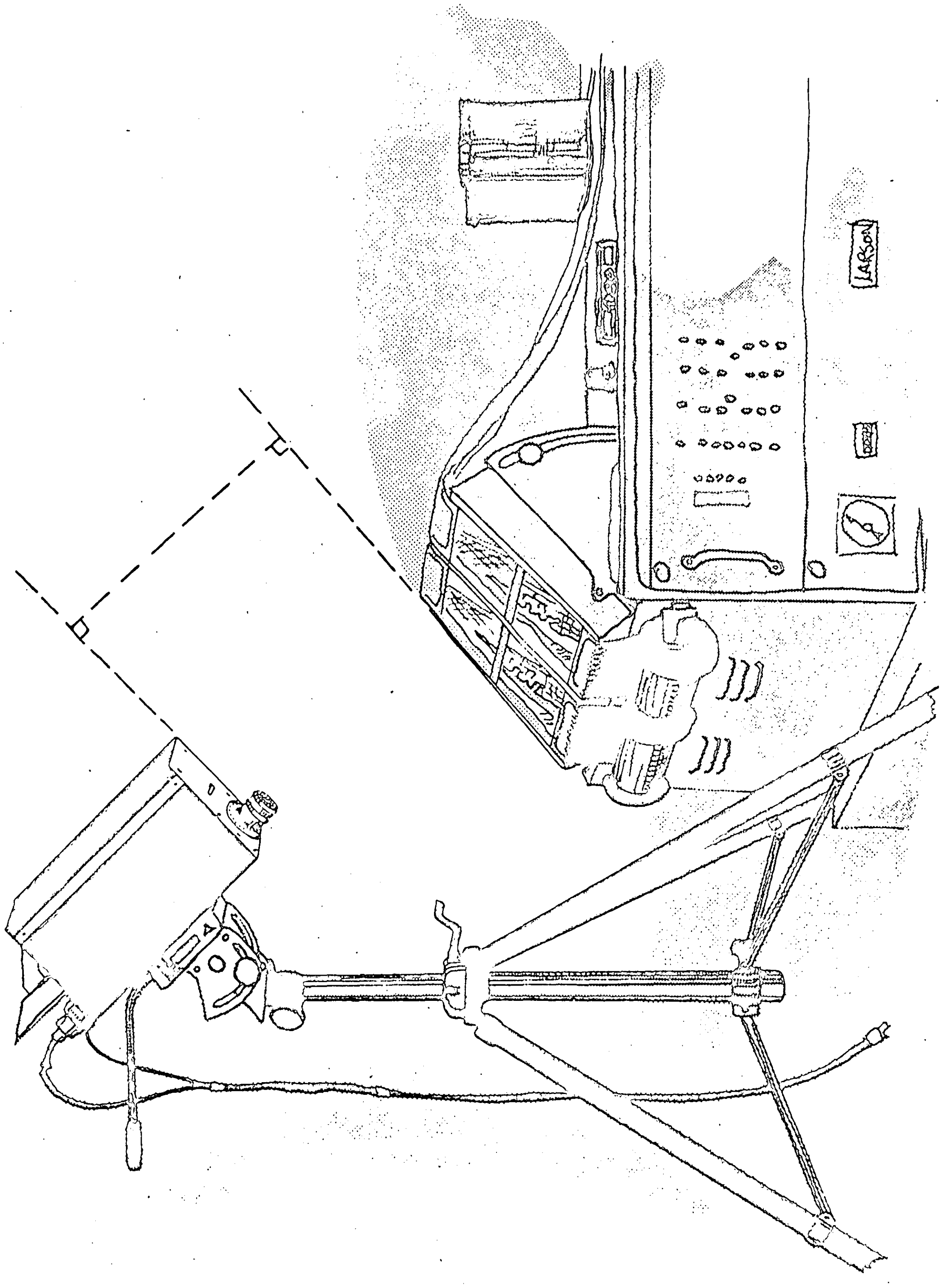

Figure 21.

Waveform and Monitor Recording

It was necessary to photograph both waveforms and monitor images. Waveforms were recorded on film enabling them to be enlarged for evaluation. Each time a waveform was photographed the televised image and superimposed trace line were also recorded. This was done to insure accurate scan line orientation when identical frames of the second film were scanned.

Two Nikkorex Zoom 35 cameras were used to photograph waveforms and monitor images. When photographing waveforms, a tunnel chamber was adapted to the camera lens system to collect sufficient light being generated by the waveform analyzer's cathode-ray tube (Figure 22). It was first anticipated to use a Polaroid camera and film but because of blurred waveforms and the extended time to photograph waveform segments this recording medium was abandoned. Tri-X film offered the best resolution quality and was used to record all waveforms.

Both Tri-X and Plus-X film offered similar results in reference to photographing the monitor images. Other films tested did not offer adequate contrast capabilities and the scan line crossing bright areas of the photo could not be detected.

During each waveform recording session the procedure involved photographing waveform segments and monitor images for one type of film. These negatives were subsequently developed and the monitor photos were used as a record for scan line alignment when identical frames of the second film type were scanned.

Figure 22. Photographing waveforms with the aid of a "tunnel chamber."

The Tektronix 529 Waveform Analyzer (modified) had a magnification feature enabling a waveform to be represented at 1X, 5X, or 25X magnification along the horizontal axis. As Witmer discovered, a 1X waveform was compressed to such an extent that geographic data could not be extracted; 25X proved too large but a 5X magnification contained a maximum amount of geographic information.[3] When using the latter magnification each waveform was photographed in four or five segments. The five inch analyzer tube was not large enough to display the entire waveform.

In using negative films all photos comprising the waveform segments could be exposed in a matter of seconds, whereas, it took up to 20 minutes with the Polaroid process.[4] To overcome the "burned" image factor involved with television scanning of a stationary subject the time factor was extremely important.

Scan Line Systems

All previous geographic waveform studies utilized the 525 scanning line rate. With recent equipment acquisitions this researcher had at his disposal four different scanning systems (525, 729, 843, and 945 lines). After several tests it was decided to utilize the highest line rate. The primary factor responsible for the decision centered on a relationship between the number of scan lines constituting a graytone image and the resolution quality of the system; higher line systems "have increasingly higher resolution

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[3] Ibid., pp. 57, 60.

[4] Ibid., p. 60.

capability.[5]

Therefore, an individual waveform recorded from a 945 system was less generalized than an identical line from a 525 line rate. Since approximately twice as many lines constitute a television image in the former type and scanning appertures are narrowed, each line selected for waveform analysis was thus a narrower trace. It incorporated fewer generalizations when compared to an identical line from a 525 scan image.

Because the Cohu 3200 series variable line rate television camera incorporated variable line components, it was a simple task to convert the camera to scan each scene with 945 lines. A modified Tektronix 529 Waveform Analyzer was set for any of the line scan patterns, in this case 945. A Conrac Monitor was also available which was designed for the 945 line system.

Waveform Analyzer Response Signal

The waveform analyzer, via a frequency-response switch, enabled the researcher to graphically view a waveform in either a flat or IEEE (Institute of Electrical and Electronic Engineers) form. Flat signal responses exemplified the maximum frequency the television system was capable of producing. It contained both system noise and voltage fluctuations resulting from density changes on the imagery being scanned

[5]Ibid., p. 75.

by the television camera.[6] To the contrary, the IEEE signal produced a more generalized waveform. With the frequency-response switch set in this position most of the signal noise was filtered from the system, but in certain examples minor geographic occurrences were also removed from the analog signal.

To solve the first research objective of the dissertation, the effectiveness of discriminating geographic phenomena recorded on aerial color and color IR aerial imagery, flat waveforms were chosen as the research medium. Conversely, IEEE waveforms were utilized to computer analysis experiments.

Concerning the first example, it was felt that the flat signal discriminated more secondary geographic occurrences than the IEEE. Because initial experiments were designed to evaluate how effectively a black and white television system could discriminate, waveforms were photographed in flat form.

After the first research objective was completed, it was determined that for an automatic photointerpretation system the flat response could not be feasibly utilized. The major drawback centered around the fluctuating signal and the difficulty a digital comparator and printer would have in recording graytone signals at equal distances along each waveform trace. The IEEE waveform would offer optimum conditions for the above systems to operate.

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[6]Nelson R. Nunnally, A Comparison of Microdensitometry and TV Waveform Analysis as Expressions of Observed Landscape Patterns on Radar, Technical Report No. 6, NR 389-151 (Washington: Office of Naval Research, August,1968), pp. 4-5.

As evidenced in Figures 23 and 24 the flat waveform does reveal more geographic phenomena than the IEEE form but both discriminate major geographic occurrences. These broader patterns would be of substantial benefit to geographic problem solving because they would in effect constitute land use patterns.

Source Light

Before any television scanning could commence a source of white light, or light containing all colors, had to be passed through the transparencies. A Glow-Box, Model 12-21D fulfilled the requirement for providing the direct source of white light.

In addition to the glow-box the only other light generated in the laboratory was produced by the monitor picture tube, but it was located at the rear of the television camera. A large screen was placed between the two sources so monitor light would not interfere with the source light reaching the camera lens. If for any reason the ceiling lamps were required a cap was placed over the television lens until such a time when they were no longer required.

B. Color Discrimination Tests

I Introduction

As previously stated, films recorded on three overflights were used in color discrimination tests. The September (1968) overflight encompassed both the Boca Raton and Belle Glade Test sites. Because of adverse weather conditions only Belle Glade was covered on the

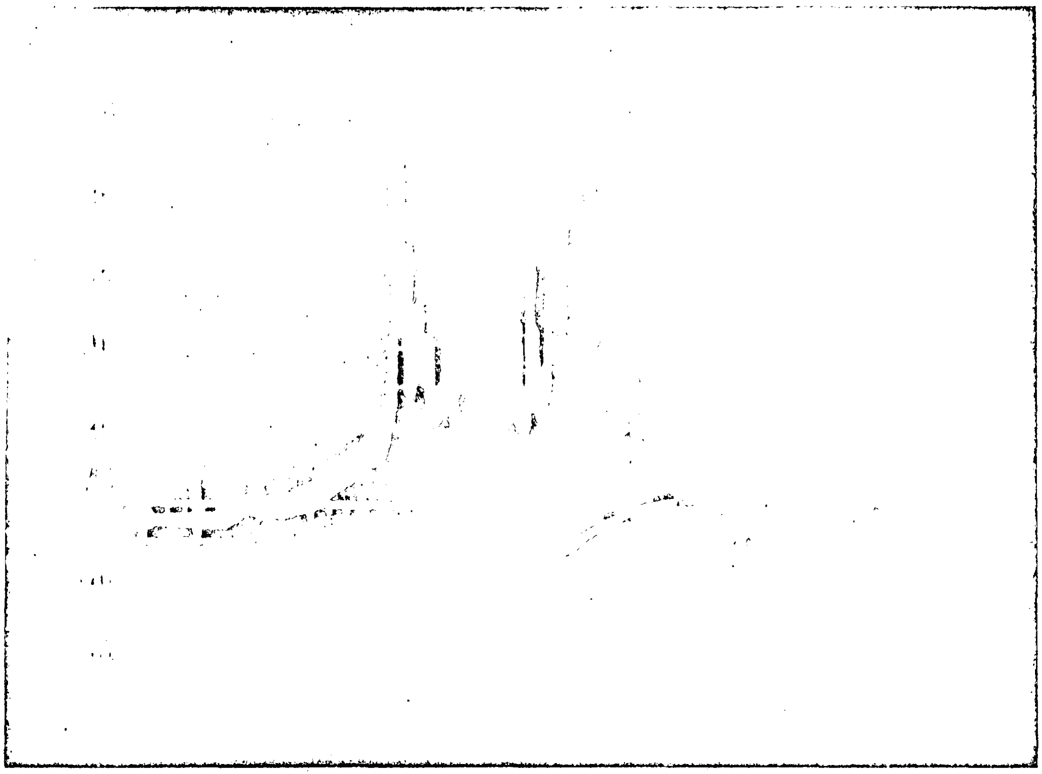

Figure 23. Flat geographic waveform at 1X magnification.

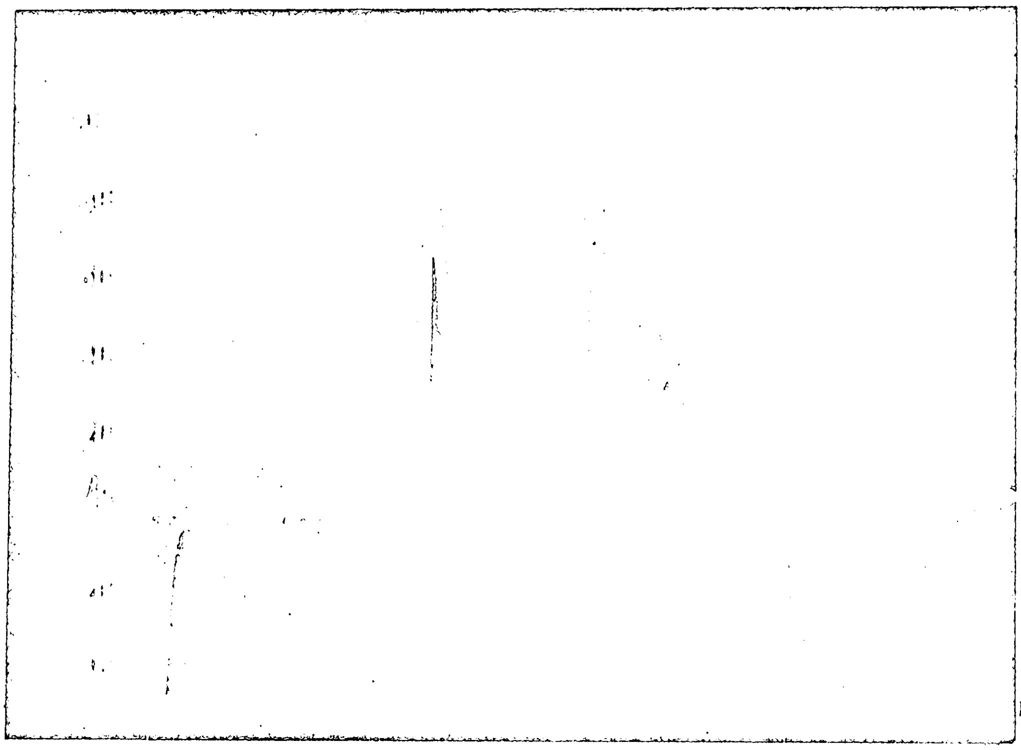

Figure 24. IEEE geographic waveform at 1X magnification.

January (1969) flight and Boca Raton on the March (1969) run. All flights obtained simultaneous matched sets of color and color IR multispectral transparencies.

After initial tests, it was decided to evaluate a total of ten scan lines. Special emphasis was placed on the September imagery because of extraction potential realized once the television camera was calibrated via the imagery scanned rather than a test pattern.

Altogether, four sites were selected for color discrimination tests - two each within Boca Raton and Belle Glade. Identical traverses from both the color and color IR frames were photographed and evaluated as to their effectiveness in discriminating various colors which represented geographic phenomena.

Because of human eye deception, detailed discussions centering on particular colors or hues inherit in the films are omitted. It is extremely difficult to adequately describe these color phenomena, especially shades, to a reader. As Strandberg notes, it is very difficult "to describe color or its variations to someone who is not physically present to observe that color."[7] Therefore, to minimize confusion only occassional references are made to specific color criteria. The color and color IR photographs of the two test sites instead will serve as a visual record for comparisons (Figures 11 and 12).

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[7] Carl H. Strandberg, "The Language of Color," Manual of Color Aerial Photography, ed. John T. Smith (Falls Church, Va.: American Society of Photogrammetry, 1968), p. 3.

Boca Raton, Site One - September Imagery

Site one in Boca Raton centered on a largely undeveloped coastal area that was dominated by the Atlantic Ocean, accompanying beach, mangrove swamp, and Intracoastal Waterway (Figure 25). Various vegetational types were at peak growth stages because of numerous convectional showers received during the month of September.

Comparing the color and color IR waveforms for the selected scan line, several similarities are noted (Figures 26 and 27). Both waveforms revealed the house and beach as near maximum gray-tone levels. The urban unit rendered the highest percentage, 95 and 80, for the color and color IR waveforms, respectively. These two phenomena were responsible for high excursion levels because of the hueless or near-whiteness of the features. Other high readings coincided with scattered sand areas and paved highways.

A second similarity between the two waveforms was the similarity in their silhouette shapes. But a close examination revealed that although appearing similar from an overview, the color waveform better discriminated the geographic occurrences. Perhaps the most obvious difference recorded by the waveforms centered on the Atlantic Ocean. The color film waveform clearly differentiated submerged beach rock, whereas the same differentiation was absent on the color IR waveform. In the former, the film recorded beach rock as dark grayish-blue and the immediate water area light greenish-blue.

On the color IR film the beach rock was largely obscurred by a very dark blue hue representing the ocean. Past studies have revealed

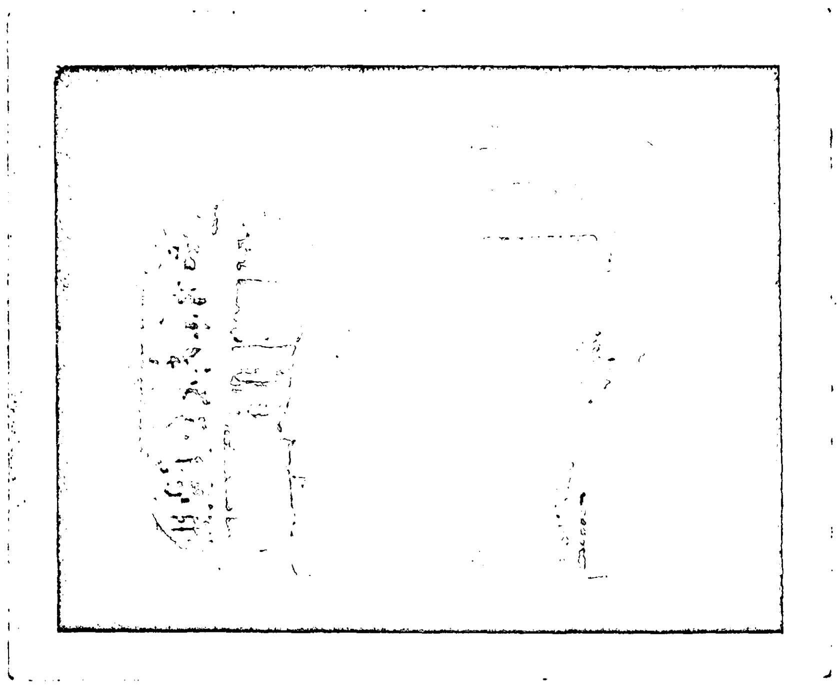

Figure 25. Boca Raton test site 1 and accompanying scan line (NASA-ERS Mission 79, Frame 9956).

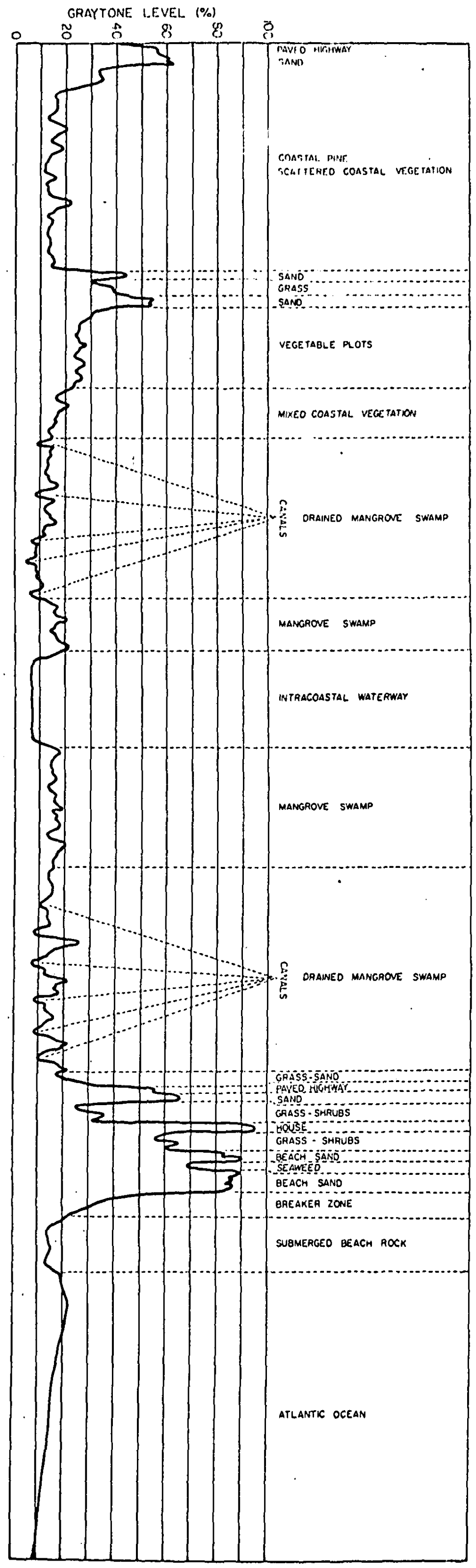

Figure 26. Graphical display of waveform representing September (1968) color image - Boca Raton, Florida (Site 1).

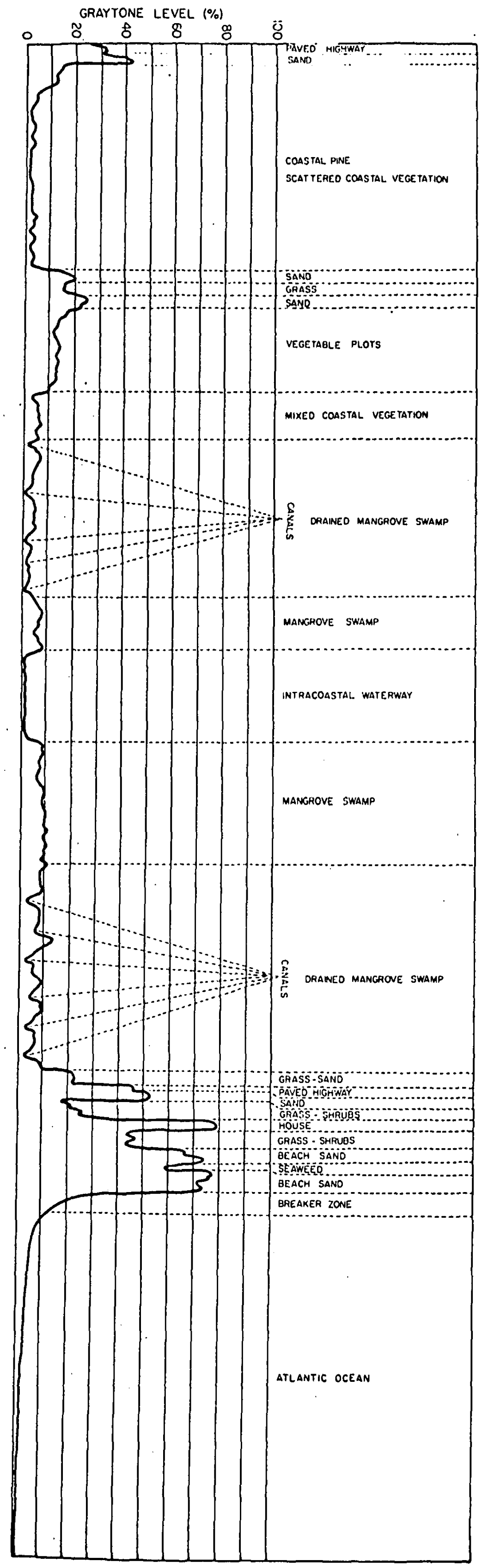

Figure 27. Graphical display of waveform representing September (1968) color infrared image - Boca Raton, Florida (Site 1).

the water penetrating ability of color IR is much less than that of conventional color film. Graytone percentages substantiated these findings: electronic returns extracted from color film revealed greater water depths - as the water deepened the graytone level decreased.

Another variance was also noted in the range representing the geographic phenomena. Very little graytone variance appeared between the different types of vegetation on the color IR waveform. Along all areas of both waveforms the range was quite apparent. The most limited range for the color IR waveform centered on the sector representing coastal pine-scattered coastal vegetation. The range only approached 3% between occurrences, whereas, it reached 15% on the color traverse. This latter figure indicates that the vegetation types were better isolated on the color waveform. On the color IR frame the coastal pine-scattered coastal vegetation was largely recorded as a blue-black hue which was slightly less dense than the near-black representing the Intracoastal Waterway. The closeness in color was responsible for the similar graytone returns between water and vegetation on the color IR waveform.

A third difference centered on mangrove-canal discriminations. After initial interpretation, it was concluded the television-waveform system had difficulty discriminating colors representing mangrove swamp and drainage canals, for some segments of the mangrove waveform were identical to canal percentages on both waveforms.

After examining the scan line and traversed occurrences at an 8X magnification, three variances were discovered. First, in certain areas the scan line, instead of intercepting all canals, had run parallel to certain canal segments. Second, in other instances the line coincided with mangrove-canal boundaries because the scan line actually covered a "ground" width of approximately 10 feet. The electronic signal contained both mangrove and canal information. The third deviation was encountered in areas where mangrove was encroaching into the drainage canals. This encroachment phenomenon was also responsible for a "mixed" electronic signal.

With these three factors in mind, it then became apparent the waveforms representing both films were actually capable of segregating mangrove and canals. Range levels were, however, larger for the color waveform. The different graytone levels indicated the presence of the three previously discussed factors. Where the scan line clearly traversed the canals, graytone percentages were minimal.

Waveform data extracted from the color frame did, however, reveal more detailed information than the color IR within mangrove areas. In certain sections exposed soil was prevalent and its brownish-yellow hue registered higher percentages than the deep reds and greens representing mangrove on the color and color IR films, respectively.

It is apparent that both waveforms revealed or segregated geographic phenomena. The color waveform offered a wider range of values, however, making percentage differences for individual occurrences larger than for phenomena present on the color IR waveform. As an aid for additional comparisons, percentage values for each occurrence were averaged and presented in Table 1.

It must be remembered that the previously discussed geographic phenomena discriminations were made possible only by calibrating the television camera for relative data extraction. If absolute values had been used, segregations would not have been possible. Figure 20 represents a waveform extracted along the same traverse as that utilized for site one. It was apparent that no useful information could be extracted from such a waveform based on absolute graytone percentages.

Boca Raton, Site Two - September Imagery

Site two in Boca Raton centered on an intracoastal subdivision which is typical of recent urban developments in southeastern Florida (Figure 28). A scan line traversing several individual houses was selected to test the television camera and waveform analyzer system's ability to discriminate housing units in a complex urban environment (Figures 29 and 30).

Both the color and color IR waveforms proved successful in segregating the housing units from surrounding phenomena, in fact both recorded houses as near maximum graytone percentages. White roofs of concrete tiles are common in this section of Florida and that hueless sensation explained the high graytone percentages. Small differences in value among roofs result from differences in roof paint condition.

TABLE I

GRAYTONE AVERAGES, BOCA RATON - SITE 1[a]

(SEPTEMBER IMAGERY)

GEOGRAPHIC PHENOMENA	COLOR		COLOR IR	
	%	RANK	%	RANK
Housing Unit	95	1	80	1
Beach Sand	92	2	64	2
Seaweed (Dry)	70	3	59	3
Paved Highways	57	4	28	6
Sand	56	5	34	4
Grass - Shrubs[b]	45	6	31	5
Vegetable Plots	25	7	12	7
Mangrove Swamp[c]	20	8	08	8
Mixed Coastal Vegetation[d]	18	9	06	9
Atlantic Ocean	17	10	03	10
Coastal Pine-Scattered Coastal Vegetation	16	11	03	11
Drainage Canals	09	12	02	12
Intracoastal Waterway	07	13	01	13

[a]Percentages are approximate.

[b]Includes groomed and wild grasses and ornamental shrubs.

[c]Includes areas with scattered Australian pine and exposed soil.

[d]Includes mangrove, Australian pine, coastal pine, cabbage palm, and palmetto.

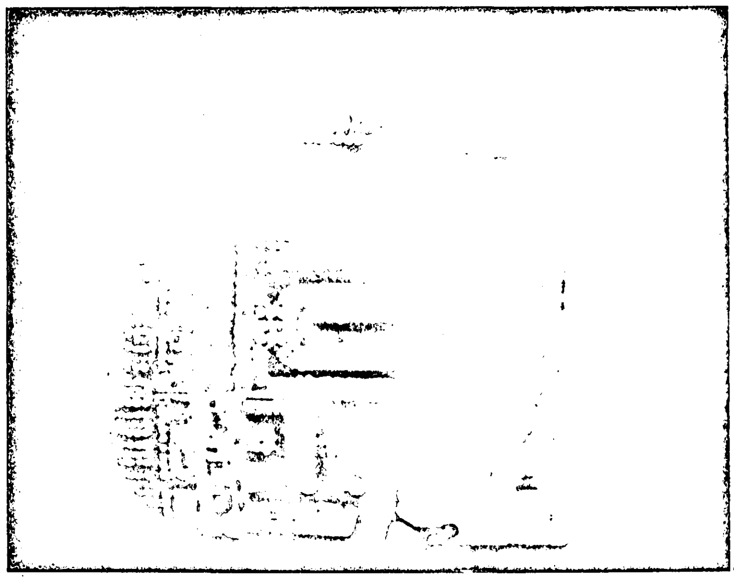

Figure 28. Boca Raton test site 2 and accompanying scan line (NASA-ERS Mission 79, Frame 9955).

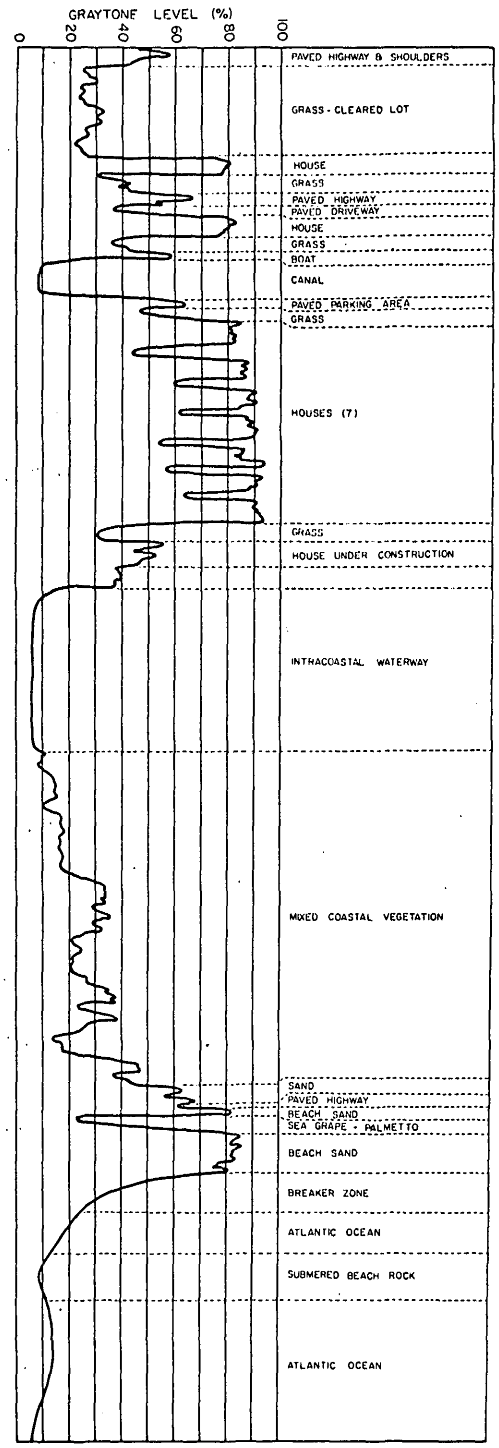

Figure 29. Graphical display of waveform representing September (1968) color image - Boca Raton, Florida (Site 2).

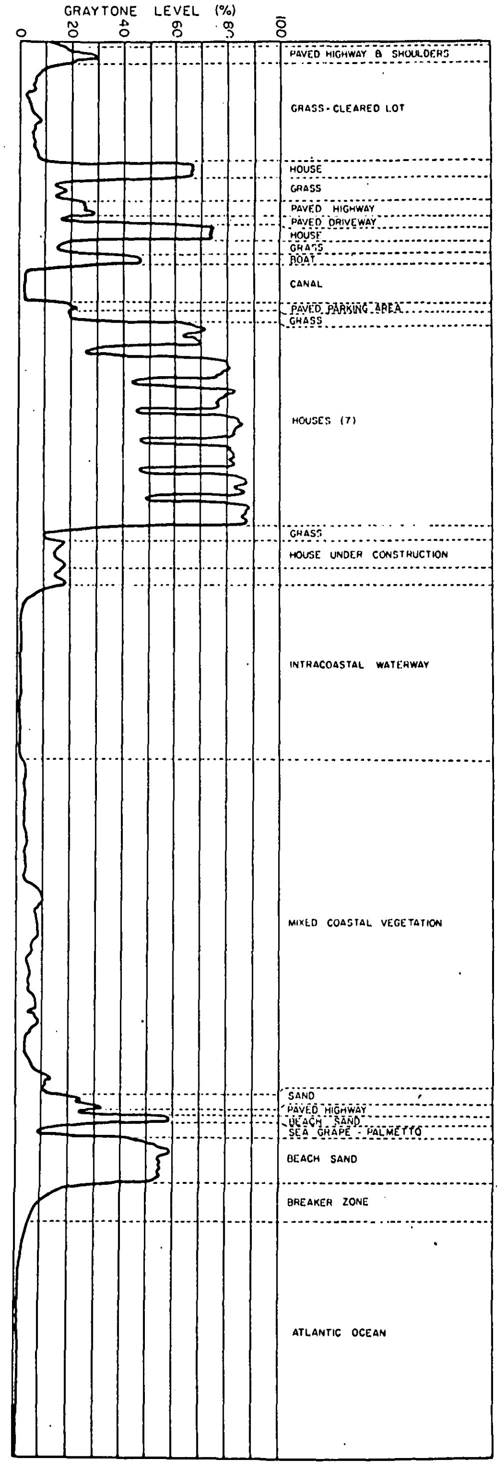

Figure 30. Graphical display of waveform representing September (1968) color infrared image - Boca Raton, Florida (Site 2).

A large range was evidenced between the nine completed houses and the one under construction. The range approached 60% on the color waveform and 70% for the color IR. An examination of the transparencies revealed the typical white roof to be missing on the latter and instead a dark gray pre-roof material was present. That graytone was responsible for the relatively low percentage level representing the house under construction on both waveforms.

Also similar to the waveforms representing site one, the largest range in graytone levels corresponded to the color waveform (Figures 26 and 29). Of the 12 geographic occurrences listed in Table II, seven registered 10% or less for the color IR but only two for the color waveform.

Two factors accounted for the limited color IR graytone levels. First, in a mixed vegetational environment a color film not only rendered many shades of green but also other hues depending upon environmental conditions (e.g., water availability) and health states. Conversely, color IR film recorded the vegetation mainly in red or magenta shades and involved a smaller variety of colors than the color image.

The second factor centered on the sensitivity of the Cohu television camera. Like the human eye, the camera's vidicon tube was more sensitive to wavelength areas within and near the green portion of the visible spectrum (e.g., greens, yellows, browns). Both the human eye and camera are least sensitive to wavelengths in the red sector of the spectrum. Therefore, the camera had more difficulty in discriminating various shades

TABLE II

GRAYTONE AVERAGES, BOCA RATON - SITE 2[a]
(SEPTEMBER IMAGERY)

GEOGRAPHIC PHENOMENA	COLOR		COLOR IR	
	%	RANK	%	RANK
Houses	90	1	80	1
Beach Sand	84	2	58	2
Paved Highways	64	3	27	4
Paved Parking Area	64	4	18	5
Boat	59	5	46	3
Paved Driveway	36	6	16	6
House Under Construction	31	7	10	7
Grass - Cleared Lot	27	8	07	9
Mixed Coastal Vegetation[b]	24	9	06	10
Sea Grape - Palmetto	23	10	08	8
Atlantic Ocean	13	11	02	11
Canal	09	12	02	12
Intracoastal Waterway	06	13	01	13

[a]Percentages are approximate.

[b]Major dispersants within this group include: mangrove, Australian pine, coastal pine, cabbage palm, palmetto, and sea grape.

of reds than of greens. The maximum green sensitivity accounted for the larger range of values evidenced in vegetational types recorded on the color waveform. Similar results were also apparent on waveforms representing site one (Table II).

Analyzing the colors representing mixed coastal vegetation,[8] a wide array of hues were visible on the conventional color image. On the waveform, the higher graytone percentages coincided with light greens and browns, with the latter color recording the higher graytone percentage. Deep or dark greens registered much lower levels. One such example was the occurrence bordering the Intracoastal Waterway (Figure 29). Mangrove is the dominant vegetation, registering a deep green on the color film.

By contrast, only two major hues represented mixed coastal vegetation on the color IR image: dark magenta-red and bluish-green. Minimum percentages (e.g., mangrove swamp adjacent to Intracoastal Waterway) represented the former hue with higher percentage levels representing the bluish-green color.

As in the past example the waveform representing the color scan recorded the submerged beach rock as a lower percentage than the surrounding water. The feature, although slightly visible, was not detected by the camera when it scanned the color IR image.

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[8]Mixed coastal vegetation accounted for a complex varitial network, but major types included: mangrove, Australian pine, coastal pine, palmetto, cabbage palm, and sea grape.

Boca Raton, Site Two - March Imagery

The identical scan line utilized for the Boca Raton September imagery (Figure 28) was rematched on the March color and color IR transparencies. In effect, the same ground phenomena were viewed at two different seasonal periods. In addition, the television-waveform system extracted graytone data from image sets recorded under varied atmospheric states.

As evident in Figure 31 and 32, both waveforms again identified geographic phenomena. It was also noted on the color IR waveform that a larger percentage range segregated the occurrences than on the waveform extracted from the September imagery. The range on the former was primarily an effect created by clear skies on the day of the overflight.

When restricted by clouds, infrared radiation has difficulty in reaching the earth's surface. Therefore, only a segment of potential radiation was intercepted and reflected from the vegetation on the day of the September overflight. The lack of reflection (September imagery) was evident because of an overall dark magenta hue representing vegetation and in the small range of graytone values recorded from mixed coastal vegetation (Figure 30).

By contrast, optimum conditions (e.g., cloud cover less than 10% and atmosphere free of turbulence)[9] for acquiring color IR photos were

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[9] Harland R. Cravat, "Planning and Operations of a Color Aerial Photographic Mission," Manual of Color Aerial Photography, ed. John T. Smith (Falls Church, Va.: American Society of Photogrammetry, 1968), p. 43.

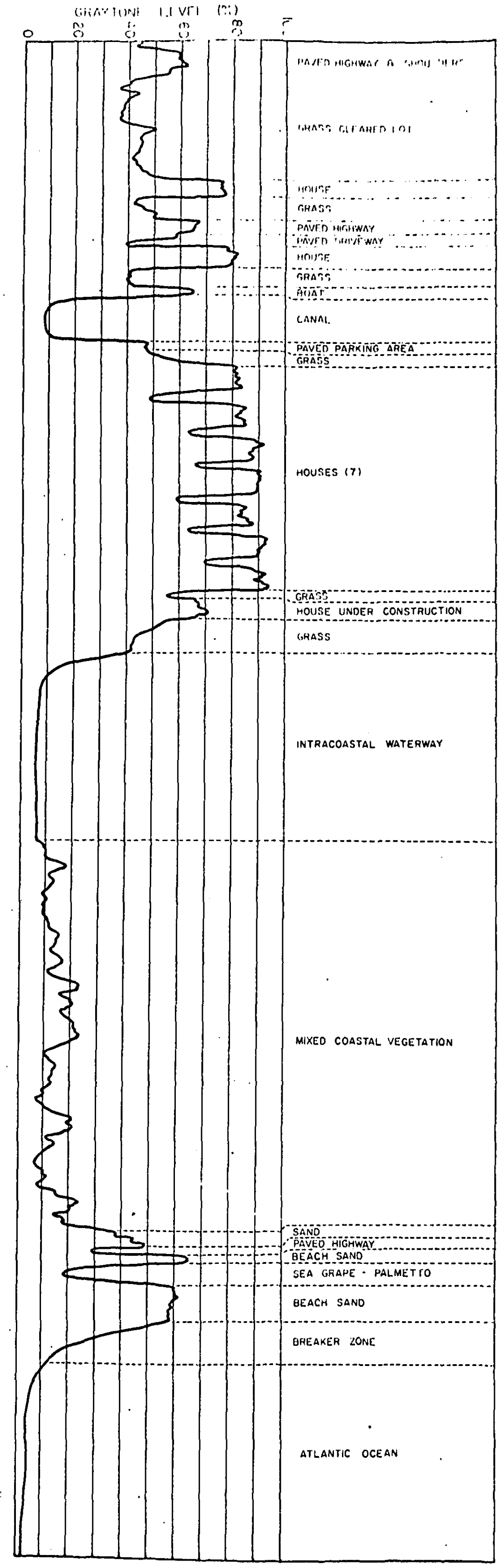

Figure 31. Graphical display of waveform representing March (1969) color image - Boca Raton, Florida (Site No. 2).

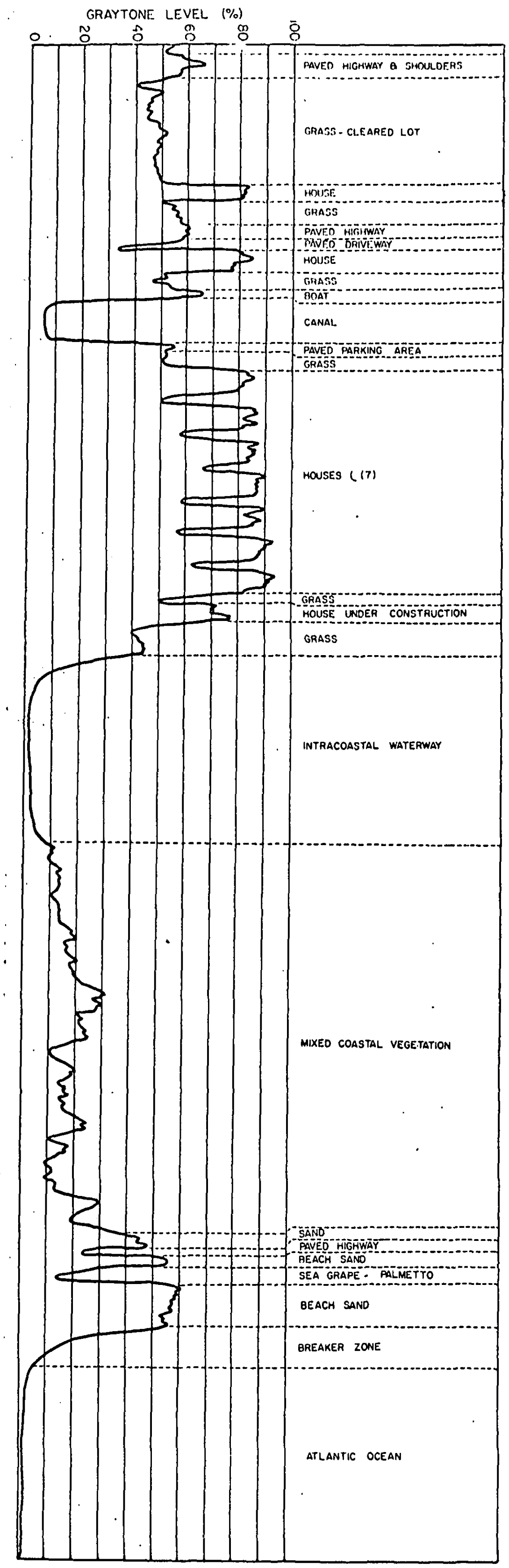

Figure 32. Graphical display of waveform representing March (1969) color infrared image - Boca Raton, Florida (Site 2).

present on the day of the March overflight. With clear skies, infrared radiation was unhampered and a wider range of hues were captured on the color IR film.

One major difference in graytone levels appeared when the September and March waveforms were compared. The house that was under construction in September was nearly completed at the time of the March overflight. Because of a dark gray roof material the house registered a low graytone percentage. The identical house recorded on the March imagery had the typical cement roof and, of course, resulted in the waveform analyzer registering a higher graytone level. The percentage was still below other house levels, but the house under construction had yet to receive a white paint coating. Instead the hue was a light gray.

A Comparison of Tables II and III reveals several similarities. The houses represented near maximum percentages and the ocean, canal, and Intracoastal Waterway near minimum percentages. With the exception of the Atlantic Ocean the readings were very similar.

Different sea states accounted for the ocean graytone deviation. The submerged beach rock was not detectable on the color waveform for the above reason. It was visible on the September color waveform because of a lower and calmer sea (Figures 29 and 31).

Belle Glade, Site One - September Imagery

Belle Glade is a major sugar cane center with cane in some stage of growth being under cultivation at all times during the year. Beef cattle

TABLE III

GRAYTONE AVERAGES, BOCA RATON - SITE 2[a]
(MARCH IMAGERY)

GEOGRAPHIC PHENOMENA	COLOR		COLOR IR	
	%	RANK	%	RANK
Houses	86	1	89	1
House Under Construction	69	2	78	2
Boat	65	3	70	3
Beach Sand	61	4	60	4
Paved Highways	52	5	52	7
Paved Parking Area	48	6	56	6
Grass - Cleared Lot	44	7	58	5
Paved Driveway	38	8	33	8
Mixed Coastal Vegetation[b]	17	9	18	9
Sea Grape - Palmetto	18	10	16	10
Canal	09	11	06	11
Intracoastal Waterway	07	12	03	12
Atlantic Ocean	06	13	01	13

[a]Percentages are approximate.

[b]Major dispersants within this group include mangrove, Australian pine, coastal pine, cabbage palm, palmetto, and sea grape.

also add to the economy and large acreages are devoted to improved pastures. The scan line chosen for the September photography exemplified these two land uses, but other types were also visible along the traverse (Figure 33).

In examining the waveforms (Figures 34 and 35) attention was immediately directed towards the maximum graytone levels representing the house, unpaved roads, paved roads, and cattle feed lots. These phenomena registered high percentage levels because of near-white signatures. Graytone averages also indicated the high percentage levels (Table IV).

In the Lake Okeechobee area crushed limestone is used extensively for road surfacing and as a base for cattle feed lots. One such road peaked at 90% graytone - the highest value on the color waveform (Figure 34). The amount of use accounts for the graytone variances in unpaved road returns.

Because of poor drainage conditions, crushed limestone serves as a medium to insure a dry environment for cattle feeding operations. These lots also registered high graytone percentages. On the color IR waveform, one such lot registered 72% - the maximum level for the particular traverse (Figure 35).

A second uniform trend centered on the waveform level associated with exposed muck soil found in three locations along the traverse. Muck photographed dark brown to black, depending upon the amount of fibrous peat. In the above example the three occurrences of muck had a photographic color closely resembling the color for deep water. It was

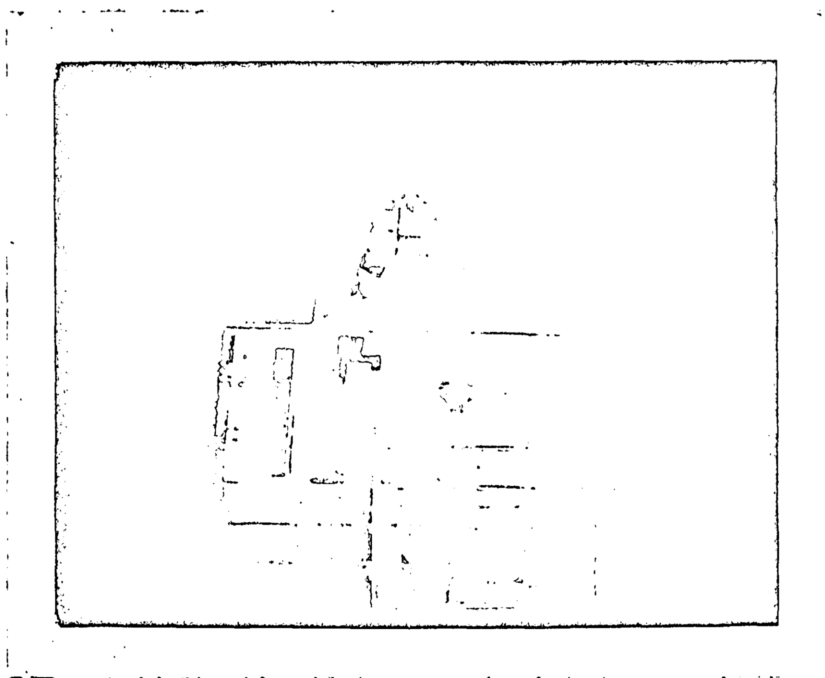

Figure 33. Belle Glade test site 1 and accompanying scan line (NASA-ERS Mission 79, Frame 9861).

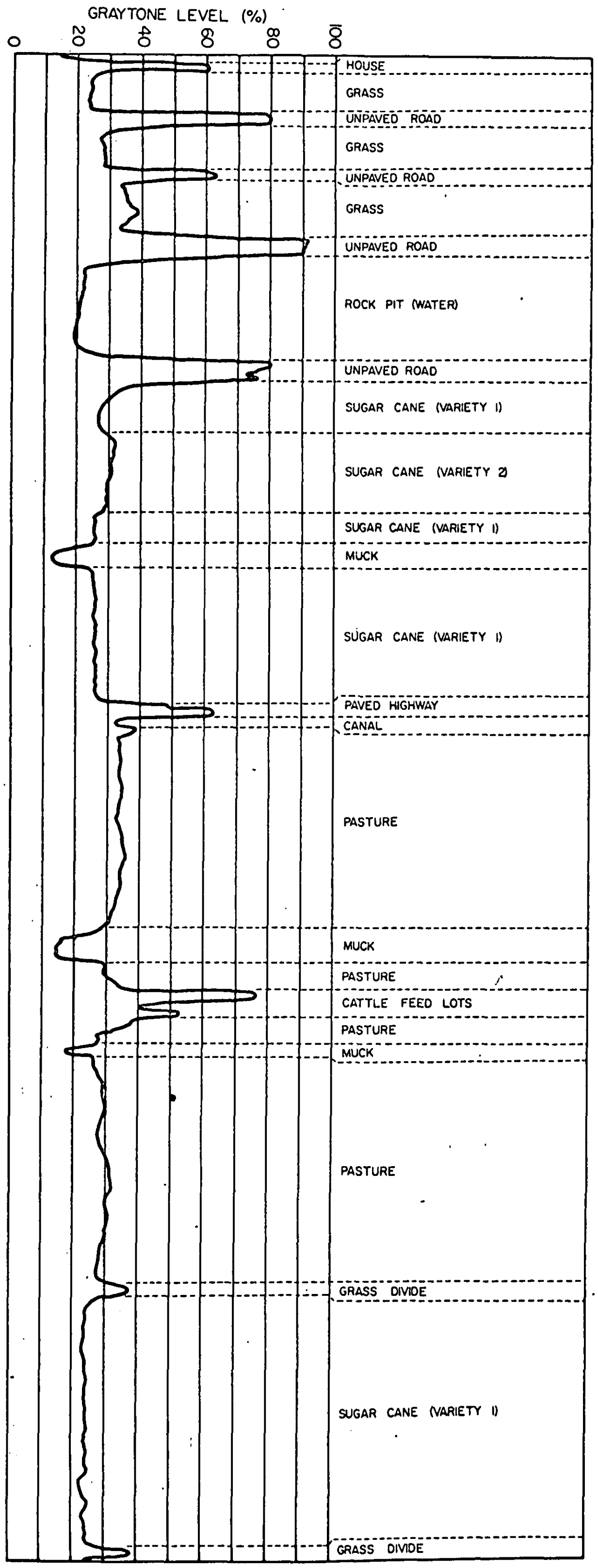

Figure 34. Graphical display of waveform representing September (1968) color image - Belle Glade, Florida (Site 1).

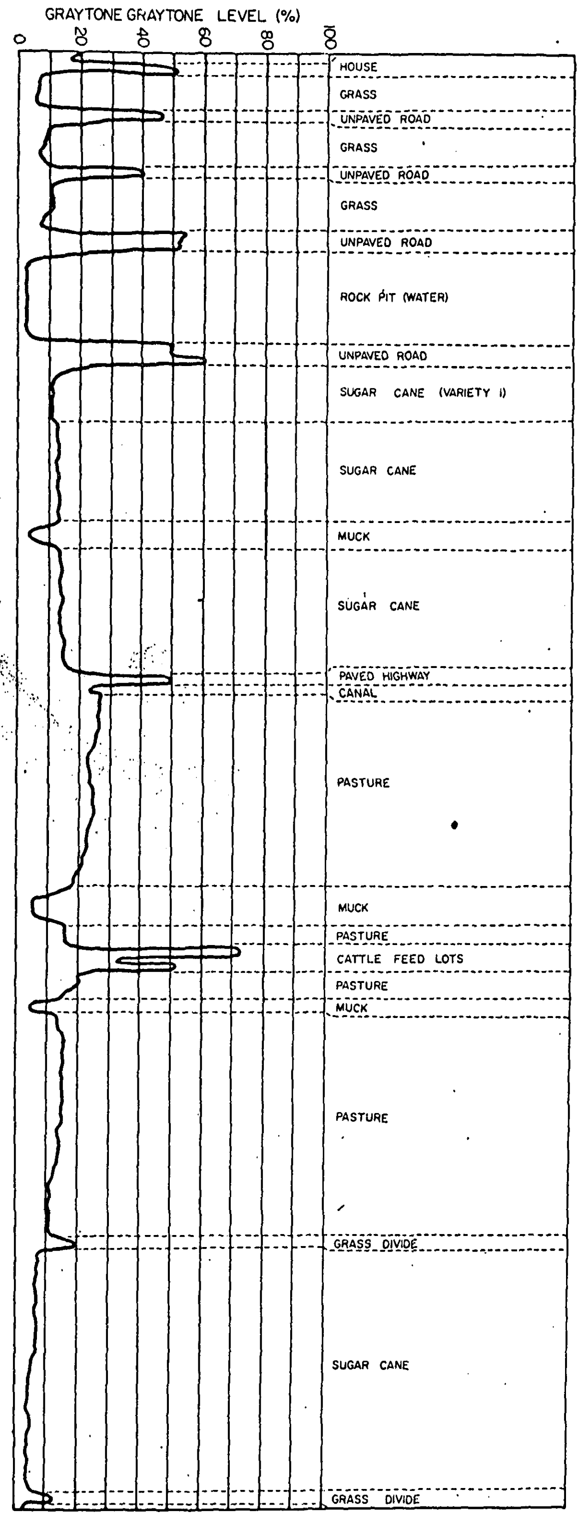

Figure 35. Graphical display of waveform representing September (1968) color infrared image - Belle Glade, Florida (Site 1).

TABLE IV

GRAYTONE AVERAGES, BELLE GLADE - SITE 1[a]
(SEPTEMBER IMAGERY)

GEOGRAPHIC PHENOMENA	COLOR		COLOR IR	
	%	RANK	%	RANK
Unpaved Roads	77	1	48	4
Feed Lots	65	2	62	1
Paved Road	63	3	50	2
House	62	4	50	3
Grass Divides	38	5	16	7
Pasture	33	6	20	6
Canal	32	7	23	5
Grass	29	8	08	10
Sugar Cane (Variety 2)	30	9	13	8
Sugar Cane (Variety 1)	26	10	11	9
Water Rock Pit (Water)	20	11	02	11
Muck	14	12	05	12

[a]Percentages are approximate.

impossible in many examples to visually distinguish water and muck on the basis of color. The television camera, however, had no difficulty in discriminating the two features. On the color IR waveform the muck registered higher values than the water in the rock pit (Figure 35) and lower on the waveform representing the color image (Figure 34).

Similar to water features on the Boca Raton waveforms, the percentages for the quarry site were low on both waveforms. The small canal traversed by the scan registered 32% and 23% on the color and color IR waveforms, respectively. More shallow than the quarry water, bottom reflections within the canal tended to increase graytone percentage levels (Figures 34 and 35).

A major difference between waveform signatures was the ability to distinguish sugar cane varieties. The color waveform discriminated the two varieties, but the same segregations were not evident on the color IR waveform. Again the television camera segregated green shades more readily than the reds present on the color IR frame.

Percentage ranges for pasture represented maximum levels on both waveforms (Figures 34 and 35). In the color IR example, variations of red were not the only hues present; blues were also recorded. Prior to the overflight severe storms hit the Belle Glade area, and saturated soils were evident in low lying sections.

The interpretation clue was the blue hue in detecting water saturated pasture. Because reds were replaced with blues, the television camera had a higher ration of color discriminations. On the color IR waveform segments depicting pasture, the lower graytone percentage areas represented water saturated pasture.

The color film captured the identical pasture areas in greens and browns. The frame areas corresponding to the blue shades were rendered in dark greens; drier areas ranged from moderate green to light brown. Television discrimination was very successful, again because of the colors in question.

Belle Glade, Site Two - January Imagery

The January imagery captured the apex of the sugar cane harvest period in Belle Glade. The scan line traversed several stages in the harvesting cycle (Figure 36). Waveform results indicated each of these stages were segregated on both electronic returns (Figures 37 and 38).

Unlike previous examples, the geographic data contained on the color IR waveform closely approached the segregation potential realized from the color photography. These larger discrimination levels were a result of a wider hue range on the color IR image than encountered in previous frames. Because the sugar cane was at maturity, unharvested fields were reflecting only minimal amounts of infrared radiation. This low reflectivity was immediately detected on the photography. Instead of deep reds or magentas the sugar cane foliage recorded in light pinkish-reds. In fields where the cane had already been harvested color IR hues were absent, no infrared reflectance was experienced, and colors were directed toward brown wave lengths.

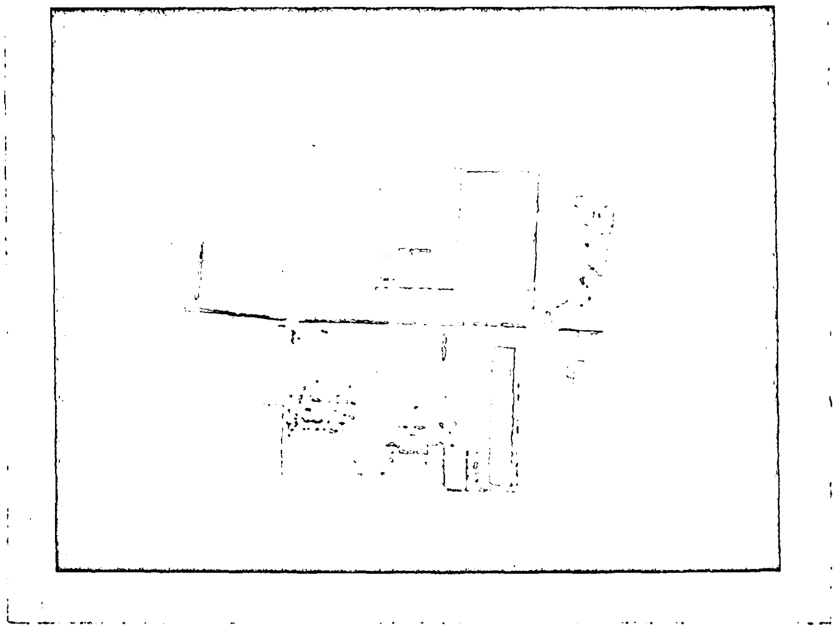

Figure 36. Belle Glade test site 2 and accompanying scan line (Mission 85, Frame 2407).

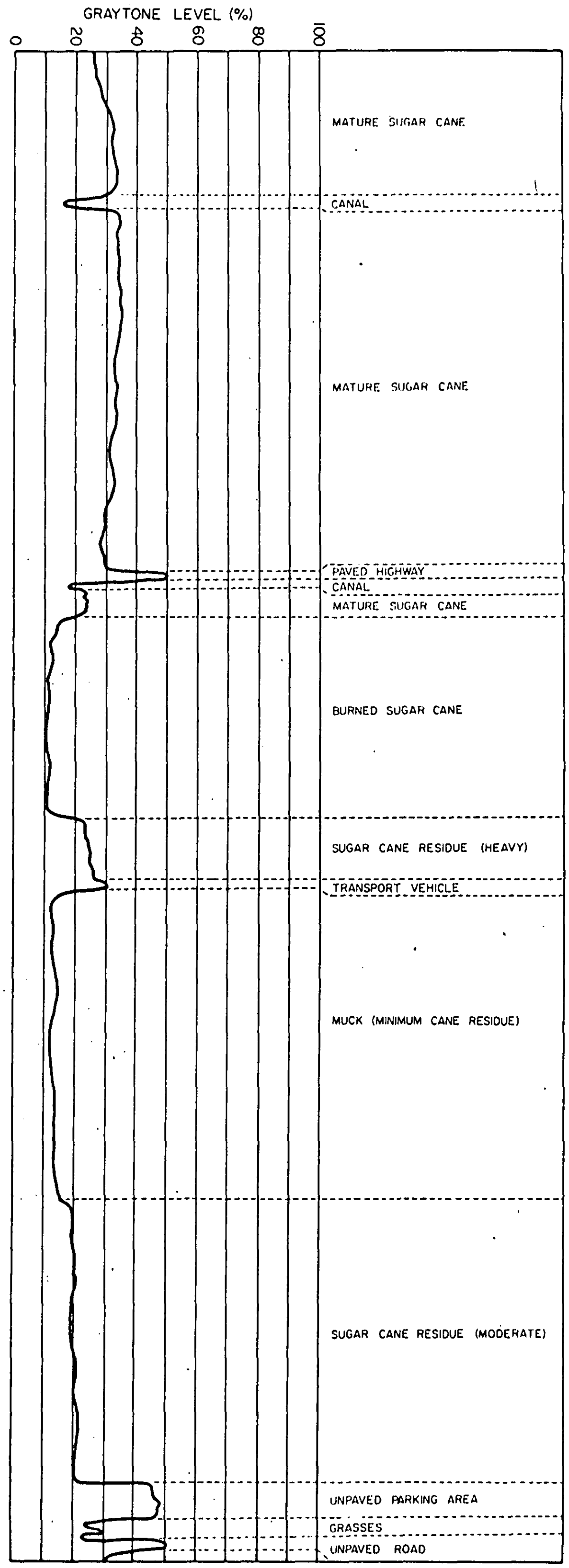

Figure 37. Graphical display of waveform representing January(1969) color image - Belle Glade, Florida (Site 2).

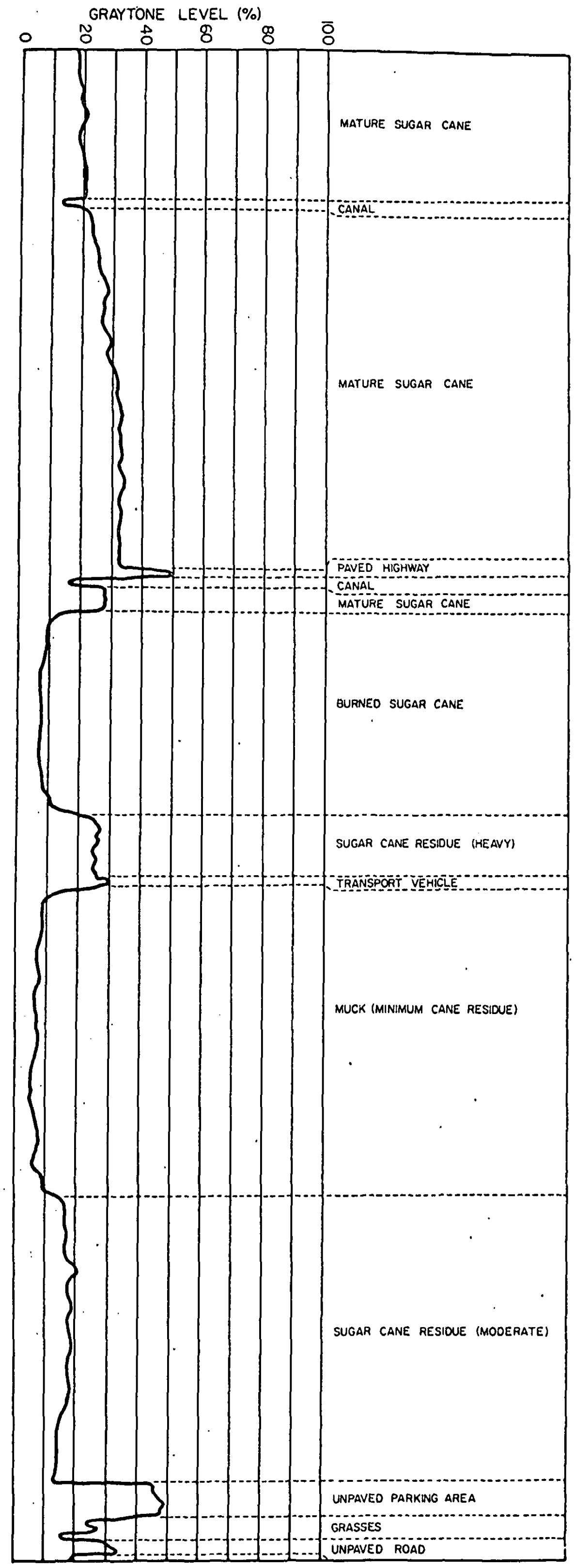

Figure 38. Graphical display of waveform representing January(1969) color infrared image - Belle Glade, Florida (Site 2).

Several examples bear out the above statement. In the color IR waveform, the burned cane photographed dark reddish-brown, sugar cane residue (heavy) was light reddish-brown, muck (medimum cane residue) was brownish-black, and sugar cane residue (moderate) was moderate reddish-brown. With the presence of such colors, the camera more readily segregated the phenomena.

Concerning color, all stages of cane were photographed as some shade of brown. For this reason, the television camera readily discriminated these hues. Table V reveals graytone averages for these occurrences.

Conclusions

Although more waveforms could have been analyzed in detail, the ten previously discussed traverses revealed sufficient data. From a general overview the television waveform system successfully detected color differences on both color and color IR transparencies. Results reveal, however, that graytone percentages extracted from color imagery offer better discrimination potential.

Because of the larger number of colors and associated shades recorded on color and color IR films, it is apparent that duplications of graytone percentage match-ups are bound to occur. However, even with the large number of colors traversed in the experiments, waveform percentages and percentage averages presented in Tables I-V reveal little duplication. Once automatic recording instruments (e.g., chart recorders) are operative the duplication will be reduced even further because precise readings will be extracted.

TABLE V

GRAYTONE AVERAGES, BELLE GLADE - SITE 2[a]
(JANUARY IMAGERY)

GEOGRAPHIC PHENOMENA	COLOR		COLOR IR	
	%	RANK	%	RANK
Unpaved Road	52	1	50	1
Unpaved Road	50	2	34	2
Unpaved Parking Area	48	3	48	4
Mature Sugar Cane	33	4	30	7
Transport Vehicle	30	5	30	6
Sugar Cane Residue (Heavy)	25	6	25	8
Unburned Sugar Cane	23	7	28	3
Sugar Cane (Moderate Residue)	20	8	18	5
Canals	18	9	15	9
Muck (Minimum Sugar Cane Residue)	13	10	06	11
Burned Sugar Cane	10	11	08	10

[a]Percentages are approximate.

Three factors favor phenomena identification via the television-waveform system: (1) colors associated with geographic categories of phenomena, (2) the IEEE signal, and (3) high altitude and space photography. It is apparent when comparing Tables I-V that certain hues on color and color IR images have similar percentage averages. The important factor is that hues representing major land use types are portrayed by substantially different colors on the two films. For example, red and magenta hues are absent on color films, and by the same reasoning greens, browns, and yellows are rarely found on color IR film. Thus, graytone similarities are further reduced since each film is characterized by certain primary colors.

A second factor in identifying phenomena centers on the use of the IEEE signal for computer mapping and analysis. As previously stated, the IEEE signal is "smoothed" or averaged to the extent that only major geographic phenomena are recorded for low altitude photography. Therefore, isolated pockets of colors representing phenomena covering small spatial units are averaged as a part of the larger occurrence. The averaging or IEEE signal further reduces the number of colors to be segregated - a definite advantage for computer coding. Accuracy is not affected because the end result is land use mapping.

Space or high altitude photography, the third factor favoring the utilization of television-waveform analysis, will further reduce the number of reproducible colors. As the scale of the photography decreases the number of colors will also decrease. Therefore, a photo recorded at orbital heights will be rendered in less colors than photographs covering the same ground area exposed at sub-orbital altitudes. Again with space photographs, the identifications of land use types will be more generalized than, for example, those recorded at 15,000 feet. Land use identifications from space photography will, however, be very useful for geographers.

In the color discrimination tests several conclusions were apparent. A comparison of the color and color IR waveforms revealed several similarities.

1. Objects which photographed as a white or near white (e.g., beach sand, highways, and house roofs) were representative of maximum graytone percentages.
2. Intermediate percentages coincided with features as isolated sand pockets and certain paved highways.
3. Hydrologic features were representative of minimum graytone percentages.
4. Silhouttes were similar.

Variances extracted from the color and color IR waveforms include:

1. A larger range of graytone values separated geographic phenomena on color waveforms.
2. Color IR waveforms did not detect submerged beach rock.
3. Color IR waveforms did not detect sugar cane variety differences.
4. In certain instances, water features rendered similar graytone percentages as surrounding vegetation on color IR waveforms.

Concluding, because of the success of previous tests it was decided to further the investigation. However, because of the better results extracted from color imagery this film type will be used exclusively in later tests. In Chapter V the research centers on computer mapping and analysis. Tests center on imagery recorded at 15,000 feet and from orbital altitudes.

CHAPTER V

COMPUTER ANALYSIS AND MAPPING EXPERIMENTS

A. Waveform Analysis - High and Orbital Altitude Photography

Introduction

Previous experiments and resulting waveforms demonstrated that the television-waveform system transformed an ample array of colors recorded on low altitude photography to identifiable graytones. Because of these successful conversions, the statistical requirement necessary for computer analysis was met - geographic distributants were coded in the form of digital percentages. However, it was decided to further evaluate color discriminations on color photos exposed from high altitudes.

Although graytone percentages extracted from low altitude imagery would be useful in identifying and analyzing specific distributions, the scale of the photography would make it difficult to extract digitized data from a large area. Digitized information retrieved from small scale photography would, however, be very beneficial to geographers who were interested in analyzing generalized patterns of land use.

To meet the methodological requirement for small scale tests, three images were selected for waveform analysis. From 15,000 feet photography, one frame was chosen from the Belle Glade test site. The graytone data extracted from imagery recorded at this scale will be extremely pertinent since large focal length lenses will permit spacecraft photography to be exposed at such an altitude equivalent. Two space orbital altitude photos were also subjected to waveform analysis.

Belle Glade Image Results - 15,000 Feet

The frame selected from the Belle Glade test site was photographed during the January (1969) overflight. Both agricultural and urban occurrences were positioned along the individual scan line (Figure 39).

As evidenced in Figure 40, the waveform clearly segregated the phenomena. It was noted that the waveform clearly identified major land use types - agricultural, residential, and commercial occurrences. Percentage averages also revealed the discriminations (Table VI).

As with past Belle Glade waveform examples, paved - unpaved parking areas and roads, plus buildings accounted for the highest graytone percentages. Near-white photographic hues were responsible for the high excursions or positive peaking points. Muck, because of a near-black color, registered near minimum graytone percentage levels. Because of varietal and growth variations, grass and sugar cane waveform segments revealed percentages or range fluctuations, but each of the two major occurrences did fall into definite range levels.

Upper Nile Delta - Orbital Altitude

The first space photo chosen centered on a segment of the upper Nile Valley. A scan line was selected, traversing the Western Egyptian Desert, Lake Qarun, and Faiyum Depression (Figure 41). The photo was taken

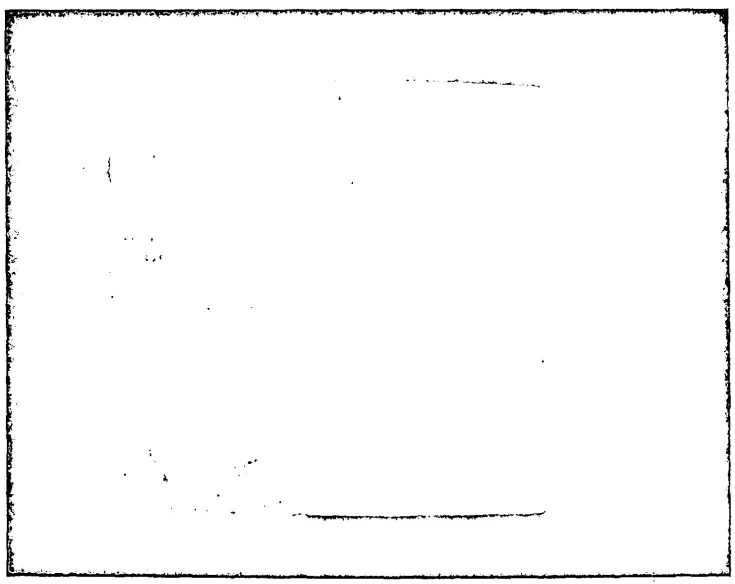

Figure 39. Belle Glade (15,000 feet) and accompanying scan line (NASA-ERS Mission 90, Frame 2533).

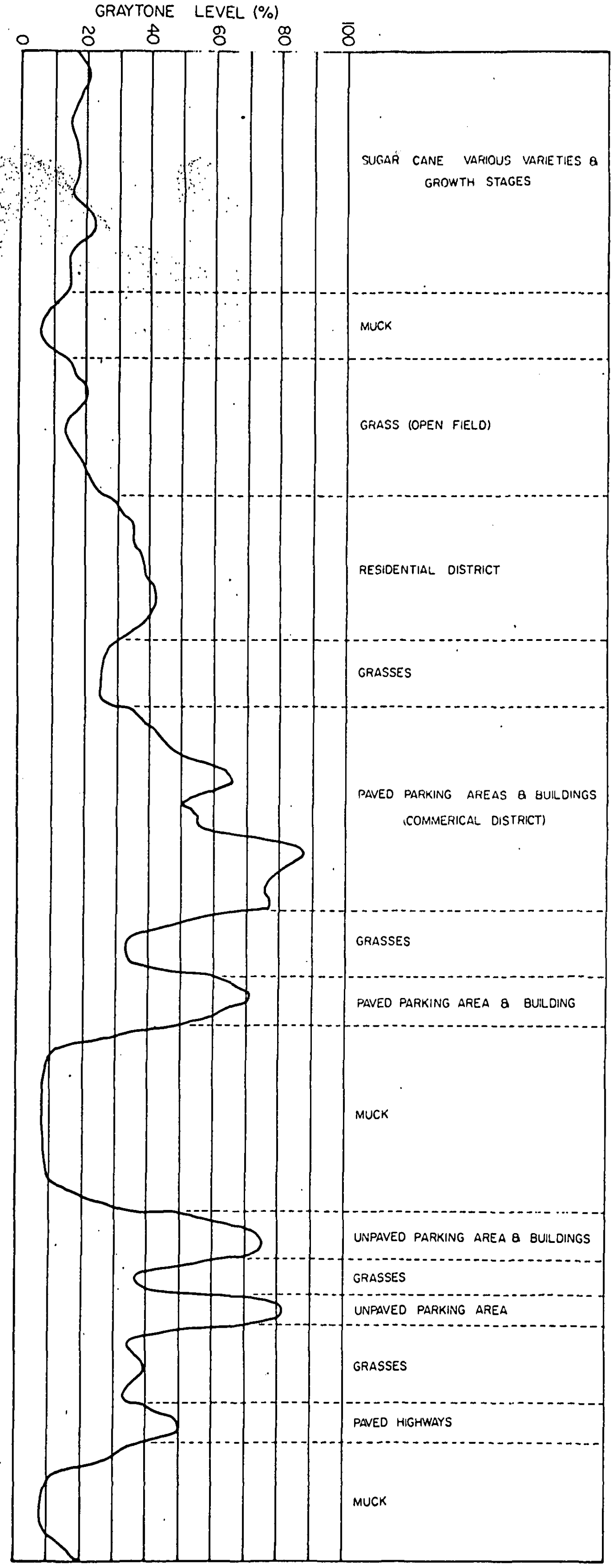

Figure 40. Graphical display of waveform representing Belle Glade, Florida, high altitude - 15,000 feet - color image. NASA Mission No. 90, January 1969.

TABLE VI

GRAYTONE AVERAGES, BELLE GLADE[a]
(JANUARY IMAGERY - 15,000 FEET)

GEOGRAPHIC PHENOMENA	PERCENTAGE
Unpaved Parking Area	72
Paved Parking Areas & Buildings (Commercial District)	69
Unpaved Parking Area & Buildings	68
Paved Highways	51
Grasses - Grass (Open Field	42
Residential District	37
Sugar Cane (Various Varieties & Growth Stages)	20
Muck	08

[a]Percentages are approximate.

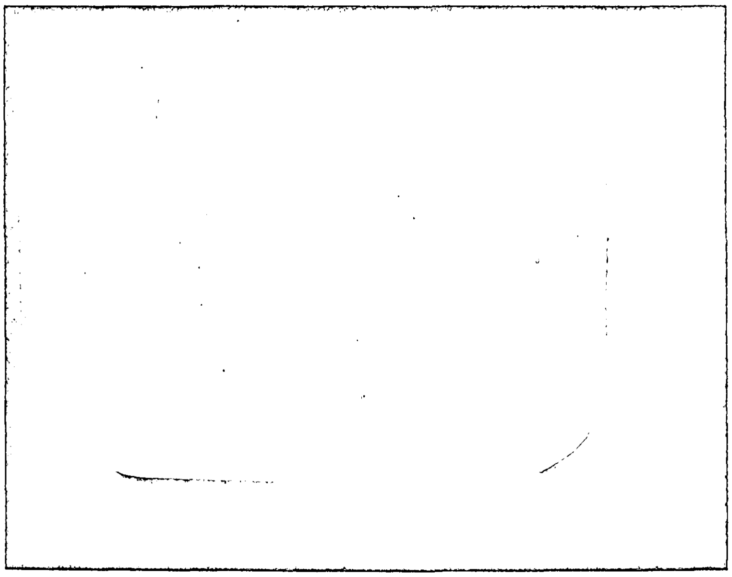

Figure 41. Upper Nile Delta and accompanying scan line (Gemini 4, Roll 5, Frame 50).

during the flight of Gemini 4 (Roll 5 - Frame 50), and the scale, although varying, is approximately 1:600,000 in the vicinity of Lake Qarun.

In analyzing the waveform (Figure 42), the major occurrences visible to the naked eye on the original photograph were also detected by the waveform analyzer. Graytone percentage averages add further weight to the considerable ranges separating the various distributants, (Table VII).

It had been first anticipated that the electronic system might have difficulty in separating blue hues representing Lake Qarun and the irrigated land of the Faiyum Depression. The analyzer not only segregated these two phenomena, but it also separated flooded land from irrigated land within the Faiyum Depression. The flooded area photographed as a darker blue than the surrounding irrigated land. The blue hue of flooded land was, however, lighter than the water of Lake Qarun and registered a higher percentage than the latter feature.

The major hue representing the Western Desert of Egypt was a light brownish-white which accounted for high graytone percentages. Shade variations were responsible for small percentage range fluctuations. One such notable example centered on the escarpment waveform sector.

This feature photographed a deeper brownish-white and, therefore, registered a lower percentage than the remainder of the desert distributant.

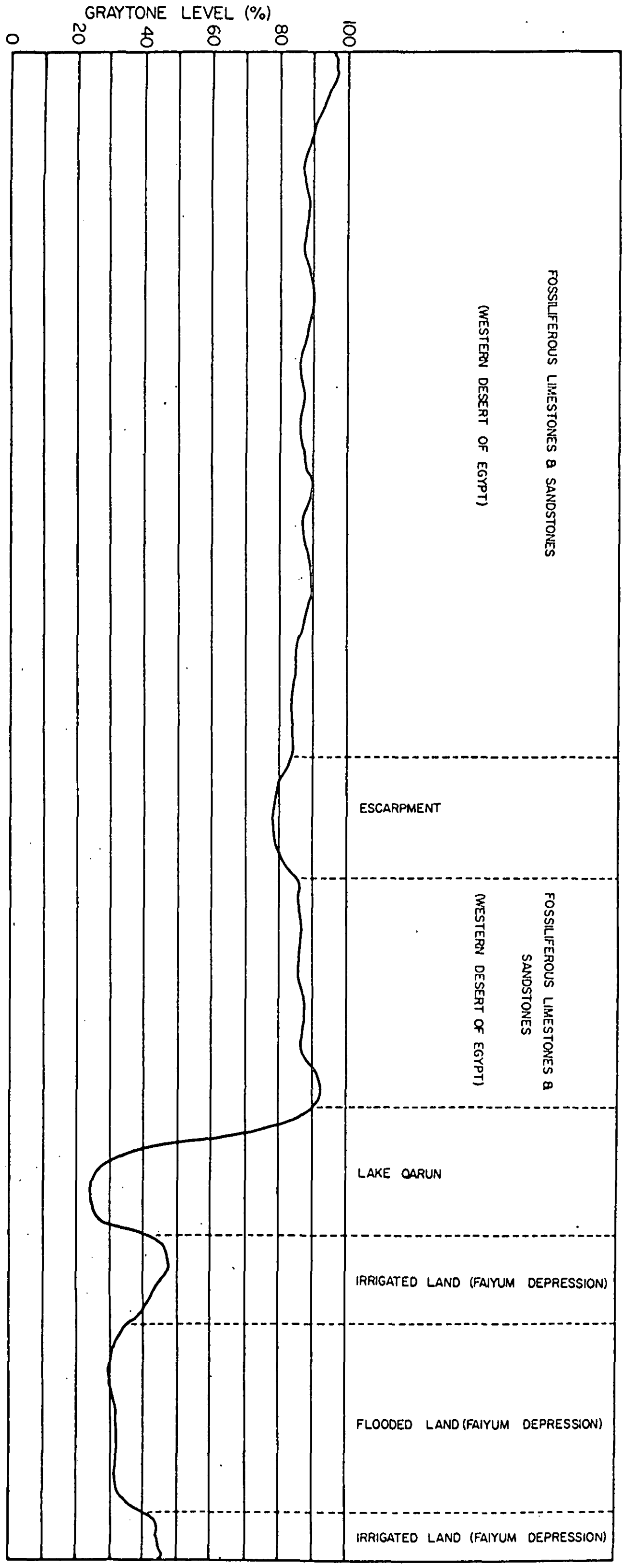

Figure 42. Graphical display of waveform representing spacecraft color image of the Upper Nile Delta (Gemini 4, Roll 5, Frame 50).

TABLE VII

GRAYTONE AVERAGES, UPPER NILE DELTA[a]
(GEMINI 4 - ROLL 5, FRAME 50)

GEOGRAPHIC PHENOMENA	PERCENTAGE
Fossilferous Limestones & Sandstones (Western Desert of Egypt)	87
Escarpment	81
Irrigated Land (Faiyum Depression)	45
Flooded Land (Faiyum Depression)	31
Lake Qarun	25

[a]Percentages are approximate.

El Paso-Juarez Area - Orbital Altitude

During the mission of Gemini 5, an excellent color photograph was taken over the El Paso-Juarez area (Roll 4 - Frame 69). It was chosen for waveform analysis because of the variety of features recorded and on the optimum photo resolution quality (Figure 43).

The waveform results, like previous examples, clearly isolated all geographic areas found along the selected traverse (Figure 44 and Table VIII). The lava flow, flood plains and terraces of the Rio Grande, and Hueco Mountains were representative of low graytone percentages. Largest percentage range fluctuation centered on the Husco Mountains. Hues varied from bluish-black to purplish-blue, accounting for graytone percentage differences. Both the lava flow and the flood-plain terraces photographed blackish-blue, the former being slightly darker.

The two waveform segments representing sedimentaries and red desert soils also accounted for percentage fluctuations. The Mexican sector (waveform-left) photographed light grayish-red, whereas on the American side (waveform-right) the sedimentaries and red desert soils photographed moderate grayish-red. The latter, because of a darker hue, recorded as a lower graytone percentage level.

B. Computer Applications[1]

Introduction

As earlier discussed, it is becoming an impossible task to fruitfully analyze all imagery generated from remote sensing systems. The

---

[1] Mr. Peter Stone, Geography Student Assistant - Florida Atlantic University, contributed substantially to the procedures in this section of the study.

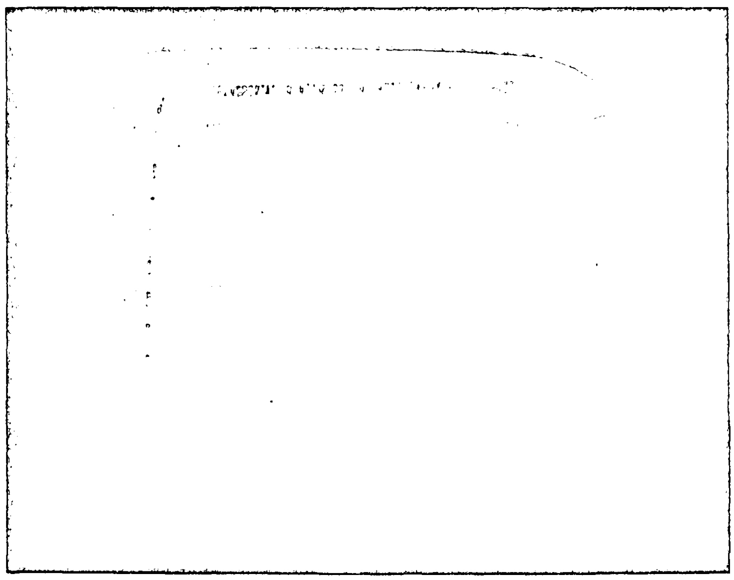

Figure 43. El Paso-Juarez area and accompaning scan line (Gemini 5, Roll 4, Frame 69).

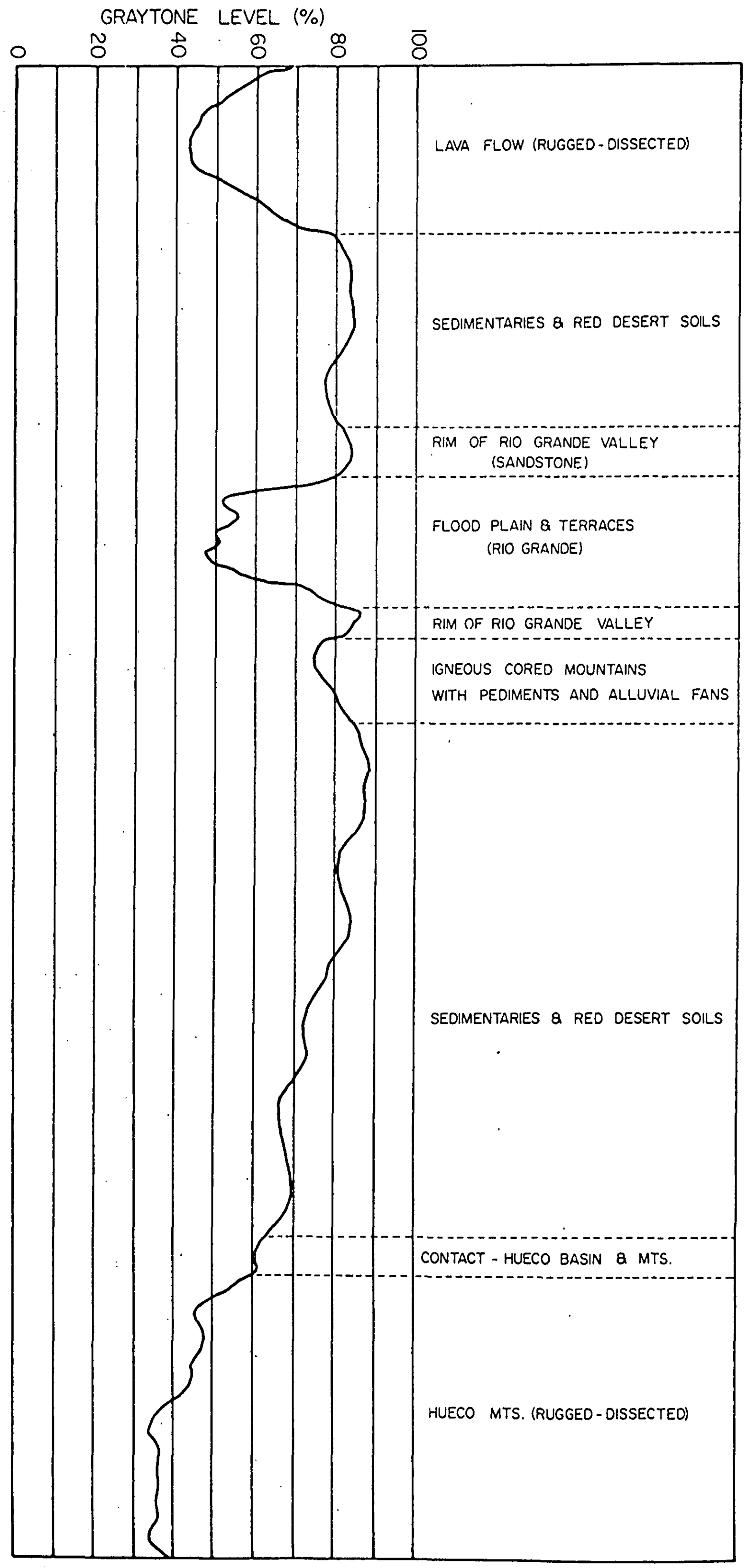

Figure 44. Graphical display of waveform representing spacecraft color image of the El Paso-Juarez area (Gemini 5, Roll 4, Frame 69).

TABLE VIII

GRAYTONE AVERAGES, EL PASO-JUAREZ AREA[a]
(GEMINI 5 - ROLL 4, FRAME 69)

GEOGRAPHIC PHENOMENA	PERCENTAGE
Rims of Rio Grande Valley (Sandstone)	85
Igneous Cored Mountains with Pediments and Alluvial Fans	78
Sedimentaries & Red Desert Soils	74
Contact (Hueco Basin & Mountains)	60
Flood Plain & Terraces (Rio Grande)	50
Hueco Mountains	45
Lava Flow	40

[a]Percentages are approximate.

computer, however, offers high promise for analyzing data recorded on aerial photography. Following sections treat one possible application of the computer to accept image input information and then generate output signals that classify, map, and analyze the geographic occurrences.

Research Procedure

In an effort to evaluate computer analysis and mapping experiments, the digital data was manually recorded from the waveform analysis of the space photo of the Upper Nile Delta. With the scale remaining relatively constant on the bottom-half of the photo, digital extractions centered on this segment (Figure 45).

Utilizing a 945 line monitor, a vertical scan line movement of eight lines corresponded to a horizontal reading every centimeter on the cathode ray tube of the waveform analyzer. These distances insured a square field, which in turn eliminated distortion problems with the televised image. Therefore, once the beginning scan was selected, percentage readings were extracted every centimeter along the Y axis. Once the extractions were completed, the scan was moved eight lines along the X axis and the process repeated. In all, graytone percentages were extracted from 22 lines; along each line 20 percentage readings were extracted.

The digital data was then placed on punch cards with an accompanying program especially designed for this type of digital analysis. When completed the data was ordered into an IBM 360 computer. The program (Figure 46) ordered the computer to do the following tasks:

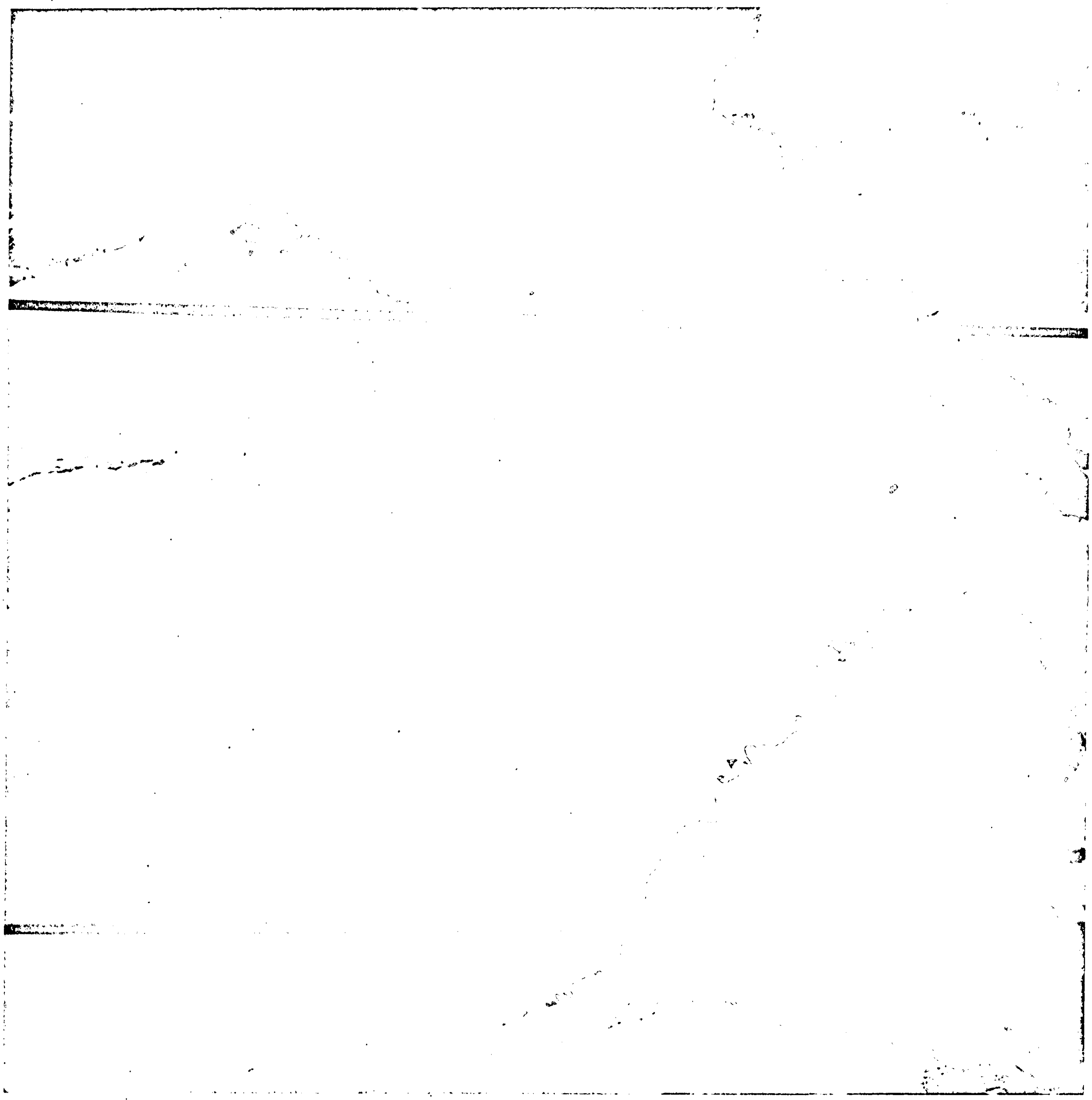

Figure 45. Photo showing the upper Nile Delta and the boundaries limiting the area of graytone percentage extraction.

```
                         DISK OPERATING SYSTEM/360 FORTRAN    360N-FO-451   CL 3-3
C       BERLIN 192-32-5716
        DIMENSION KAT(10),KBT(10),NAME(10),NM(10),J(440),ARIA(10),APER(10)
       1,FKAT(10),K(440),KSUM(440),NA(10),NB(10),NC(10)
        READ(1,1)S,KTT
1       FORMAT(F7.0,3X,I2)
        KI=KTT/2
        DO 3 NI=1,KI
        READ(1,2) NAME(NI),NA(NI),NB(NI),NC(NI),NM(NI),KAT(NI),KBT(NI)
2       FORMAT(4A4,3X,A2,3X,I2,1X,I2)
3       CONTINUE
        READ(1,4)(J(I),I=1,440)
4       FORMAT (20I2)
        WRITE (3,5)(J(IN),IN=1,440)
5       FORMAT(20X,31HBRIGHTNESS VALUES  ENTIRE ARRAY//20X,63H*************
       1**************************************************/(20X,1H*,20I3,
       12H *))
        WRITE (3,6)
6       FORMAT (20X,63H*************************************************
       1**************////)
        KK=0
        DO 18 LI=1,440
        KSUM(LI)=00
18      CONTINUE
        DO 12 IK=1,KI
        DO 11 ID=1,440
        K(ID)=00
11      CONTINUE
        KK=KK+1
        FKAT(KK)=000.
        DO 8 II=1,440
        IF(J(II)-KAT(KK))8,7,16
16      IF(J(II)-KBT(KK))7,7,8
7       K(II)=NM(KK)
        FKAT(KK)=FKAT (KK)+1.
        KSUM (II)=NM(KK)
8       CONTINUE
        WRITE(3,9)NAME(KK),NA(KK),NB(KK),NC(KK),(K(LL),LL=1,440)
9       FORMAT(20X,4A4//20X,63H****************************************
       1***********************/(20X,2H* ,20A3,1H*))
        WRITE (3,10)
10      FORMAT(20X,63H***************************************************
       1************////)
12      CONTINUE
        WRITE(3,17)(KSUM(NN),NN=1,440)
17      FORMAT(20X,10HLAND TYPES//20X,63H********************************
       1*******************************/(20X,2H* ,20A3,1H*))
        WRITE(3,6)
        DO 13 IJ=1,KI
        ARIA(IJ)=FKAT(IJ)*(S**2.)/(144.*(5280.**2.))
        APER(IJ)=FKAT(IJ)/440.*100.
13      CONTINUE
        WRITE(3,19)
19      FORMAT(20X,17HAPPROXIMATE AREAS//)
        DO 15 MI=1,KI

07/24/69              FORTMAIN                                               0002

        WRITE(3,14)NAME(MI),NA(MI),NB(MI),NC(MI),NM(MI),ARIA(MI),APER(MI)
14      FORMAT(20X,4A4,5X,A2,5X,F10.0,13H SQUARE MILES,5X,F4.1,22H PERCENT
       1 OF TOTAL AREA)
15      CONTINUE
        STOP
        END
```

Figure 46. Computer program which analyzes and maps geographic information extracted from color aerial imagery via the television-waveform system.

1. Transform digital percentages to letter equivalents. A series of instruction cards registered range limitations for each occurrence and when each was contacted in the digital search the computer printed specific letters. With double digits (percentages) representing graytone levels, double letter coding were used to equalize the conversion. For example, II represented irrigated land, WW - water, and AA - desert.
2. Map geographic distributants. Once the computer had been instructed to transpose digits to letters it was then programmed to print out the letters in map form, both as to total array and each distributant separately.
3. Estimate the proportion of area occupied by each of the distributants. The computer counted the number of readings corresponding to each distributant. It was then instructed to calculate (1) percentage coverage and (2) square mile coverage.

Computer Results

The computer methodology for identifying, mapping, and analyzing land use categories proved to be very successful. As seen in Figures 47-51, the computer successfully converted the digits to letter codings and mapped each occurrence, both separately and collectively as a single land use map.

BRIGHTNESS VALUES ENTIRE ARRAY

84	83	85	84	87	96	92	88	85	83	83	82	84	52	41	39	50	70	82	89
89	88	88	84	85	96	89	89	89	88	87	88	88	89	70	46	42	42	67	82
92	91	90	91	92	92	97	97	95	96	94	93	92	93	94	95	60	42	40	40
94	96	99	99	99	99	99	99	99	99	99	99	99	98	97	96	99	67	42	43
98	99	99	99	99	99	99	99	99	99	99	99	99	97	96	94	98	99	90	49
99	99	99	99	99	99	99	99	99	97	98	99	99	98	98	96	94	96	94	95
99	99	99	99	96	94	95	95	93	94	97	94	95	96	94	93	92	91	90	93
99	99	99	99	97	93	94	91	89	91	94	95	94	93	92	91	90	90	91	90
99	99	99	99	95	90	91	92	94	96	94	95	94	93	91	89	89	89	90	93
99	99	99	97	90	92	93	94	94	94	93	96	97	97	92	88	67	60	75	92
99	99	99	99	98	98	96	96	93	92	92	95	97	93	67	60	62	68	57	57
99	99	98	97	99	97	96	93	90	90	93	85	80	96	70	63	63	57	54	53
98	97	98	98	97	98	96	93	92	84	99	99	98	85	65	68	72	61	55	59
93	92	90	92	90	94	95	93	92	95	99	85	65	53	53	62	52	53	48	49
92	90	83	87	92	94	95	98	99	99	90	47	51	49	47	47	49	45	45	45
88	87	86	90	91	93	94	98	90	50	34	32	46	47	47	48	45	43	42	50
88	94	95	99	97	98	97	99	82	40	34	50	52	48	47	45	45	46	45	52
88	90	93	99	97	96	97	99	40	38	50	48	46	45	43	49	46	43	43	47
88	92	97	94	96	98	60	39	33	47	50	48	41	33	40	45	42	40	44	58
88	89	93	97	98	99	40	47	40	48	47	45	38	39	42	42	40	45	41	42
89	92	92	93	96	60	31	30	33	46	47	44	36	38	39	40	40	39	39	42
89	88	86	90	92	95	40	29	30	42	52	45	43	38	40	44	40	40	39	35

Figure 47. Computer printout of brightness values (graytone percentages).

LAND TYPES

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***************************************************************
* AA AA AA AA AA AA AA AA AA AA AA AA AA II II WW II    AA AA *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA    II II II II AA *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA II II       *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA II II II *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA II *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA II II    AA *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA II II II II II II *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA    II II II II II *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA II II    II II II *
* AA AA AA AA AA AA AA AA AA AA AA AA II II II II II II II II *
* AA AA AA AA AA AA AA AA AA AA AA II II II II II II II II II *
* AA AA AA AA AA AA AA AA AA II WW WW II II II II II II II II *
* AA AA AA AA AA AA AA AA AA    WW II II II II II II II II II *
* AA AA AA AA AA AA AA AA    WW II II II II II II II II II II *
* AA AA AA AA AA AA II WW WW II II II II WW    II II    II II *
* AA AA AA AA AA AA    II    II II II WW WW II II    II II II *
* AA AA AA AA AA II WW WW WW II II II WW WW WW       WW WW II *
* AA AA AA AA AA AA       WW II II II II WW    II       WW WW *
***************************************************************
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APPROXIMATE AREAS

DESERT	AA	4562.	SQUARE MILES	66.6	PERCENT OF TOTAL AREA
WATER	WW	343.	SQUARE MILES	5.0	PERCENT OF TOTAL AREA
IRRIGATED LAND	II	1619.	SQUARE MILES	23.6	PERCENT OF TOTAL AREA

Figure 48. Computerized land use map and spatial coverage (square miles - percentage of total area) of each distributant extracted from spacecraft photograph of the upper Nile Valley.

DESERT

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****************************************************************
* AA AA AA AA AA AA AA AA AA AA AA AA AA                AA AA *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA                AA *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA             *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA          *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA    *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA AA          AA *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA                   *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA                   *
* AA AA AA AA AA AA AA AA AA AA AA AA AA AA                   *
* AA AA AA AA AA AA AA AA AA AA AA AA                         *
* AA AA AA AA AA AA AA AA AA AA AA                            *
* AA AA AA AA AA AA AA AA AA                                  *
* AA AA AA AA AA AA AA AA AA                                  *
* AA AA AA AA AA AA AA AA                                     *
* AA AA AA AA AA AA                                           *
* AA AA AA AA AA AA                                           *
* AA AA AA AA AA                                              *
* AA AA AA AA AA AA                                           *
****************************************************************
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Figure 49. Computerized map of desert distributants.

IRRIGATED LAND

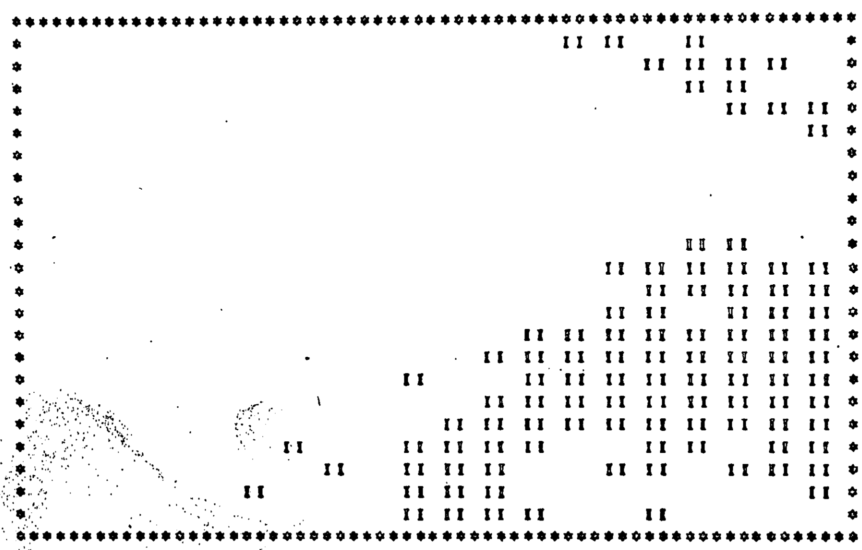

Figure 50. Computerized map of irrigated land distributants.

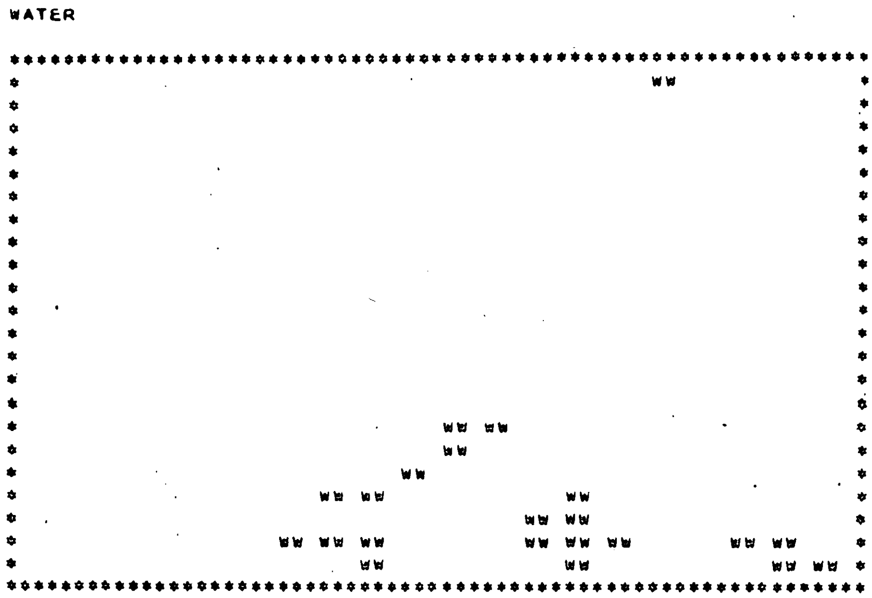

Figure 51. Computerized map of water distributants.

It is noted in Figure 48 that void areas were found in certain locations of the map. These voids represent transition zones, and hence the computer did not categorize them since graytone percentages were different from range categories of the three major distributants.

The statistical results included:

Desert (AA).........................4562 square miles

Water (WW).......................... 343 square miles

Irrigated Land (II).................1619 square miles

Concerning the percentage coverage of each land use the results were:

Desert(AA)............................66.6 per cent

Water (WW)............................ 5.0 per cent

Irrigated Land (II)...................23.6 per cent

It will be noted that the percentages did not total 100. The 4.8% not accounted for coincided with transition zones not fitting the statistical parameters established for the various land uses. The problem of voids will be reduced once multiple graytone readings are automatically extracted from each waveform signal. In the previous example one reading was extracted every centimeter, but with a larger number of readings the accuracy will increase. Such a system is discussed in latter sections.

Conclusions

Foregoing experiments, involving high altitude color imagery conversions and computer analysis of graytone digital data, revealed positive results. In fact phenomena discriminations at both 15,000 feet and space altitudes proved to be just as successful as the graytone results from imagery exposed at 5,000 feet. The IEEE signal, therefore, revealed ample graytone information extracted from high altitude imagery to identify and isolate various geographic distributants.

In reference to the computer experiments, manual graytone extraction tasks greatly limited the scope of analysis. However, the results did reveal enough positive information to justify additional experiments incorporating the automation of more procedural steps.

The manual step which involved "reading off" graytone percentages from the waveform analyzer cathode ray tube consumed considerable amounts of time and also incorporated distortions in extracting precise graytone percentages. This procedural step can now be automated because of the success of this investigation. Automatic equipment, now available, has possibilities of becoming incorporated into the television-waveform system.

For example, a strip-chart recorder could construct waveform profiles and at the same time record graytone percentages onto magnetic tape for direct computer input. Recorders are also available that can make up to 1,200 quantitative measurements per inch. The number of readings could change with the scale of the photography and with the particular arrangement of ground phenomena.

With the automation of this segment, the scan line could be manually operated. When in correct position, the chart recorder would proceed to analyze that one line - proceeding along the next line only when the traverse was correctly positioned. The major operation for the immediate future is to, therefore, automate the extraction of recording graytone percentages onto magnetic tape. Once the graytone percentages are thus recorded, the tape can be rapidly processed.

CHAPTER VI

CONCLUSIONS

A. Summary

Evaluation of Research Objectives

This study is one of a series of investigations that have utilized the television-waveform system and has, like its predecessors, further advanced the instrumentation techniques. It has established the following:

1. The 945 line system proved superior to lower line systems because one such traverse covered a lesser "ground" distance than line components totalling 873, 729, and 525.
2. After exhaustive testing of various light sources, a glow box provided optimum illumination qualities. This source light permitted image illumination.
3. Waveform photographs were best recorded on Tri-X film.
4. The flat electronic signal revealed more geographic information than the IEEE signal.

Major research findings included:

1. The television-waveform system proved successful in converting colors representing earth phenomena to identifiable graytone levels (ranges) from imagery exposed at 5,000 feet, 15,000 feet, and from orbital altitudes exceeding 100 miles. Because of a low red sensitivity the television camera better discriminated colors extracted from conventional aerial color film than color IR.

2. Relative television-waveform calibration, via the imagery scanned, enabled reliable graytone percentage data to be extracted from imagery of lesser contrast. No data extraction from the same imagery was possible when the camera was calibrated from a standard broadcast test pattern incorporating a normal graytone scale.
3. A computer program was successfully developed to analyze and map the graytone information which, in reference to specific ranges, represented distinct geographic distributants. The computer was successfully ordered to estimate areas and to map the distributants by letter codings.

Continuation of the Research

The positive findings of this investigation have revealed added avenues for continued research. First, an effort should be made to acquire space photography of good quality when it becomes available for large portions of the earth's surface. Tests could center on time sequence photography to see if land use changes can be detected by the waveform analyzer.

Second, instruments such as a strip chart recorder should be tested as an aid in accelerating the process of graytone percentage extractions and recording. For the success of computer analysis and mapping, an instrument such as the chart recorder will have to be incorporated into the research package to justify computer time, and to analyze large areas thereby making the resulting data useful to geographers.

Thirdly, this study revealed the possibilities of identifying different varieties of sugar cane and growth stages by their gray-tone "signatures." A systematic investigation should be directed towards specific crop identifications - both for different crop varieties and stages of growth for the same crop.

The television-waveform system clearly segregated broad land use categories involving both agricultural and urban distributants. Once time lapse photography is available for an urban-rural area graytone data could be extracted from the aerial imagery and placed either on punch cards or magnetic tape. In effect the cards or tape would be maps in stored form, and one such use would be to quantitatively trace the spread of the city into agricultural land.

Lastly, research should continue into additional computer applications. One example would be to alter the program previously discussed for earth curveature when spacecraft photography is utilized.

B. Contributions to Geography

The techniques and results discussed in previous chapters have both immediate and future potential in geographic problem solving.

> To the geographer the ability to analyze complexly distributed phenomena by objectively measuring the nature of its distribution represents a step forward in the understanding of distribution, and the description of that distribution by readily comparable and absolute quantitative terms. Such quantitative values can then be subjected to the vigorous mathematical tools that establish comparisons and contrasts on an objective basis.[1]

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[1] James P. Latham, Possible Applications of Electronic Scanning and Computer Devices to the Analysis of Geographic Phenomena. Technical Report No. 1, NR 387-023 (Washington: Office of Naval Research, 1959), pp. 24-25.

A few specific potentials of waveform and computer analysis of color aerial imagery included:

1. Identification of geographic distributions.
2. Analyzing geographic distributions in quantitative terms.
3. Accurate and rapid method of statistically evaluating data corresponding to specified geographic distributants.
4. Magnetic tape or punch cards containing geographic data in the form of graytone percentages are actually maps in stored form; the computer can be programmed to reproduce a map incorporating all digitized data or pre-selected segments.

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