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REMOTE SENSING APPLICATION TO LAND USE CLASSIFICATION IN A RAPIDLY CHANGING AGRICULTURAL/URBAN AREA--CITY OF VIRGINIA BEACH, VIRGINIA

by

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1. INTRODUCTION

The beginnings of "remote sensing" were as romantic as they were simple, by present standards, and basic. Many scholars contributed to its roots. Aristotle (384-322 B.C.) investigated the nature of light. Johann Heinrich Schulze (1687-1744) discovered "light writing" and made images outside of a glass filled with a mixture of white chalk and silver nitrate. Josiah Wedgewood (1771-1804) copied transparent and opaque pictures on glass and paper coated with silver salts. These and other experiments demonstrated the light sensitivity of several substances, chiefly silver compounds.

Photography did not remain terrestrial-bound for very long. The first known suggestion (Quackenbush, 1960) of aerial photography (from a balloon) appeared as a joke in a French lithographed caricature, "Daguerreotypomania", in 1840. Gaspard Felix Tournachon (1820-1910) attempted to produce a topographic map from "bird's eye" photographs taken from a captive balloon at a height of several hundred meters. In England, Paris, Vienna, and Russia, intelligence gatherers, physicists, army men, and other balloonists "took to the air". The development of the piloted aircraft at the beginning of the 20th century and the two world wars further advanced the technique of aerial photography.

Today, this technique finds application in no less than sixty problem situations (Avery, 1970, p. 8), and new applications are being tried daily. Among the major users of this technique are the federal Forest Service, Soil Conservation Service, Agricultural Stabilization and Conservation Service, Geological Survey, and many other federal agencies. State, county, and metropolitan planning agencies also use the technique.

In its everyday use, the term 'Land Use' refers both to the prevalent land-using activities, i.e. man's activities on it (Clawson and Stewart, 1969), and to the land cover which, according to Burley (1961), describes "the vegetational and artificial constructions covering the land surface". Some activities of man can be directly related to the type of land cover. Other activities, such as wildlife hunting, are more difficult to relate to land cover by use of remote sensing techniques. In other words, whenever we use aerial photographs to study land use we are by implication using both precepts.

In manual interpretation of aerial photographic imagery, object identification is based on shape, size, pattern, shadow, tone, texture, site, and color when a color film is used. The relative importance of each characteristic is largely dependent on the object to be identified. In land use photo interpretation, the pattern, texture, site, and tone are especially useful. Of these four parameters tone, which refers to the gray scale gradation from black to white, is perhaps the most important.

In contrast to manual interpretation which is image-oriented, machine analysis may require either an image or a numerical data source. Most machine processing systems will accept input either in digital tape or film transparency formats, and in multispectral form. They classify objects according to their spectral response characteristics in each band. The LARSYS system, developed at the Laboratory for Applications of Remote Sensing (LARS) at Purdue University, is one of several computer software systems requiring digital input formats developed in recent years.

All classification schemes are designed to fit specific needs, and land use classification schemes are no exception. They classify the land according to dominant use and characteristically tend to stress the current conditions of the land being investigated.

Possible approaches in land use classification include the physiographic, the terrain type, the cover type, the activity, and the aesthetic value approaches. In urban areas, where much of the original landscape has been altered, many of these approaches are undesirable.

The City of Virginia Beach was selected for study because: (1) there is a very rapid change in land use, mainly from agricultural to urban, and (2) there is no comprehensive land use map, at any level, covering most of the City.

In an area such as the City of Virginia Beach, where living fifteen feet above the sea is tantamount to looking down upon the rest of the city, there is little variety in the terrain or physiography. In such a situation, Clawson's (1960) definition of land use, as ". . . the end to which land is allocated, assuming a conscious decision to use it for a desired end", seems to deserve close consideration.

The changes in land use in this area, mainly from agricultural to urban-suburban, are taking place very rapidly. This was underscored by the participants in a conference in Remote Sensing of Chesapeake Bay held in April, 1971 (National Aeronautics and Space Administration, NASA, 1972), who noted that "urban development and growth on the shoreline of the bay, along its tributaries, and in the headwaters in the bay, present special problems with respect to the bay". Several problem areas were recognized, some of which were characterized as "very important". Consequently, one of the recommendations adopted was to "urge NASA Wallops to prepare a list of studies within the Chesapeake Bay area by national, state, regional, and local agencies revealed by the participants at the conference".

Thus, the study reported herein was done with the following purposes:

1. To test the applicability of the LARSYS pattern recognition software in land use studies with satellite multispectral scanner data and high altitude aircraft imagery in an area where land use is rapidly changing from agricultural to urban.
2. To determine the extent that present land use and recent changes in land use relate to the soils of the area.
3. To investigate the feasibility of determining and quantifying land use changes via automated or computer implemented analysis.

2. LITERATURE REVIEW

2.0 INTRODUCTION

The work reported in this dissertation specifically relates to the application of remote sensing techniques to land use classification and mapping. The discussion in this section will be divided into two broad areas. The first area will review literature pertaining to the use of remote sensing techniques in land use classification and mapping. The second area will present a summary review of the literature pertaining to the effects of the more important parameters which determine the quality of the remotely sensed data.

Land use classification must take into consideration both the land using activities and the land cover. On the other hand, land classification whether via the terrain type approach or the physiographic subdivision approach (Heath, 1956), is designed to facilitate systematic description of land units for a clear topographic (geomorphological) understanding and interpretation. Land can also be classified for the benefit of land use planners (Klingebiel, 1963). The Countryside Commission of Scotland (1971) has presented a forthright and convincing argument for a Landscape Classification and a Landscape Resources Classification. The latter approach, of necessity, takes into account aesthetic quality as well as other human-centered, value-judgement parameters.

There seems to be a lack of clear distinction in the literature between "land classification" and "land use classification". The word "use" in the latter case clearly refers to an activity. It is also assumed that "activity" is in reference to man. Thus, a land use classification must refer to a classification of man's activity on the land. Certain activities of man can be interpreted directly from an aerial photograph, while others can be reliably inferred via what covers the land. Some land use activities can only be ascertained by inspection of the area being classified. In other words, "land cover" also must enter a land use classification study.

On the other hand, to classify land according to its terrain type or physiographic subdivisions the researcher does not necessarily have to consider the use of each type or subdivision. This is more aptly classifying a natural landscape (land classification).

The introduction of "aesthetic value" into the land use concept further complicates the matter. This places an additional parameter involving a subjective value judgement, and removes it from strict land use classification and land classification.

Lastly, Clawson's (1960) concept which includes " . . . the end to which land is allocated, assuming a conscious decision to use it for a desired end" differs from all the others basically in time. It includes both current and future times, while the others assume only current conditions. If this perspective is adopted in land use classification and mapping studies, especially in an urban area, the map produced would be difficult to distinguish from a zoning map.

Remote sensing is a term that is rapidly becoming a "household" word. Simply defined (Weaver, 1969), remote sensing "means getting information about things at a distance, or about things one cannot see." According to Colwell (1969) remote sensing "pertains primarily to the acquiring of information about natural resources through the use of aerial cameras or other remote sensing devices operated from aircraft or spacecraft that are situated at a distance from the areas being sensed". MacDonald and Landgrebe (1967) noted that "Remote sensing technology is concerned with the determination of characteristics of physical objects through analysis of measurements taken at a distance from the objects." In a still broader scope, Luney and Dill (1972), defined remote sensing as denoting " . . . the joint effects of employing modern sensors, data processing equipment, information theory and processing methodology, communications theory and devices, space air-borne vehicles, and large-systems theory and practice for the purpose of carrying out aerial or space survey of the earth's surface." Essentially, therefore, remote sensing is the procurement and analysis of data concerning an object without physically contacting that object. By this definition, all of the senses of sight, smell, hearing, and even feel can be used in remote sensing activities. Generally, the use of a sensor system to collect reflected or emitted energy from a scene of interest and to record it in a usable manner is considered remote sensing as it is used in the earth sciences today.

2.1 REMOTE SENSING IN LAND USE

In the report of the Committee on Remote Sensing for Agricultural Purposes (NAS, 1970), P. R. Luney and H. W. Dill included the following paragraph: "Historically, land-use data have been compiled by census interviews or by field mapping. In some countries, major classes of land use are mapped in the field and published, usually on a small scale. For most countries, land use data consist of data compiled by census from personal interview, mail questionnaire, study sample areas, or some combinations of these means. Generally, these methods take a relatively long time because the number of trained scientists is limited or because the number of less-well-trained people required is large. These factors account for the relatively long intervals between census projects in many countries."

This situation is changing rapidly. In recent years, pressing needs for increased food production, environmental protection, and the preservation of prime agricultural land from encroachment of sprawling urban and suburban development have awakened the interests of many professional as well as non-professional groups in the subject of land use and the problems it entails. Indeed, the interest in the subject has been so intense that it deserved a special conference at the sponsorship of the Soil Conservation Society of America in Des Moines, Iowa, in November 1972 (SCSA, 1973). One side effect of this intensified interest has been that certain aspects of land use are being emphasized at the expense of others, no less important. For example, land use as it applies to urban and suburban development is very current, especially since the environmental, community, urban, regional, and other land use planners have come to the forefront of the "save the environment" crusade. However, a cursory look at the available literature reveals that it can be divided into two broad categories: rural land use and urban land use.

2.1.1 REMOTE SENSING IN RURAL LAND USE

The first suggestion of the use of remote sensing techniques in rural land use appeared in the well known British Land Utilization Survey, executed between 1931 and 1939 (Huson, 1970). Reportedly it is famous for two reasons: first, because the maps produced became within a few years an essential instrument for planning of the physical environment in

Britain and, secondly, because it was the only consistent basis for further classification of agricultural land (Board, 1968, pp 32,33).

Impressed by the success of the British Land Utilization Survey and the need for planning of land resources, the Congress of the International Geographic Union, in 1949, appointed a commission of the Union devoted to World Land Use. Thus, the I.G.U. Commission on World Land Use Inventory was born (Huson, 1970). The commission had a dual purpose: first to test working methods, particularly with reference to the applicability of aerial photographs, and secondly to promote national surveys, carried out according to a uniform legend. These national surveys were then to be the basis of World Land Use map on a scale of 1:1,000,000. In 1952, the Rural Land Use Working Party (Nunnaly and Witmer, 1970) of the commission presented a proposal for a "master key" which distinguished the basic categories of land formulated by collecting land use statistics from aerial photos.

The use of remote sensing techniques in rural land use studies has grown steadily since the 1930's. The U.S.D.A. Agricultural Stabilization and Conservation Service has obtained extensive photographic coverage of many farms and range lands since that date. The U.S. Forest Service uses the same techniques very extensively. Marschner (1958) prepared a small scale land use map for the United States using air photos. Steiner (1965) claims this to be the only sample in the world of such an accomplishment. The map is 1:5,000,000 scale with major land use classes outlined. As of 1966 (Munn et al., 1966), Canada was in the process of inventorying one million square miles via remote sensing techniques.

Huson (1970) applied remote sensing techniques to mapping land utilization in an area of 774 km^2 in the Crati Valley, Italy. At a photographic scale of approximately 1:32,000, he was able to delineate twelve major land use categories in a reconnaisance survey, solely on the basis of photo interpretation. During the field work for verification, "only a few, insignificant, corrections of the photo-interpretation appeared to be necessary . . . due to the fact that only minor changes in land use (had) occurred . . ." Most categories of the legend could be recognized without ambiguity in the photographs.

Allan and Alemayehu (1975) carried the rural land use application one step further. Using the rural land use parameters as interpreted from 73 overlapping aerial photographs at the scale of approximately 1:20,000, they estimated the rural population of a rural area 200 km^2 in Wolamo, Ethiopia, with a 10 to 15 percent sampling error at the .05 percentile significance level. Keech (1974) was able to make an almost complete farm plan on aerial 1:20,000 photographs for the "European" farmers in Rhodesia. Proposed communication network, potential earth dam sites, soil boundary changes, land capability classes, arable and non-arable units, fence lines, and farm house location could all be sited using the photos. In addition, carrying capacity of grazing areas and a sampling traverse route could also be estimated.

In recent years there has been a shift in concentration from what has become known as "conventional aerial photography" to small scale high altitude and space photography. Experimentation in the 1960's resulted in the birth of NASA's Earth Observation Program which, in addition to its numerous "underflight" programs, sent LANDSAT-1 (formerly Earth Resources

Technology Satellite--ERTS-1) into earth orbit in July, 1972. Imagery obtained through this program has been tested for applicability in numerous fields, among them, both rural and urban land use classification and mapping. Alexander (1973 b) reported on a regional-scale overview that used LANDSAT-1 data in attempting to link land use and environmental processes in the CARETS (Central Atlantic Regional Ecological Test Site) area. Dolan and Vincent (1973) reported an attempt to evaluate land use mapping from LANDSAT-1 data for barrier islands of the mid-Atlantic coast.

Vegas and his colleagues (1972) developed a procedure by which, for 20 percent of the normal cost, a land use map can be produced from small scale photography (LANDSAT-1 underflight), depicting land use in a total of 18 categories with an average accuracy of 83 percent. In addition, they pointed out that other advantages which could be derived from these photographs were the large areas covered by a single frame, and the lack of distortion resulting in very little sacrifice in accuracy. The authors also noted that "over large, rural areas which comprise the majority of the land area of the United States, the small scale photography is extremely effective in determining land use which can be used in resource control and management". They (Vegas, 1972) believe "that this is the area which could benefit immediately" from the results of their experiments.

One significant development, bound to have a very far-reaching effect on the handling of remotely sensed data, has resulted from the very large amount of data that LANDSAT-1 has relayed to the earth, and which will continue to be augmented by LANDSAT-2, now in orbit. It became clear early in the program that the 'conventional' manual analysis and interpretation techniques would not be adequate to handle this amount of data. Some automated or machine-assisted techniques would be required.

Consequently, research has been conducted at several locations to meet this challenge. Several computer software systems, and electronic-optical analytical equipment have been developed. At the Laboratory for Applications of Remote Sensing (LARS) at Purdue University, a computer software system, the LARSYS, has been developed. The system was developed basically for use in classifying agricultural land use and cover types.

Fitzpatrick and Lins (1973), using the International Imaging System (I^2S) Additive Color Viewer, were able to recognize Level I land use categories (Anderson et al. 1972) on a LANDSAT-1 frame covering parts of Maryland and Pennsylvania. They also found many of the highways to be "clearly recognizable". In addition, they were able to detect areas in the process of land use change.

Wilson and Petersen (1973) have successfully employed the ORSER software system (of the Space Science Engineering Laboratory, Pennsylvania State University) to map forest land, cultivated land, and water in three diverse agricultural sites from LANDSAT-1 data. In addition, Borden et al. (1973) have used the same system to "reasonably well" define high density suburbs, old suburbs, industrial areas, and parking lots and concrete.

Joyce (1974) used the Data Analysis Station and the UNIVAC 1108 pattern recognition software (of the Lyndon B. Johnson Space Center, Texas) to perform computer-implemented land use classification utilizing three sets of LANDSAT-1 digital data for a three-county test site in coastal Mississippi. Each set pertained to a different season of the year. Preliminary findings showed that the performance of the August and January classification in the areas outside of the training sample areas was not substantially different from the results of the classification within the training sample areas. Griffin (1974) also used the UNIVAC 1108 pattern recognition software to classify agricultural land in another part of Mississippi. He demonstrated that LANDSAT-1 data could be used with computer-implemented techniques to achieve an 80 percent classification accuracy of this agricultural region.

At the Laboratory for Application of Remote Sensing (LARS), the LARSYS software system has been used successfully on many occasions to classify crop species (LARS, 1970, Hoffer, 1967). Weissmiller and Baumgardner (1974) successfully used the LARSYS software to inventory the land use of the Great Lakes Basin.

Lastly, one aspect of the use of remote sensing techniques in "rural land use" classification deserves mentioning. The environmental awareness and closer studies of estuarine aquatic biology has brought into the limelight the fundamental part played by the coastal wetlands in the nutrient generation process. This recognition has created an urgent need for intelligent and realistic management for areas which were once considered "useless swamp" (Wetlands Mapping Team, 1972). In recognition of this need, the State of New Jersey contracted with Earth Satellite Corporation to map its coastal wetlands as part of a program for data collection for better future management. Anderson and Wobber (1973) reported that biological discrimination techniques based on remote sensing data could be used in the mapping process.

Klemas et al. (1974) combined visual and multispectral photoanalysis to inventory Delaware's wetlands. They concluded that "the real-time operation of the analysis system allowed enhancement of selected species and assessment of their relative abundance in a fraction of the time required if the same study were performed using field reconnaisance manual interpolation". They recommended this method for assessing the general community structure for large, inaccessible areas. Klemas, Bartlett, and Rogers (1975) also applied satellite imagery to a Delaware Bay test site. All categories tested were correctly classified more than 80 percent of the time. Holman (1974), using high altitude aircraft photography (U-2), was able to determine three salt marsh types in Lynnhaven Bay, Virginia Beach, and Carter and Schubert (1974) produced highly accurate computer-generated maps for Chincoteague Marsh, Virginia, from LANDSAT-1 digital data.

In Nevada, Steher and Tueller (1973) found remote sensing techniques reliable for mapping inaccessible marshes. Reimold, Gallangher and Thompson (1973) evaluated these techniques in Georgia as being "of value to those planning industrial and recreational development of the coastal zone by providing information on the spatial distribution of species and primary production in the marsh."

2.1.2 REMOTE SENSING IN URBAN LAND USE

A city requires adequate statistics about itself. Thus, urban area analysis is concerned with generating and interpreting these statistics. The analyst poses many questions. Where is the urban area, and how large is it? What is the regional setting? What are its internal spatial patterns? What functions does the city perform? Some of these questions can be answered with the aid of remote sensing techniques, others cannot.

It might seem that the application of remote sensing techniques to urban area analysis has not advanced very far--especially since the concept of a planned urban environment seems to be a relatively recent idea. But this is not the case. Wray (1960) lists a number of reasons that may cause this fallacy. In fact, remote sensing techniques have contributed to urban area analysis since early in the century. Lee (1920) and Joerg (1923) were aware of the possibilities of photo interpretation in urban research. Russel, Foster, and McMurry (1943) used aerial photography to identify objects in urban areas. Wray (1948) published an atlas of the Chicago Municipal Airport, which illustrated the importance of aerial photographs taken at different times in tracing the sequences of land use in the urban periphery.

Pownall (1950) explained an early attempt at urban land use classification using aerial photos in which areas were categorized as commercial, recreational, and vacant. These classifications were keyed on the basis of tone, texture, stereo appearance, pattern, distribution, and associative characteristics. Witenstein (1954, 1956) studied Rockville, Maryland over a number of years and classified urban areas according to function, structure, type, and density of roof coverage patterns. Visser (1974) discussed the use of aerial photographs in urban cadastral survey.

Little (1973) reported the use of aerial photography in mapping "Natal and (its) growth points" in South Africa. In Tokyo, Japan, Nakajima and Oshima (1974) applied remote sensing techniques to "survey (the) degree of progressing destruction of the environmental conditions", and Tschiya (1974) monitored surface temperatures of many locations in the urban area.

Wellar (1973) described a complex municipal information system for Wichita Falls, Texas, in which remote sensing plays a vital role.

Lindgren (1973) listed urban land use mapping, transportation studies, engineering projects, municipal inspection, population and dwelling unit estimation, and housing quality analysis as six areas in the urban information system in which remote sensing can make important contribution. He stressed the "useful qualities" of the color infrared photography in urban land use mapping. Witenstein (1956) considered aerial photography vital in urban land use inventory, analysis, and planning. Cissna (1963) explained how airphotos can help solve the problems involved in a comprehensive city plan.

Polle (1974) used aerial photographs for land use surveys in four city centers between 80,000 and 750,000 population and came to several informative conclusions:

1. Although the use or function of many buildings in city centers cannot be reliably established by photo interpretation, the aerial photograph is considered very useful in land use surveys in the inner parts of towns. Aerial photography can play a key role in making a survey feasible.
2. With aerial photographs, field work surveys of the centers of cities of up to 750,000 inhabitants was less than 45 mandays.
3. In cities of up to 750,000 inhabitants, the entire survey procedure, including mapping and reporting, took not more than three months.
4. Even photographs two or three years old are useful in a survey; mapping of changes in built-up areas observed in the field can be annotated on the aerial photographs.

5. The end product of the inventory can be very detailed: space use data for each building, and each floor, (can be) aggregated at any number of classes.

As in other fields, urban applications of high altitude and space remote sensing data are under investigation. Alexander (1973 a) used LANDSAT-1 data in his attempt to classify land use and to analyse changes in land use in a South Norfolk test site of the CARETS region. Simpson, Yuill, and Lindgren (1972) used high altitude (50,000 and 60,000 feet) photography to map land use of the Boston, Massachussetts, and New Haven, Connecticut urban areas, and to produce a computer land use data base. They argued that since urban sprawl has made almost meaningless the showing on a map of the outer boundary of either Boston or New Haven, the Census Cities Project should consider interpreting photography directly into machine-readable form, rather than first into a traditional land use map.

Dueker and Horton (1972) explored the application of remote sensing technology to provide inputs to systems for urban-change detection, and recommended increased research activity focusing on automated data extraction systems. Richter (1969) studied the sequential urban change of Janesville, Wisconsin, and concluded that the remote sensing approach was feasible and useful even for communities under 50,000 population.

Ogrosky (1975) found a high degree of linear association between Puget Sound, Washington, regional population and four independent variables, most notably urban area, as measured directly from unmagnified high-altitude imagery (1:135,000 scale). He concluded that by objective definition and measurement of independent variables, investigators could use SKYLAB and LANDSAT imagery to "obtain reasonably accurate population estimates for politically, physically, or economically inaccessible areas at a reasonable cost."

Ellefsen, Swain, and Wray (1973) experimented with machine processing of LANDSAT multispectral data for urban land use in San Francisco Bay. They concluded that it was feasible to produce land use maps of a large scale by machine processing of these data, and that a remarkable level of accuracy was attainable if the land use classes were kept broad. Todd, Mausel, and Wenner (1973) derived statistics for nine spectral classes of urban phenomena in Milwaukee. The classes were Suburban, Inner City, Industry, Grassy (open area), Road, Wooded Suburb, Water, Cloud, and Shadow. When the same statistics were used to classify the Chicago area, within the same LANDSAT frame, a problem arose in the central, older part of the urbanized area, most of which was classified as "Inner City". Here, many data points were classified as "Industry" suggesting that another type of residential area existed in Chicago that was not found in Milwaukee. They concluded that machine processing of LANDSAT Multispectral Scanner (MSS) data in urban areas produced spectral classes which could be of value to the urban planner, and forecast the development of statistics, taking into account seasonal variations, which may be used to classify automatically many urban areas.

Thus, it seems reasonable to conclude that recent innovations in remote sensing techniques have opened a promising avenue for urban area analysis, planning, and development.

2.2 BASIC CONSIDERATIONS

There are several factors which both individually and collectively affect the quality of remotely sensed data and thus the quality of the information that can be derived from such data. These factors are very important and always have to be considered not only in interpretation of the data obtained but, even more importantly, in planning and implementing the data collection process. To underscore the importance of these parameters, this section will give a summary review of some literature pertaining to their effects on the quality of the remote sensing data.

In all cases where remote sensing is being used, the property being sensed is, of course, energy emanating from the object. In most instances this is the electromagnetic energy. A single beam or bundle of such energy travelling from a feature on the ground towards the sensor contains energy of variable wavelengths. Remote sensing is commonly done at one or more of several points in this electromagnetic spectrum (see Fig. 1).

In any given instance the characteristics of energy reaching the sensor will depend upon (1) the nature of the illuminant; (2) the atomic, molecular, and macro-molecular composition of the matter composing the object being sensed; (3) the nature of the medium intervening between the illuminant and the object and, (4) the nature of the medium intervening between the object being sensed and the sensor.

In most parts of the electromagnetic spectrum for which remote sensing capability is available, the information is recorded either directly in photo-like form or in a form which can be readily converted into a photo-like image. Consequently, in order for a remote sensing

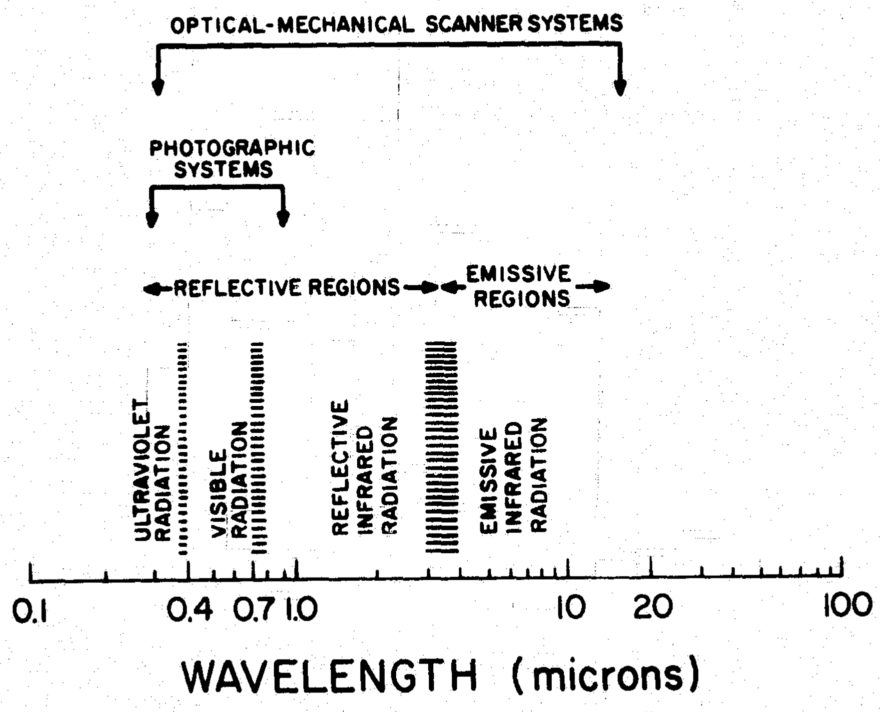

Fig. 1. A portion of the electromagnetic spectrum (from Hoffer and Johannsen, 1969)

system to operate effectively within any specified wavelength range of the electro-magnetic spectrum five conditions must be satisfied (Colwell, 1969):

1. There must be an energy source which will provide photons having the right wavelength.
2. There must be a target which will interact with photons in this range.
3. There must be an energy detector which is sensitive to energy in this range.
4. There must be a propagating medium (or else a vacuum) between detector and target, which will transmit photons in this range.
5. There must be an energy filter which will screen out unwanted photons to which the detector is sensitive while transmitting the desired ones.

2.2.1 PARAMETERS BEING SENSED

Land use classification and mapping classifies man's activity on the land, either as directly observed, or as inferred by observing and identifying the land cover. Especially where remote sensing data is the basis of the classification, the land cover becomes vital. The ability to identify and evaluate the land cover in order to be able to infer land use becomes the key to interpretation. Therefore, the spectral characteristics of the different land covers become important.

Land cover can be natural or man-made. On the natural side are some of the more obvious ones such as water in lakes, rivers, and seas; and vegetation of all descriptions and characters. The major man-made land covers are buildings of all descriptions and roads of all sizes. In addition, one of the most important land covers can actually be termed a non-land cover: bare ground. This may be an agriculturally active farm which may be bare only at certain short periods during the year, or bare rock, or bare sand in a desert area, which may remain bare throughout the year for generations.

The spectral characteristics of some of these land covers have been investigated, others have not. Hoffer and Johannsen (1969) used a Beckman DK-2A spectrophotometer to obtain a total of 2,352 spectra of 2,131 leaf samples of 7 crop species and 24 varieties, and of 221 soil samples. They found significant differences among all the species studied and among some of the varieties studied. In addition, they determined four major absorption bands of a healthy green leaf between 0.35 and 2.6 microns (Fig. 2). These were shown to be associated with the presence of chlorophyll and water in the leaves. Also, the spectra for three tree species studied (Tuliptree, Silver Maple, and American Elm) were shown to have the same approximate general shape, characteristic of green vegetation, but with significant differences in amplitude of reflectance in certain wavelength bands. Thus, these authors determined that the spectral reflectance of green vegetation depended on several factors including the species and variety, the leaf moisture content and color, and the wavelength band used in the study. There are, no doubt, other factors contributing to these differences. Age is likely to be one of these.

Forsythe and Christison (1930) showed the relative degree of water absorption between 0.4 and 2.6 micron wavelengths (Fig. 3). Reflectance was shown to be highest in the 0.4 to 1.3 micron range and to be lowest between 1.4 and 1.6 micron wavelengths, and again above 1.9 micron wavelength.

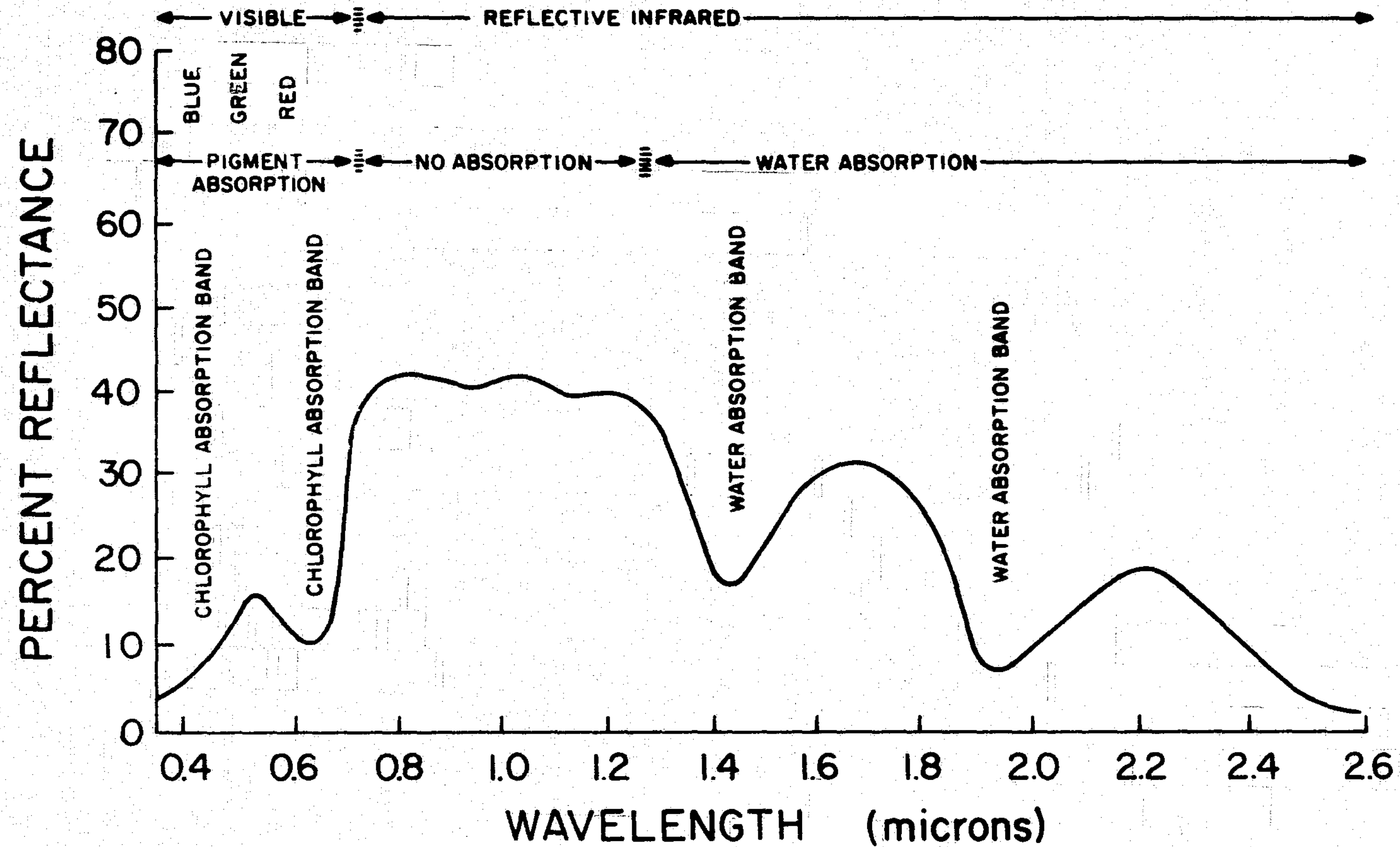

Fig. 2. Characteristic spectral reflectance of a green leaf (LARS, 1970)

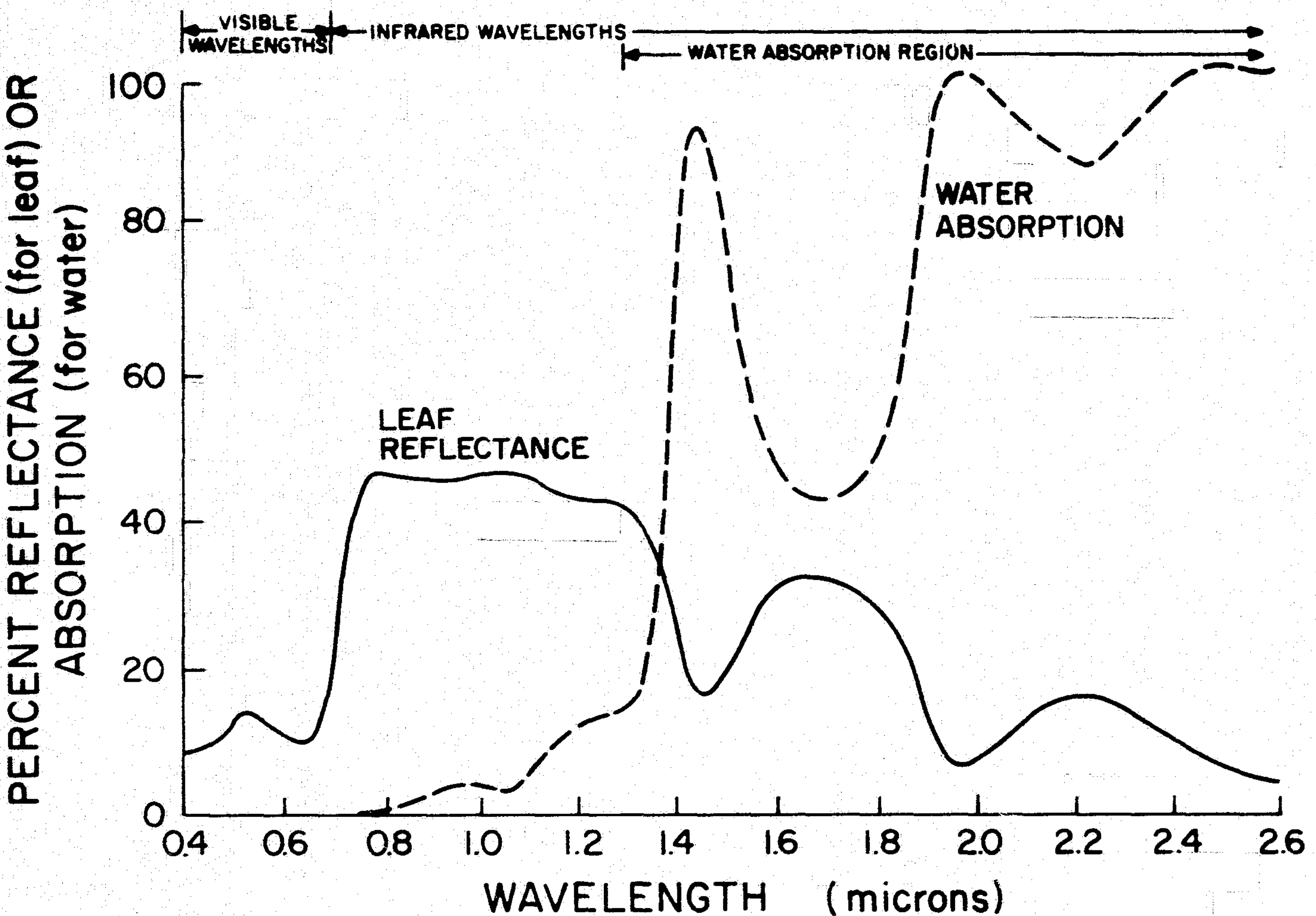

Fig. 3. Relationship between leaf reflectance and water absorption between 0.4 and 2.60 micron wavelengths (LARS, 1968)

Gates (1970) lists the following as determining the reflectance of the soil surface: coloration, texture, moisture content, roughness, mineral composition, angle of illumination, and degree of shadowing by plants, buildings, etc. Some of these factors have been investigated also by Hoffer and Johannsen (1969), and by Cipra et al. (1971). Horvath and Baumgardner (1971) found a high correlation between soil reflectance and soil organic matter, and also that the correlation varied with various spectral channel combinations.

Condit (1970) made measurements of spectral reflectance extending from 320 to 1000 nanometers (.32 to 1.0 micrometers) on 160 soil samples collected from 36 states. He found that with respect to their curve shape, all the soils could be categorized into three general types, and concluded ". . . It seems evident that the spectral reflectance of a wide variety of soils . . . can be predicted with sufficient accuracy from measurements made in only five wavelengths."

Most of the man-made features consist of concrete, asphalt, rocks, and bricks, all of various colors. Depending on their color and the smoothness of their reflecting surfaces, these objects reflect electromagnetic radiation to a lesser or greater degree, and they may also be expected to reflect more in certain wavebands than in others. Of these, asphalt, because of its normally black color, probably has the lowest overall reflectance within the region of the spectrum used by photographic imaging systems.

2.2.2 OTHER FACTORS AFFECTING THE QUALITY OF REMOTE SENSING DATA

2.2.2.1 GENERAL

In addition to the factors discussed in the preceeding section, there are other factors which do not bear directly on the type of land cover present. The Manual of Photographic Interpretation (ASP, 1960, p. 344) adds the following to the list: light sensitivity of the film used, light transmissivity of the filter, and techniques of processing (and printing). Hoffer (1972) summarized the major causes of spectral variability as follows:

a. Natural, geographic variability.

b. Illumination conditions.

c. Instrumentation drift and adjustments.

d. Data systems imperfections.

Frost (1953) added to this list what he calls "human" factors. Thus, it seems that those factors pertaining to the photography, the interpreter, and the natural causes are of greatest importance.

2.2.2.2 PHOTOGRAPHIC FACTORS

Many different types of photography are available, and they differ in their fidelity to varying degrees. These include Trimetrogon Photography, Continuous Strip Photography, Composite Photography, and Vertical Stereoscopic Photography (Frost, 1953, ASP, 1960). In addition SLAR (Side Looking Airborne Radar) and satellite imagery have lately been added to the list. These are now being evaluated (Colwell, 1973, Alexander, 1973 a, b, Colvocoresses, 1970).

The scale of the imagery imposes one of the most serious limitations on the results to be obtained for any study, since the amount of recognizable details is reduced when the scale is decreased. Fortunately, this is one of the photographic factors over which we have considerable control. The major determinants of the imagery scale are the focal length of the camera and the distance between the camera and the object.

Most photographic films used in natural resource remote sensing activities are sensitive to the reflected energy of the electromagnetic spectrum between approximately 400 and 700 nm (Fig. 1). This is the light or visible range of the spectrum. There are also films which record reflected invisible energy. These are sensitive to the near infrared range of the spectrum up to about 900 nm (Eastman Kodak, 1971). Because of the difficulty of shielding film from radiated heat, the range above 900 nm is not generally applicable for field work (Eastman Kodak, 1968) though the longest actinic wavelength is approximately 1350 nanometers.

Photographic films in general use are either negative producing films or reversal (positive transparencies) films. There are both black-and-white and color negative films in use. Reversal films in general use are either natural color or false color. Sorem (1967) and Welch (1968) have both evaluated the films in general use.

The function of filters is to provide a means to select, amplify or eliminate portions of the electromagnetic spectrum in which photo-sensitive material respond. Their ability to screen out haze is essential to the production of good photography. Avery (1970) listed the common Kodak Wratten filters in use for panchromatic and infrared films. The spectral transmittance curves of three haze-cutting filters most commonly used in remote sensing are given by Heller (1970). Smith (1968) has given a detailed discussion of filters used in aerial photography.

Resolution, tone, density, and physical characteristics are also other factors. Frost (1953), Swanson (1954), Colwell (1954) and Heller (1970) have all cogently addressed themselves to these factors.

2.2.2.3 NATURAL CAUSES

This limitation is due largely to natural features of the terrain pattern. Haze may also be regarded as a natural cause. In order to evaluate the landscape correctly, certain conditions existing at the time the imaging was done must be considered. These limitations include anomalies caused by climate which in photographs are reflected in photo tones. Illumination, angle of the sun, and scattering of the light are factors to be considered. Frost (1953) and Heller (1970) have discussed some of these factors.

The photographic tones are influenced materially by the prevailing environmental conditions, and it is, therefore, vitally important that the photo interpreter is able to relate the variation of the tone to the landscape under investigation. This is where the spectral characteristics of the different land covers discussed in section 2.2.1 become important.

2.2.2.4 ABILITY OF THE PHOTO INTERPRETER

Although in recent years numerous experiments to automate the interpretation of remote sensing data have been successfully carried out (see section 2.1.1), in most application situations this remains a manual job. This makes it imperative that the human element be always considered. Wilson et al. (1960) divided image characteristics into two groups: (1) those that are judged qualitatively and (2) those that are judged quantitatively. Rosenfeld (1965) further explained that in the qualitative interpretation (pattern recognition) the real-world original of the image is not fully known to the interpreter while in the quantitative interpretation the interpreter derives quantitative conclusions about the image's real-world original form. Although numerical values can be entered for the latter group of data, variations will be due, in part, to the variations of human evaluations of tone, texture, pattern, and shape, as well as the human errors in measurements.

Colwell (1952) emphasized that " . . . the qualifications for a good interpreter are acuity of vision, power of observation and imagination, patience, judgement and professional background." Later, Colwell (1954) went into more detail and subdivided the requirements into (1) visual acuity, and (2) mental acuity. The "visual acuity" is referred to as "stereoscopic acuity" by the ITC (International Training Center for Aerial Surveys, Enschede, The Netherlands) which (Zorn, 1965) has developed an instrument for testing it.

The chapter on "Fundamentals of Photo Interpretation" (Rabben et al. 1960) in the Manual of Photographic Interpretation discusses in detail the human factors in photo interpretation. In the same Mânual, (p. 345), Frost et al. (1960) emphasized that photo interpretation requires adequate visual powers, the ability to reason logically, knowledge of the basic principles of the earth sciences, and experience in the relevant earth science field. These cannot be replaced by the computer.

3. MATERIALS AND METHODS

3.1 MATERIALS

Numerous materials go into the analysis process in most studies. In this section, a description of only the major materials contributing to the results will be given.

3.1.1 THE STUDY AREA

The City of Virginia Beach, formerly Princess Anne County, occupies the extreme southeastern tip of Virginia. Its northern edge extends along Chesapeake Bay about 23 km (14 miles), and its eastern edge borders the Atlantic Ocean from Cape Henry to the Virginia-North Carolina state line, about 40 km (25 miles). The total area is approximately 700 km^2 (270 square miles). The location of the study area is given in Fig. 4.

The study area lies in the Coastal Plain physiographic division in the Tidewater Section of Virginia. Although dunes at Cape Henry are as high as 26 m (85 ft) above sea level, few places are above 6 m (20 ft). Relief of as much as 6 m occurs locally in the northern one-third of the study area. Oaks and Coch (1973) have described these and other morphologic subdivisions of the area.

Most of the natural drainageways reach sea level within a few kilometers of their source. According to Simmons and Shulkcum (1945), no part of the City is more than 13 km (8 miles) from a point that lies at sea level. Short, northward flowing streams, emptying into the Chesapeake Bay, characterize the northern part of the area. These include the Elizabeth River, Little Creek, and Lynnhaven River. The major southward flowing river is the North Landing River, with its West Neck Creek and Blackwater Creek tributaries, which flow into Currituck

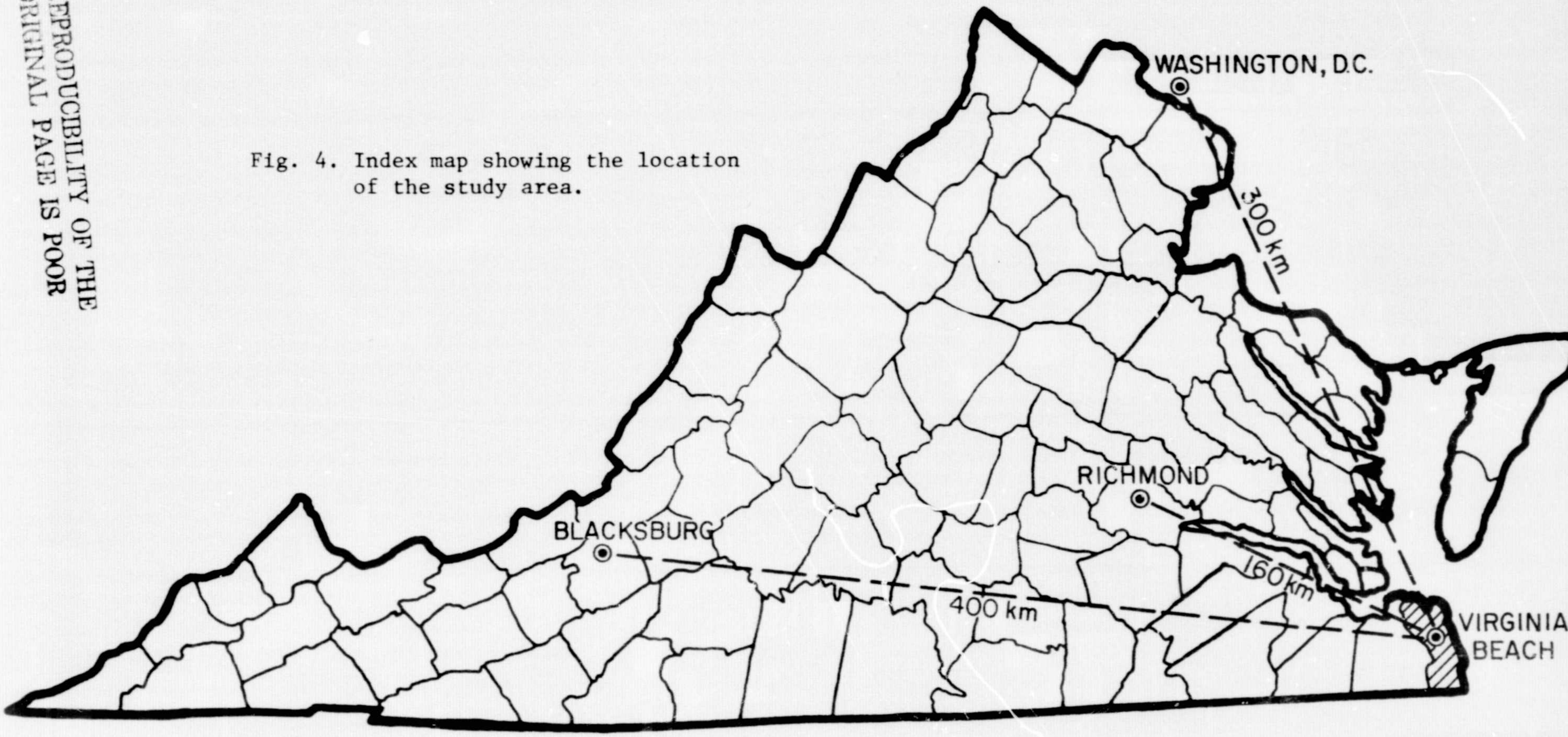

Fig. 4. Index map showing the location of the study area.

Sound. Back Bay is a shallow, slightly brackish lake with marshy borders, separated from the ocean by a narrow ridge of beach and dune sand. It can also be considered as flowing into Currituck Sound. The closest opening to the sea for the southern drainage is Oregon Inlet, 90 km (56 miles) south of the Virginia-North Carolina state line. A small area in the vicinity of the resort area drains directly into the Atlantic Ocean through Rudy Inlet. A number of inland lakes are also present, the largest of which are Lake Tecumseh and Stumpy Lake. The major drainageways and communication routes are shown in Fig. 5.

The climate of the area is oceanic; that is, it is moderated by the proximity of the Atlantic Ocean and Chesapeake Bay. The summers are long and temperate, but with a few very hot days; the winters are mild, with few days below freezing. The average temperature is about 24.6°C in summer and 7.4°C in winter. Average annual precipitation is 1,361 mm (53.6 inches).

The most common tree vegetation is loblolly pine, found under both well drained and imperfectly drained situations. Other species are red oak, white oak, hickory, and holly, found on well drained areas; beech, sycamore, sweetgum, black tupelo, yellow poplar, and red maple are on the wetter areas, and cypress in swamps. Understory vegetation primarily consists of a thick undergrowth of gallberry, waxmyrtle, greenbriar, blackberry, wild grape, and, in poorly drained places, cane and reeds. Coarse "reed-like" grasses are abundant in the tidal and fresh water marshes, and cattails are the most common in the latter.

Although the southern half of the City is predominantly agricultural, the urban area is rapidly advancing southward. Many residential and

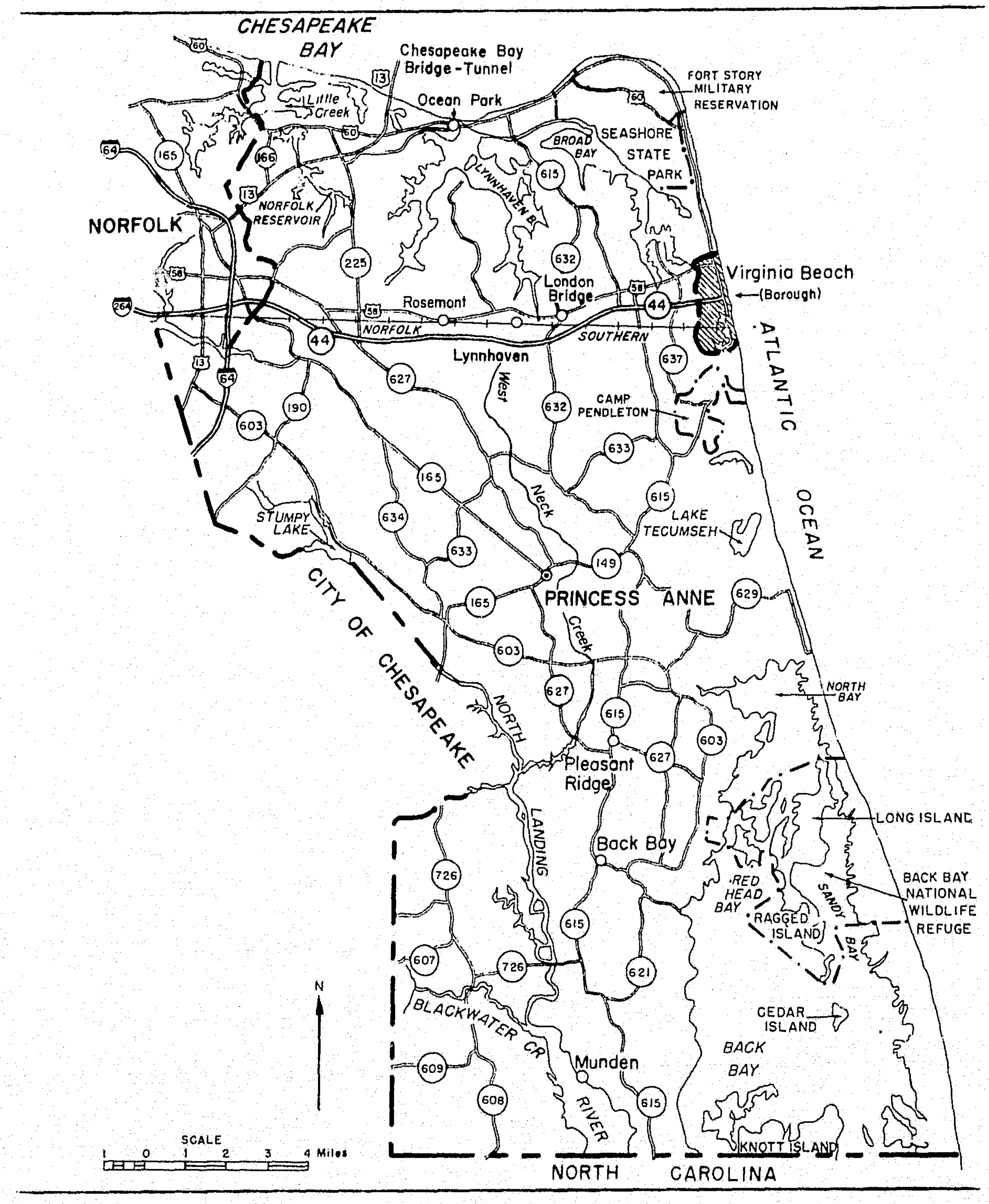

Fig. 5. General map of the study area showing major drainage and communication routes.

resort-related construction activities are widespread. Limited agricultural activities exist in the northern one-third of the area, but these are rapidly converting to urban, mostly residential single family suburban types. In the north-central part of the City, south of Highway 44 and west of Oceana Naval Air Station, a number of multi-family residential subdivisions are currently under development.

A soil survey of Princess Anne County was done in the late 1930's and published in 1945 (Simmons and Shulkcum, 1945). Presently, a new, more detailed and more modern survey is in progress. Thus, the names of soil series and associations are in the process of being reorganised, modified, or redefined. Thus, the soil names will not be used in this section. In a later section soil names will be used where they have been established or widely recognized in the current survey.

The soils have developed from unconsolidated beds of sand, silt, and clay, and they differ widely in physical and chemical charcteristics. Drainage is a very important parameter in this area because of the low elevations above sea level. Most of the well drained and moderately well drained soils occur north of Highway 44, and along Pungo ridge and other lesser ridges in the southern portion. The dominant proportion of the soils are poorly drained and somewhat poorly drained. The water table fluctuates within one meter of the surface in most places, thus subsoil mottling is common. More detailed discussion of some soils will be given in a later section.

3.1.2 THE IMAGERY

The imagery which is the principal source of data examined in this study consists of LANDSAT-1 (ERTS-1) Multi-Spectral Scanner (MSS) imagery obtained August 30, 1973, over Virginia's Atlantic coastline. All the four bands of the MSS have been used in the analysis. These are shown in Figs. 6a through d. They were taken at 1013 hours. Because the major thrust of this research utilized machine processed LANDSAT-1 MSS data, the direct imagery usage was limited. Rather, the computer-compatible tapes (CCT), containing the original electro-optical data from which the imagery in Fig. 6 were obtained, were directly utilized. The principles and operation of the LANDSAT equipment have been described in several NASA publications (Wolff, Cote, and Painter, 1975) and the fidelity of these imagery have been investigated and evaluated in previous research (Colvocoresses, 1970; McEwen, 1973).

Other data used were imagery obtained by NASA's U-2 Aircraft Support Flight No. 73-185 flown on November 1, 1973 at 19,805 m (65,000 ft). The imagery was taken with an RC-10 camera, of 152 mm focal length. The film used was Aerochrome Infrared Type 2443, with a spectral band of 510-900 nm. It was exposed between 1504 and 1521 hours, at an f stop of 8 and a shutter speed of 1/150 of a second, with a 60% overlap. The imagery was slightly underexposed but of fairly good quality. It was flown for the CARETS project. Frames 5576 and 5575 (Figs. 7 and 8, respectively) were used in this study.

Low altitude imagery was also available, and it was used mainly for ground truth verification. This imagery was obtained at altitudes of 1976 m and 3040 m (6,500 and 10,000 ft) by NASA's C-54 aircraft. Both conventional (SO-397) and color infrared photography (2443) were available for one of the flights and included imagery taken by cameras of 152 mm and 306 mm focal lengths. The photographs used were on 23 x 23 cm

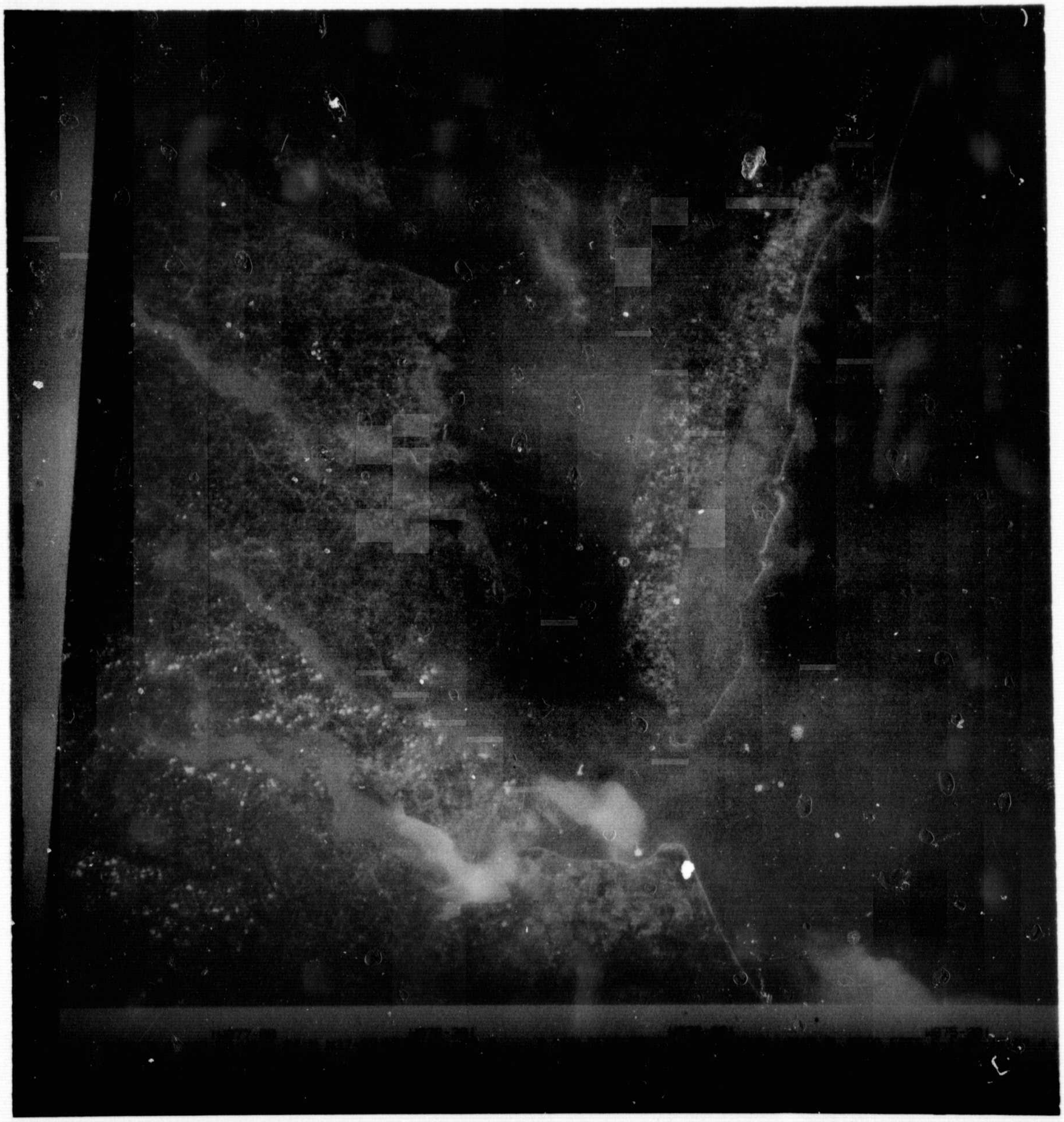

Fig. 6 a. Band 4 of LANDSAT-1 MSS image of August 30, 1973

Fig. 6 b. Band 5 of LANDSAT-1 MSS image of August 30, 1973

Fig. 6 c. Band 6 of LANDSAT-1 MSS image of August 30, 1973

Fig. 6 d. Band 7 of LANDSAT-1 MSS image of August 30, 1973

Fig. 7. Part of frame 5576 of flight U-2 73-185 used. Strips A and B were digitized in the first step to evaluate the different channels. Area C was used in the sample unsupervised classification.

Fig. 8. Part of frame 5575 of flight U-2 73-185 used. Area A was digitized with two filters for detailed analysis. Area B was used in the sample unsupervised classification.

(9 in x 9 in) format and on carousel slides. Relevant information of the three flights used are given in Table 1, and some relevant climatological data during the week preceding the photography data are given in Table 2.

3.1.3 INSTRUMENTS

The major automatic data processing instrumentation used in this study comprised the 2780 remote terminal (Fig. 9) consisting of four units located at NASA Wallops Flight Center. These are the printer, card reader, card punch, and the typewriter terminal. The Central Processing Unit (CPU) that can be accessed via this terminal is located at the Computer Center of the Laboratory for Applications of Remote Sensing (LARS), Purdue University, West Lafayette, Indiana. The two are connected via the Goddard Space Flight Center (GSFC), Greenbelt, Maryland. The card reader and printer can also be used off-line as a card lister. This adaptation is important in controlling the accuracy in card punching. The CPU can be accessed either through the card reader or through the typewriter terminal, the response coming on the printer or typewriter, respectively.

The complementary instrumentation which is utilized in conjunction with the hardware described in the above paragraph is the LARSYS software system. This system was developed at LARS. This is a "fully documented software system for installation on a general purpose computer to provide tools for remote sensing research" (Phillips, 1973). The following passage from the LARSYS Users Manual, vol. 1 (Phillips, 1973), paraphrases the principles on which the system is based:

> LARSYS . . . uses multispectral . . . and/or multitemporal . . . data in image orientation as its primary input data.. . .

Table 1. Summary information on the low altitude flights used.

Mission	Flight	Date	EDST	Alt. m	Camera	Film	Focal Length mm	Filter	Weather
W083	1	8/25/71	0800-0857	3,040	T-11	2443	152	12AV+20M	Clear
		8/25/71	0800-0857	3,040	T-11	2443	152	12AV+20M	
W187	1	2/13/73	0828-0904	1,976	T-11	SO-397	152	CAV+H	Clear
			0828-0904	1,976	T-11	2443	152	12AV+10CCM	
			0828-0904	1,976	K-17	SO-397	306	Haze	
W271	1	6/4/74	1042-1051	3,040	T-11	2443	152		Clear

Table 2. Total precipitation for the 14 days preceding the photography days (August 30 & November 1, 1973) for two stations in the study area.

Week	Precipitation, mm Back Bay	Diamond Springs
August 16-22	56.4	78.2
August 23-29	no entry	4.3
October 18-24	no entry	no entry
October 25-31	8.6	8.1

Fig. 9. The 2780 remote terminal located at Wallops Flight Center. (1) printer; (2) card reader; (3) card punch; (4) typewriter terminal (IBM 2741 Communications Terminal).

The analysis algorithms used in LARSYS and applied to remote sensing were developed as pattern recognition techniques. The basic analysis concept consists of locating data points hypothesized to be representative of classes of interest, calculating the Gaussian statistics of these data points, using these statistics to classify a data set of interest, and evaluating the classification result. The data bases used to calculate the statistics are called training data points, or more commonly . . . , training fields. The data points used to evaluate the classifiers are called test fields. The pattern recognition algorithms implemented in LARSYS include an algorithm for calculating the statistics of training fields, a feature selection algorithm, and two classification algorithms.

The digital data input to LARSYS is in the form of a Multispectral Image Storage Tape. The measurements from the remote sensors . . . may be processed through several storage media before they are reformatted into the specific format of a Multispectral Image Storage Tape required by LARSYS. Each data element stored on the tape is a vector relating to measurement bands or multiple measurement times. These measurements are from a small portion of the earth's surface and are associated with the resolution of the sensor system. The data vectors are stored on the Multispectral Image Storage Type so that they retain their image orientation.

The system consists of a software implementation of 18 Processing Functions. These are:

1. IDPRINT which provides lists of the ID record information to aid user in identifying available data runs,
2. DUPLICATERUN which will copy a run from one Multispectral Image Storage Tape to another,
3. TRANSFERDATA which will extract data values from a run and print them in a listing, punch them into a card deck, or write them on a formatted tape,
4. LINEGRAPH which prints a graph showing the relative magnitude of data points from lines stored in a given run,
5. COLUMGRAPH which prints a similar graph for columns of data,

6. HISTOGRAM which calculates a histogram of the data values for each requested channel for a specified area,
7. GRAPHHISTOGRAM which prints the graph of the resulting histogram,
8. PICTUREPRINT which prints data in image orientation to enable a user to manually select subsets of data which will be useful as training fields and test fields,
9. IMAGEDISPLAY which, in addition to 8, supports a sixteen gray-level device enabling the user to manipulate the displayed data and select fields with a lightpen,
10. CLUSTER which is an unsupervised classifier which groups data vectors into the number of classes specified by the user,
11. STATISTICS which calculates mean vectors and covariance matrices for each class specified by the user,
12. SEPARABILITY which uses data from the Statistics File to measure the separability between classes of interest as a function of combinations of spectral bands,
13. SAMPLECLASSIFY which classifies groups of points by considering group statistical characteristics,
14. CLASSIFYPOINTS which performs the maximum likelihood classification on a point-by-point basis over a specified area,
15. PRINTRESULTS which produces a number of printed outputs,
16. COPYRESULTS which duplicates the Classification Results File on magnetic tape,

17. LISTRESULTS which produces a formatted listing of identification information pertaining to the Classification Results File, and

18. PUNCHSTATISTICS which punches on cards (from the Classification Results File) the Statistics File that was used in the classification.

These functions and other parameters of the system are discussed in detail in the three volumes of the LARSYS Users Manual.

Another instrument used in this study was an Optronics International System P-1700 Microdensitometer (Fig. 10) consisting of the microdensitometer, a transparency barrel, and a teletype terminal for communication. The drum is equipped with adapters to accomodate various sizes of film. Using different filters to accentuate certain wavebands, several wavebands can be created from one transparency, thus creating a multispectral situation. The instrument digitizes the optical characteristics of the transparency (in the number of bands selected) and writes these on a magnetic tape. This serves as a multispectral data source for the LARSYS software (in this case, however, the data had to be reformatted to make it compatible with the LARS computing center facilities).

Other instruments used included light tables, carousel slide projectors, and an I^2S (International Imaging Systems) Additive Color Viewer. The I^2S multispectral analysis equipment consists of four filters (clear, blue, green, and red) and up to four windows. It can take up to four separate images, usually four different wavebands, and

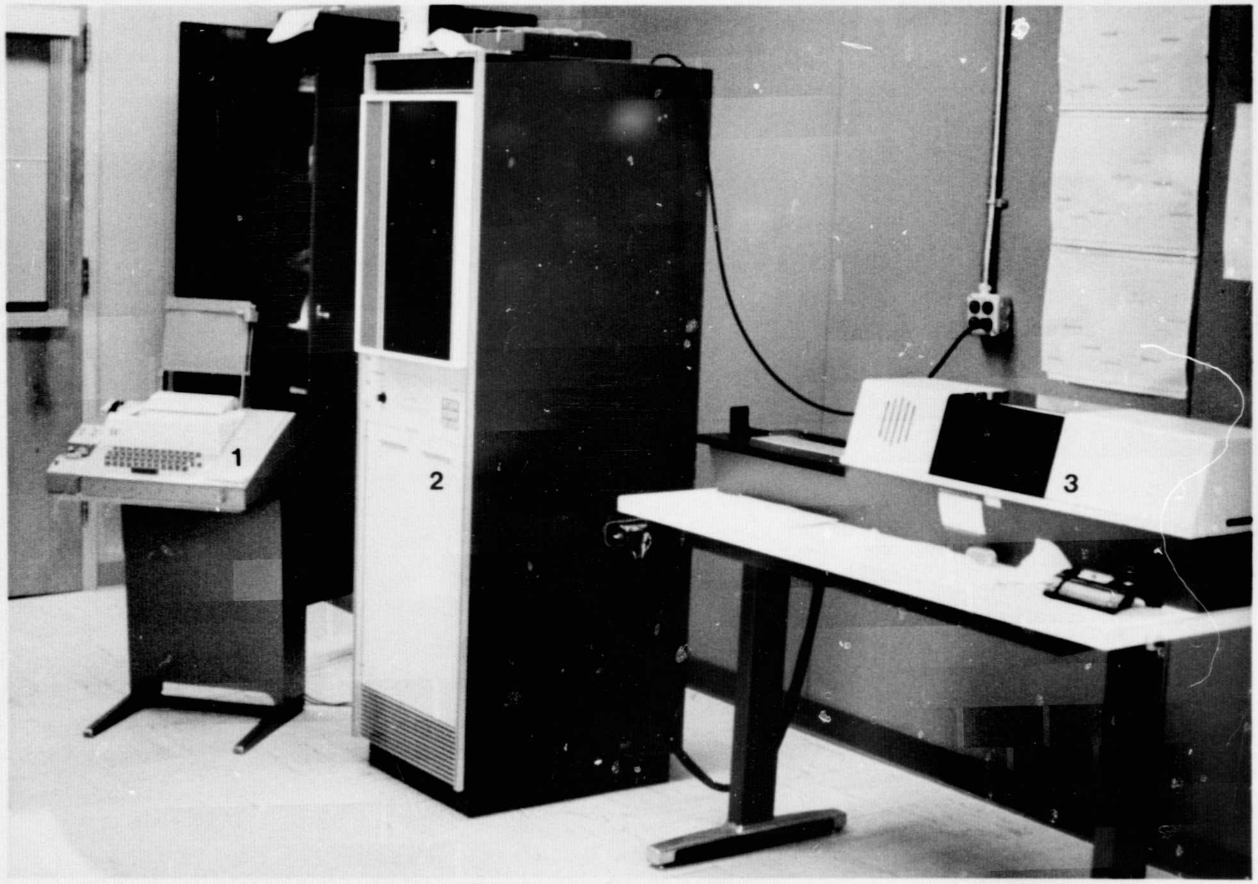

Fig. 10. Optronics International System P-1700 Microdensitometer. (1) Teletype Terminal for Communication (Teletype Corporation Model 3320 3JG); (2) Microdensitometer; (3) Transparency Barrel.

register them into a single image. By varying the filters and illumination, different features in the imagery can be accentuated or made prominent, and different renditions obtained.

3.1.4 OTHER MATERIALS

Other materials used were the USGS 7.5 min. Topo Sheets. A total of seven sheets were needed to cover the study area. In addition to contour lines, these usually give an indication of land cover, and in this case, because of the gentle rise from sea level and consequent sparse, spread-out contour lines, the topo sheet provided clear and very easy-to-read indications of land cover.

Finally, two other materials were used in the collection and verification of ground truth. These were land vehicles and a light, one-passenger Piper aircraft. The latter, equipped with pontoons, was especially useful in verifying the inaccessible and difficultly accessible parts of Back Bay.

3.2 METHODS

Because the author had no previous first-hand knowledge of the study area, the first step was to make a familiarization on site inspection. First, different materials were examined at the Chesapeake Bay Ecological Program Data Center at Wallops Flight Center. These consisted mostly of different imagery and a few topographic and other maps. Natural color and color infrared (IR) carousel slides and 23 x 23 cm (9" x 9") transparencies were closely examined to gain a general impression of the area. A slide projector and a light table were used in this step. The most evident land uses and cover types were noted. All the available low altitude and high altitude (U-2) imagery (as of that date - August, 1974) covering the relevant area were examined in this way.

Also, all the available LANDSAT imagery of this date were examined with the aid of the I^2S Additive Color Viewer. Imagery of nine passes were examined. These data were obtained January 13, 1973; February 13, 1973; May 14, 1973; August 12, 1973; August 30, 1973; September 17, 1973; February 26, 1974; March 15, 1974; and April 3, 1974. During this preliminary examination, those imagery, in both groups, which were obviously inadequate for this study, were eliminated.

Armed with the impression gained so far, the study area was then visited. This inspection included many of the features that had been recognized in the previous imagery as well as those which had not. The whole of the study area was closely examined with the help of topo sheets and other maps. Important at this stage was the number of broad categories of land uses present in the study area.

Next, the better of the two groups of images was re-examined more closely for further details. At this stage, in addition to the easily identifiable broad land use groups, they were also examined more closely for the general photographic qualities of the imagery. A closer examination of the three U-2 coverages available (December 12, 1972; January 30, 1973; and November 1, 1973) was carried out, and as a result the November 1, 1973, U-2 73-185 flight was chosen for further examination and analysis. The December 12, 1972, flight (U-2 72-208) was eliminated because of a bluish tinge which greatly reduced contrast. Likewise, the January 30, 1973, flight (U-2 73-013C) was eliminated due to a reddish tinge that also greatly reduced contrast.

Most of the LANDSAT imagery had been eliminated for this study during the previous examination, mainly due to either snow cover and/or low contrast, or due to clouds in the relevant part of the frame. The frames of August 12, and August 30, 1973, were of equally good quality as far as could be discerned. The latter was chosen for further analysis mainly because it was already reformatted and filed at the Purdue LARS computing center, which saved time and reformatting expenses.

At this stage, six preliminary broad groups of land uses were selected for the area. These were "Urban," "Water," "Wetland," "Wooded," "Agricultural," and "Bare Land." Consideration was given to naming the last class "Barren Land" to conform with the terminology of the system proposed by Anderson et al. (1972) (Table 3). However, it was decided that the beaches, which constituted most of this category, could hardly be regarded as barren in the City of Virginia Beach. The terminology apart, these major classes correspond to classes 01, 05, 06, 04, 02, and 07, of Table 3, respectively.

From this stage, the two data sources were handled separately. The LANDSAT data was on file and ready for analysis, but the U-2 imagery needed to be digitized, reformatted, and filed at Purdue. Thus, while the U-2 imagery was being so prepared, the first trial analysis was made on the LANDSAT data.

3.2.1 PREPARATION OF U-2 DATA

The Aerochrome Infrared Type 2443 film used in this coverage registered wavelengths between 510 and 900 nm on the transparency. By using different filters to screen out certain wavelengths, different

Table 3. Proposed Standard Land Use Classification System. The first level of the classification system was designed for use with ERTS imagery. (Anderson et al., 1972)

LAND USE CLASSIFICATION SYSTEM FOR USE WITH REMOTE SENSOR DATA

Level I Categories
Level II Categories

01 Urban and Built-up

- *01 Residential*
- *02 Commercial & Services*
- *03 Industrial*
- *04 Extractive*
- *05 Major Transport Routes & Areas*
- *06 Institutional*
- *07 Strip & Clustered Settlement*
- *08 Mixed*
- *09 Open & Other*

02 Agricultural

- *01 Cropland & Pasture*
- *02 Orchards, Groves, Bush Fruits, Vinelands, & Horticultural Areas*
- *03 Feeding Operations*
- *04 Other*

03 Rangeland

- *01 Grass*
- *02 Savannas (Palmetto prairies)*
- *03 Chaparral*
- *04 Desert shrub*

04 Forestland

- *01 Deciduous*
- *02 Evergreen (Coniferous & Other)*
- *03 Mixed*

Level I Categories
Level II Categories

05 Water

- *01 Streams & Waterways*
- *02 Lakes*
- *03 Reservoirs*
- *04 Bays & Estuaries*
- *05 Other*

06 Non-Forested Wetland

- *01 Vegetated*
- *02 Bare*

07 Barren Land

- *01 Salt Flats*
- *02 Sand (Other than Beaches)*
- *03 Bare Exposed Rock*
- *04 Beaches*
- *05 Other*

08 Tundra

- *01 Tundra*

09 Permanent Snow and Ice Fields

- *01 Permanent Snow and Ice Fields*

channels consisting of different wavelength bands can be obtained. This procedure creates a multispectral situation necessary for the LARSYS software system. Four filters and four channels were possible in this case.

It was necessary to make a sample run in order to select the optimum channels and filters relevant to the data used. Thus, two strips were selected for this purpose on Frame 5576 (Fig. 7): one in the northern urban section and the second in the southern agricultural area. They were digitized by the microdensitometer according to the following schedule:

Filter	Spectral Band nm.	Resulting Channel
Clear	510 - 900	1
Red	680 - 900	2
Blue	510 - 570	3
Green	590 - 660	4

It will be noted that in the red, blue, and green filter combinations, two short wavebands are lost: 570 - 590 nm and 660 - 680 nm, and that in the clear filter (channel 1), the whole of the original spectral range is retained. Channel 2 (red filter) was found to exhibit unsatisfactory contrast for optimum discrimination in both the northern "urban" strip and the southern "agricultural" strip. Channel 3 (blue filter) was found to be very similar to channel 1, and channel 4 (green filter) was found to give the best contrast in both strips. On the basis of this evaluation, clear and green filters (channels 1 and 4) were selected for use in preparing the data to be analyzed. Thus, Frame 5575 (Fig. 8) was digitized with the clear and blue filters, reformatted and filed at LARS, Purdue, with the following identifications: the northern third of the area: Run 73212301, File 1; middle third: Run 73212302, File 1; and southern third: Run 73212303, File 1. The data required three tapes. The two strips of Frame 5576 had been filed as Run 73212200 (north strip) and Run 73212300 (south strip).

3.2.2 MACHINE ANALYSIS OF THE DATA

Both the LANDSAT data and the U-2 data prepared as described were analyzed using the LARSYS software system. In addition, the LANDSAT frames were examined more closely with the aid of the I^2S Additive Color Viewer.

Two classification approaches are possible with the LARSYS software: (1) the supervised approach in which the training area is specified to the computer as containing a certain known or verified material, and (2) unsupervised approach in which the identities of the materials being classified are not known until afterward (Alexander *et al.*, 1974). Both of these approaches were used for the LANDSAT data, while the unsupervised approach only was used for the U-2 data. The procedures employed in the three analyses will be briefly described.

3.2.2.1 I^2S ANALYSIS OF ERTS AUGUST 30, 1973 PASS.

All the four 70 mm waveband frames were mounted onto the windows and registered into a single image. In the preliminary step, many filter/illumination combinations were tried. Four combinations were found to accentuate certain important features in the relevant part of the frame. These are given in Table 4.

Table 4. Filter/illumination combinations used in the I^2S instrument.

Combinations	Band	4	5	6	7
1	Filter Illumination	Blue Maximum*	Red Maximum	Green 7.5	Blue Maximum
2	Filter Illumination	Green 7.7	Green 8.0	Blue 8.0	Red Maximum
3	Filter Illumination	Blue Maximum	Clear Maximum	Green Maximum	Clear Minimum*
4	Filter Illumination	Blue 7.5	Green Maximum	Green 4.0	Red 7.5

* maximum = 8.7; minimum = 0

3.2.2.2 LARSYS ANALYSIS OF LANDSAT DATA

This data is on the computer file as Run 73120101 and in four channels. The supervised approach was tried first. The processing card deck will be given only in the key functions of the analysis procedure.

3.2.2.2.1 THE SUPERVISED APPROACH

This was the primary analysis technique utilized in this study. All the other approaches were supplementary to it.

The data quality was examined first by obtaining *COLUMNGRAPH for Columns 1760, just west of the Lynnhaven Inlet, and 1930, on the southward turn of the eastern edge of Cape Henry. *LINEGRAPH were also obtained for lines 2290 and 2420.

Next, a *PICTUREPRINT was obtained in one channel for the whole frame to determine the coordinates for the required part of the frame. Subsequently, printouts were obtained in the four channels for the relevant area. This required the following card deck:

```
*PICTUREPRINT
DISPLAY RUN(73120101), LINE(2140,2620,1), COL(1630,2070,1)
BLOCK LINE(2140,2620,1), COL(1630,2070,1)
CHANNELS 1,2,3,4
END
```

The printouts were analyzed in detail and they were found to exhibit insufficient contrast. So a *HISTOGRAM and *GRAPHHISTOGRAM were requested for each channel. These were used to assign the actual data ranges and specified to the computer by adding a HISTOGRAM LEVELS CARD for each channel to the above deck. The printouts obtained after this were used for further analysis.

The attention then shifted again to the study area. After a review of the material at hand, training and test fields were selected and outlined. Channels 3 and 4 (MSS bands 6 and 7) were selected for this purpose because of their better contrast (see Figs. 6 c and d). No limit was set in advance as to the number of training and test fields to be used. Rather, the purpose was to use as many as practical from as many parts of the study area as possible. This was deemed likely to give the most representative samples, as it would scatter the training samples over the area. Lindenlaub (1973) observed that

> . . . the accuracy of the estimate tends to increase as the number of data points used for training increases. Theoretically a lower bound on the number of training data points for any class is n+1, where n is the dimensionality of the data vector (number of channels) used by the classifier. Fewer than n+1 points leads to a singular covariance matrix which the classifier cannot use. A practical lower limit is about 10n, but 20n to 100n is desirable if enough ground observations are available.

The previously mentioned six major land uses were also adopted as candidate training classes.

Thirty-five training fields for Urban, 52 for Water, 26 for Wetland, 36 for Wooded, 25 for Agricultural, and 21 for Bare Land were selected. This required close coordination of the printouts and the field observations. Test fields were also selected at this point, from locations that exhibited a high degree of uniformity in the printouts. Some of the Urban training fields were taken from eastern Norfolk (just west of the study area) where there were more extensive urban developments than the study area. Then, the training and test fields were coded according to Appendix 1, and clustered. The following deck was required for the clustering function:

```
*CLUSTER
OPTIONS MAXCLAS(x)
CHANNELS 1,2,3,4
DATA (field description cards for Urban)
END
*CLUSTER
.
.
.
.
(continued until all classes are represented)
```

where x is the number of classes the user wants the data to be clustered into. Urban, Wooded, and Agricultural classes were clustered into four subclasses, Water into 6, Wetland into 5, and Bare Land into 2. These were selected with consideration of the variation that had been observed in the field.

The training fields were then refined and new co-ordinates described. These were coded as earlier and a *STATISTICS run for them. This function calculates statistics for subsets of data values from the Multispectral Image Storage Tape. It calculates the mean and standard deviation, a covariance matrix, and a correlation matrix of the data values for the channels specified by the user. These statistics are calculated for each of the training fields and training classes the user defines. A Statistics File is then generated and written on the user's temporary disk. It contains the mean vectors, covariance matrix, and the number of data vectors for each of those classes. An optional statistics deck was also punched in binary form. This step required the following control card deck:

```
*STATISTICS
PUNCH
CHANNELS 1,2,3,4
DATA
CLASS URBAN 1
 (Field Description Cards for Urban 1)
CLASS URBAN 2
 (Field Description Cards for Urban 2)
.
.
.
(continued until all 25 subclasses were listed with appropriate
Field Description Cards)
END
```

The binary statistics deck obtained was used to run a *SEPARABILITY function, which helps the user to select a set of channels that will produce the most accurate classification by the classifypoints function. This was run for combinations of three and four channels. On the basis of the data obtained from this run (Table 5), it was decided to use all the four channels for classification.

The statistics deck was then used to run the *CLASSIFYPOINTS function. This is an implementation of a maximum likelihood

Table 5. Separability information for channel combinations.

Channels				Weighted interclass divergence (VX)	(VY)	(WX)	(WY)	(XY)
2	3	4		2000	2000	2000	1999	1771
1	2	4		2000	2000	2000	2000	1762
1	2	3		2000	2000	2000	1999	1760
1	3	4		2000	2000	2000	1999	1754
1	2	3	4	2000	2000	2000	2000	1781

classification rule which classified multispectral data on a point-by-point basis. The rule assumes that each training class may be characterized by a multivariate Gaussian (or multivariate normal) distribution, or, equally, by the class mean vector and covariance matrix. The program uses the class means and covariance matrices (computed by the statistics function) and the data from each point to be classified to calculate the probability that the point belongs to each of the training classes. It then assigns the point to the most probable class and writes the classification on an output file for later use (Phillips, 1973). *PRINTRESULTS, which facilitates the printing of the classification results (in this case) in a variety of outputs, was run with the *CLASSIFYPOINTS function. The control card deck included:

```
*CLASSIFYPOINTS
RESULTS DISK
CARDS READSTATS
CHANNELS 1,2,3,4
DATA
  STAT deck from *STATISTICS run
DATA
RUN(73120101), LINE(2140,2620,1), COL(1630,2070,1)
END
*PRINTRESULTS
RESULTS DISK
SYMBOLS . . . . .
THRESHOLD 25* 0.1
GROUP URBAN(. . .), WATER(. . .), etc.
```

```
BLOCK RUN(73120101), LINE(2140,2620,1), COL(1630,2070,1)
DATA
TEST 1
  Urban test field description cards
TEST 2
  Water test field description cards
.
.
.
  (until the test field description cards for all the six
  classes were represented)
END
```

Thus, a classification map and evaluation statistics were obtained. This was the first attempt. It was found inadequate, and a second and last attempt was made. This meant repeating some of these steps. The training fields were refined again, the candidate training classes re-examined, and the *CLUSTER, *SEPARABILITY, *STATISTICS, *CLASSIFYPOINTS, and *PRINTRESULTS run again. In this process, one "Wooded" subclass was eliminated, leaving a total of 24 subclasses. The second map was accepted as adequate for further processing, based on the performance statistics.

3.2.2.2.2 THE UNSUPERVISED APPROACH

This approach differs from the one just described mainly in that in the former, the computer is trained to identify a known material, or sample, or training field; then it is directed to compare the unknown to the known. In this case, theoretically, there is no known material initially, but indication that some known material may be present. Thus, a classification is done first from some arbitrarily selected beginning points and then all other points are compared to these points; the beginning points are continually redefined. This is essentially what the *CLUSTER function performs.

In most cases, it is uncommon that the researcher has absolutely no idea what he/she is trying to classify. At least professional intuition can always be called upon.

Considering these circumstances, the author implemented a supervised/unsupervised classification; that is, one that does not totally belong to either. Six "training fields" ranging from 18 to 28 lines wide and from 300 to 406 columns long were selected and coded as earlier. The six fields were selected so as to include all the possible land uses recognized in the study area, but they were not defined as to classes or types. They were clustered into 30 cluster classes with a conversion point of 97.0. The 30 cluster classes were chosen as a safe high number and also as a possible check on the number of subclasses arrived at for the supervised approach. The cluster maps, the number of points per cluster, and the separability information were examined and analyzed. Using the separability quotients, the cluster classes were reduced to 22. (The function's cluster grouping suggested 17.) A second clustering was then done as follows:

```
*CLUSTER
OPTIONS MAXCLAS(22),CONV(97.0)
PUNCH STAT
```

CHANNELS 1,2,3,4

DATA

(Field Description Cards for the six fields)

END

In this way, a binary statistics deck was obtained in the same way as previously, except that the 22 classes were now unnamed. The statistics deck generated was then used to *CLASSIFYPOINTS as in the earlier cases. *PRINTRESULTS was also included. Thus, an "unsupervised" classification map was obtained. The results of both this classification and the second supervised classification were stored on Tape 867 (File 1 and 2, respectively).

3.2.2.3 LARSYS ANALYSIS OF DIGITIZED U-2 DATA

Data quality was examined as earlier described for LANDSAT data. Then two areas, one in the central area including Princess Anne, and the second in the urban north, were selected for sample classification (see Figs. 7 and 8). The unsupervised approach similar to the one just described was used for both areas. In the first clustering for the Princess Anne area, 25 cluster classes and 97.0 conversion point were used. The cluster classes were then reduced to 15 after examination of the clustering statistics. The northern urban sample area was also clustered into 15 classes. Statistics deck was generated in each of the 15 class clusters and the deck used in *CLASSIFYPOINTS, and two classification maps thus obtained.

3.2.3 PREPARATION OF THE LAND USE MAP

The map printout of the supervised classification consisted of four pages. When these were folded at the ends and joined together, the map measured 111 cm (44 inches) wide in the East-West direction, and 150 cm (49 inches) long in the North-South axis. The widest available transparency was 106 cm (42 inches). Thus, it was necessary to slant the glazed transparency on the printout somewhat to accomodate all the mapped area.

The map details were then traced directly onto the transparency without first drawing them on the printout. The first delineations were between the major classes: Water, Urban, Agricultural, Wetland, Wooded, and Bare Land, in that order. These were traced in different colored pencils. Next, the subclasses were traced in lead pencil. This was done for one major class at a time and on one page at a time. The precaution was taken to ascertain that at a given time only a small area would be under consideration. This reduced the error due to failure to observe or recognize certain clusters of symbols. The coded symbols for the subclasses were recorded as they were delineated. The map was then drawn professionally, using heavy lines for the major classes and lighter lines for the subclasses.

4. RESULTS AND DISCUSSION

4.1 INTRODUCTION

For clarity and ease of discussion, the results of each procedure will be presented separately. This does not suggest that the procedures or the approaches are mutually exclusive; indeed, they are complementary to one another.

Results of the primary technique used, the supervised approach to classification of the LANDSAT-1 MSS data, will be discussed first, followed by a discussion of results of the unsupervised approach to the same data. Discussion of results of the unsupervised approach to machine analysis of high altitude (U-2) aircraft data will follow, then a discussion of results of the I^2S analysis, and lastly, the response of land use to soil limitations.

Individual frames of the bulk MSS images are prepared at an approximate scale of 1:3,369,000 on a 70 mm format. In the reformatting process, this can be enlarged to an approximate scale of 1:24,000, the largest scale to which they can be enlarged and retain their resolution of approximately .45 hectares (1.1 acres). Thus, by classifying every data point and printing every line and column, a map is obtained that overlays the USGS 7.5 min. quadrangles (1:24,000). This is the scale at which the land use map obtained in the supervised approach was prepared.

The P-1700 Microdensitometer can be used to digitize the spectral data from a positive transparency at 12.5-, 25-, and 50-micrometer intervals. The high altitude photography was taken at a nominal scale of 1:130,000 on a 23 cm x 23 cm (9 in. x 9 in.) format. An area of approximately 21.8 cm x 21.8 cm (7 in. x 7 in.) of U-2 frame 5575 was digitized at 50-micrometer intervals. When every line and column is printed, the map of this area is 11.2 m (37 ft.) wide and 14 m (44 ft.) long.

4.2 LANDSAT-1 MSS DATA

4.2.1 THE SUPERVISED APPROACH

There are two primary advantages in using the supervised approach in the LARSYS system: (1) the researcher has better control of the classification steps, and (2) the built in possibility to evaluate the classification performance. Performance data are optional and must be requested by the user by including the relevant card in the *PRINTRESULTS deck. The researcher may request performance information on training fields, test fields, training classes, test classes, or all of these. Performance tables thus obtained, list the number of samples from each field or class that was classified correctly and the number of samples classified into each class.

In the first supervised classification attempt, an average performance by training class of 80.5 percent, and by test class of 66.9 percent were obtained. Performance of training fields was 85.2 percent while that of test fields was 77.5 percent. The lowest performance in the training class, 48.7 percent, was obtained in the "Wooded" class, followed by Bare Land, 68.4 percent. Performance for all other classes was better than 86 percent. A sample map of this classification is given in Fig. 11. On the basis of these performance statistics, the classification was found inadequate and the training fields and classes were re-examined.

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY

MAR 21,1975
3 42 06 PM
LARSYS VERSION 3

CLASSIFICATION STUDY 508049126	CLASSIFIED MAR 21,1975
RUN NUMBER............ 73120101	DATE DATA TAKEN... AUG 30,1973
FLIGHT LINE... 140315132 VA	TIME DATA TAKEN..... 1013 HOURS
DATA TAPE/FILE NUMBER.. 1822/ 1	PLATFORM ALTITUDE..3062000 FEET
REFORMATTING DATE. AUG 17,1974	GROUND HEADING..... 180 DEGREES

CLASSIFICATION WRITTEN ON DISK

CHANNELS USED

CHANNEL 1	SPECTRAL BAND 0.50 TO 0.60 MICROMETERS	CALIBRATION CODE = 1	C0 = 0.0
CHANNEL 2	SPECTRAL BAND 0.60 TO 0.70 MICROMETERS	CALIBRATION CODE = 1	C0 = 0.0
CHANNEL 3	SPECTRAL BAND 0.70 TO 0.80 MICROMETERS	CALIBRATION CODE = 1	C0 = 0.0
CHANNEL 4	SPECTRAL BAND 0.80 TO 1.10 MICROMETERS	CALIBRATION CODE = 1	C0 = 0.0

CLASSES

SYMBOL	CLASS	GROUP	THRES PCT	SYMBOL	CLASS	GROUP	THRES PCT
$	URBAN1	URBAN	0.10	J	WETLAND4	WETLAND	0.10
*	URBAN2	URBAN	0.10	X	WETLAND5	WETLAND	0.10
$	URBAN3	URBAN	0.10	*	WOODED1	WOODED	0.10
$	URBAN4	URBAN	0.10	F	WOODED2	WOODED	0.10
H	WATER1	WATER	0.10	R	WOODED3	WOODED	0.10
W	WATER2	WATER	0.10	*	WOODED4	WOODED	0.10
B	WATER3	WATER	0.10	A	AGRICL1	AGRICL	0.10
W	WATER4	WATER	0.10	A	AGRICL2	AGRICL	0.10
W	WATER5	WATER	0.10	C	AGRICL3	AGRICL	0.10
X	WATER6	WATER	0.10	*	AGRICL4	AGRICL	0.10
F	WETLAND1	WETLAND	0.10	*	BEACH1	BEACH	0.10
S	WETLAND2	WETLAND	0.10		BEACH2	BEACH	0.10
J	WETLAND3	WETLAND	0.10				

TRAINING FIELDS OUTLINED WITH A *
TEST FIELDS OUTLINED WITH A +
SHARED BOUNDARIES OUTLINED WITH A $

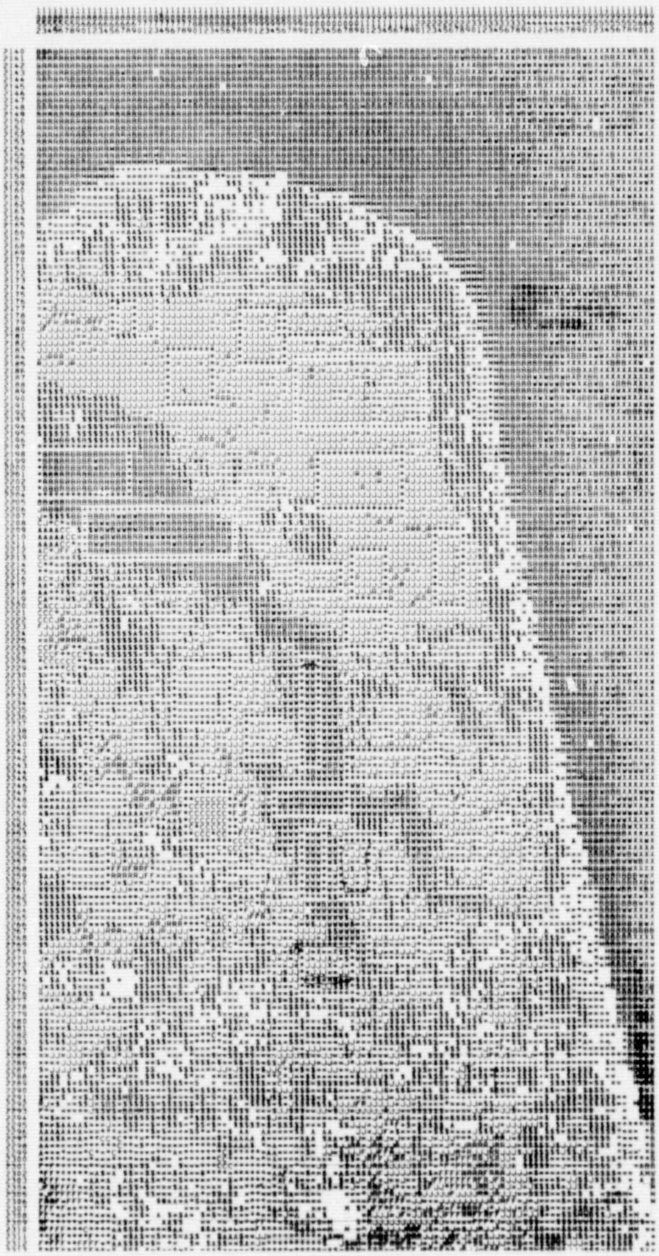

Fig. 11. Part of the first supervised classification map. Training and Test fields are outlined.

In the final classification, the training field performance (Table 6) was 97.9 percent and the test field performance (Table 7) was 93.9 percent. The average performance by class for the training class was 97.0 percent (Table 8), while that for the test class was 92.1 percent (Table 9). A sample map of this classification is given in Fig. 12. Thus, this map was adopted for further processing on the basis of performance data. This map was handled as previously described to obtain the Land Use and Land Cover Map which is in the inside back cover pocket.

The units of the map, which correspond to the subclasses of the classification process, were coded with either two- or three-letter symbols, depending on whether the unit corresponded to Level II of Anderson et al. (1972) or whether it was a subdivision of a Level II unit. The first letter, which is in the higher case, denotes the major (Level I) class; the second letter, in the lower case, denotes Level II and the third letter, also in the lower case, denotes the subdivision of Level II. For example, in the symbol "Urm", U = urban, r = residential, and m = medium density. The only exception to this designation is the Thr, which denotes "threshold" points. These points represent resolution elements which have spectral characteristics vastly different from the characteristics of any of the spectral classes used in the analysis.

4.2.1.1 THE URBAN CLASS

Perhaps more than any other class, the urban land use mapping process requires the combination of several basically different ground cover classes into a single land use. For example, single-family residential use is composed of such spectrally diverse features as

TRAINING FIELD PERFORMANCE

FIELD DESIG.	GROUP	NO OF SAMPS	PCT. CORCT	URBAN	WATER	WETLAND	WOODED	AGRICL	BEACH	THRSHOLD
				NUMBER OF SAMPLES CLASSIFIED INTO						
NWTRAN18	URBAN	14	100.0	14	0	0	0	0	0	0
NWTRAN19	URBAN	15	100.0	15	0	0	0	0	0	0
NWTRAN22	URBAN	27	100.0	27	0	0	0	0	0	0
NWTRAN24	URBAN	40	100.0	40	0	0	0	0	0	0
NWTRAN25	URBAN	40	97.5	39	0	0	0	1	0	0
NWTRAN28	URBAN	15	100.0	15	0	0	0	0	0	0
NWTRAN21	URBAN	6	100.0	6	0	0	0	0	0	0
NETRAN25	URBAN	16	100.0	16	0	0	0	0	0	0
NETRAN24	URBAN	24	100.0	24	0	0	0	0	0	0
NWTRAN23	URBAN	20	100.0	20	0	0	0	0	0	0
NETRAN30	URBAN	20	100.0	20	0	0	0	0	0	0
NWTRAN12	WATER	8	100.0	0	8	0	0	0	0	0
STRAN32	WATER	12	16.7	6	2	0	0	0	0	4
NWTRA13	WATER	25	96.0	1	24	0	0	0	0	0
NETRAN10	WATER	166	100.0	0	166	0	0	0	0	0
NETRAN10	WATER	160	100.0	0	160	0	0	0	0	0
STRAN31	WATER	28	96.4	0	27	0	1	0	0	0
STRAN20	WATER	11	100.0	0	11	0	0	0	0	0
STRAN20	WATER	20	100.0	0	20	0	0	0	0	0
NETRAN17	WATER	90	100.0	0	90	0	0	0	0	0
NWTRAN19	WATER	154	100.0	0	154	0	0	0	0	0
NWTRAN1	WATER	40	95.0	2	38	0	0	0	0	0
NWTRAN2	WATER	40	97.5	1	39	0	0	0	0	0
NETRAN18	WATER	84	98.8	1	83	0	0	0	0	0
NETRAN20	WATER	63	100.0	0	63	0	0	0	0	0
NETRAN9	WATER	312	100.0	0	312	0	0	0	0	0
NWTRAN6	WATER	6	100.0	0	6	0	0	0	0	0
STRAN22	WATER	9	100.0	0	9	0	0	0	0	0
STRAN23	WATER	5	100.0	0	5	0	0	0	0	0
STRAN24	WATER	12	100.0	0	12	0	0	0	0	0
STRAN28	WATER	15	100.0	0	15	0	0	0	0	0
STRAN36	WATER	42	100.0	0	42	0	0	0	0	0
STRAN38	WATER	56	100.0	0	56	0	0	0	0	0
NWTRAN7	WATER	5	80.0	1	4	0	0	0	0	0
NWTRAN7	WATER	4	100.0	0	4	0	0	0	0	0
NETRAN16	WATER	30	100.0	0	30	0	0	0	0	0
NETRAN15	WATER	36	94.4	2	34	0	0	0	0	0
NETRAN14	WATER	27	100.0	0	27	0	0	0	0	0
NWTRAN17	WATER	12	83.3	2	10	0	0	0	0	0
NWTRAN16	WATER	33	93.9	2	31	0	0	0	0	0
STRAN35	WATER	35	100.0	0	35	0	0	0	0	0
NETRAN11	WATER	496	100.0	0	496	0	0	0	0	0
NETRAN12	WATER	231	100.0	0	231	0	0	0	0	0
NETRA 13	WATER	676	100.0	0	676	0	0	0	0	0
STRAN3	WETLAND	24	100.0	0	0	24	0	0	0	0
STRAN1	WETLAND	26	96.2	0	0	25	1	0	0	0
STRAN1	WETLAND	56	89.3	0	0	50	5	0	0	1
STRAN2	WETLAND	24	66.7	0	0	16	8	0	0	0
STRAN3	WETLAND	96	91.7	0	0	88	4	0	0	0
STRAN5	WETLAND	63	95.2	0	0	60	3	0	0	0
STRAN7	WETLAND	84	100.0	0	0	84	0	0	0	0
NETRAN1	WETLAND	30	93.3	0	0	28	2	0	0	0
NETRAN8	WETLAND	39	94.9	0	0	37	2	0	0	0
NETRAN3	WETLAND	98	92.9	0	0	91	7	0	0	0
NETRAN5	WETLAND	49	83.7	3	0	41	5	0	0	0
NETRAN4	WETLAND	10	60.0	4	0	6	0	0	0	0
NETRAN6	WETLAND	20	100.0	0	0	20	0	0	0	0
NETRAN6	WETLAND	12	100.0	0	0	12	0	0	0	0
STRAN18	WETLAND	20	100.0	0	0	20	0	0	0	0
STRAN28	WETLAND	25	92.0	0	1	23	1	0	0	0
STRAN11	WETLAND	12	100.0	0	0	12	0	0	0	0
STRAN15	WETLAND	20	95.0	0	0	19	1	0	0	0
STRAN19	WETLAND	16	100.0	0	0	16	0	0	0	0
STRAN24	WETLAND	16	100.0	0	0	16	0	0	0	0
STRAN12	WETLAND	21	100.0	0	0	21	0	0	0	0
NWTRAN47	WOODED	44	79.5	0	0	9	35	0	0	0
NWTRAN36	WOODED	21	95.2	0	0	1	20	0	0	0
NWTRAN14	WOODED	24	95.8	0	0	1	23	0	0	0
STRAN54	WOODED	30	93.3	0	0	2	28	0	0	0
NWTRAN48	WOODED	8	87.5	0	0	1	7	0	0	0
NETRAN37	WOODED	6	100.0	0	0	0	6	0	0	0
NWTRAN41	WOODED	4	100.0	0	0	0	4	0	0	0
NWTRAN42	WOODED	6	100.0	0	0	0	6	0	0	0
NWTRAN31	WOODED	8	100.0	0	0	0	8	0	0	0
NETRAN30	WOODED	8	100.0	0	0	0	8	0	0	0
NETRAN42	WOODED	5	100.0	0	0	0	5	0	0	0
NETRAN32	WOODED	6	100.0	0	0	0	6	0	0	0
NETRAN43	WOODED	6	100.0	0	0	0	6	0	0	0
NWTRAN56	AGRICL	18	100.0	0	0	0	0	18	0	0
STRAN62	AGRICL	20	100.0	0	0	0	0	20	0	0
STRAN61	AGRICL	52	98.1	0	0	0	0	51	0	1
STRAN60	AGRICL	16	100.0	0	0	0	0	16	0	0
STRAN66	AGRICL	30	100.0	0	0	0	0	30	0	0
STRAN64	AGRICL	21	100.0	0	0	0	0	21	0	0
STRAN59	AGRICL	60	100.0	0	0	0	0	60	0	0
STRAN65	AGRICL	40	100.0	0	0	0	0	40	0	0
NWTRAN60	AGRICL	14	100.0	0	0	0	0	14	0	0
NWTRAN52	AGRICL	56	100.0	0	0	0	0	56	0	0
STRAN58	AGRICL	21	100.0	0	0	0	0	21	0	0
NWTRAN55	AGRICL	24	100.0	0	0	0	0	24	0	0
NETRAN44?	AGRICL	16	100.0	0	0	0	0	16	0	0
STRAN60?	AGRICL	18	100.0	0	0	0	0	18	0	0
NWTRAN54	AGRICL	16	100.0	0	0	0	0	16	0	0
NWTRAN48	AGRICL	12	100.0	0	0	0	0	12	0	0
STRAN57	AGRICL	38	100.0	0	0	0	0	38	0	0
NETRAN47	AGRICL	42	100.0	0	0	0	0	42	0	0
NETRAN48	AGRICL	36	94.4	2	0	0	0	34	0	0
NETRAN46	AGRICL	72	90.3	7	0	0	0	65	0	0
SBTRAN3	BEACH	24	100.0	0	0	0	0	0	24	0
SBTRAN9	BEACH	8	100.0	0	0	0	0	0	8	0
SNTRAN11	BEACH	14	100.0	0	0	0	0	0	14	0
SNTRAN19	BEACH	12	100.0	0	0	0	0	0	12	0
SBTRAN22	BEACH	9	100.0	0	0	0	0	0	9	0
SBTRAN23	BEACH	14	100.0	0	0	0	0	0	14	0
SNTRAN10	BEACH	10	100.0	0	0	0	0	0	10	0
SBTRAN5	BEACH	4	100.0	0	0	0	0	0	4	0
SNTRAN15	BEACH	6	100.0	0	0	0	0	0	6	0
SBTRAN16	BEACH	7	100.0	0	0	0	0	0	7	0
SBTRAN1	BEACH	11	100.0	0	0	0	0	0	11	0
	TOTAL	4654		270	2915	723	284	609	127	6

OVERALL PERFORMANCE(4557/ 4654) = 97.9

Table 6. Training field performance in the final supervised classification.

Table 7. Test field performance in the final supervised classification.

Field Desig.	Group	No of Samps	Pct. Corct	Number of Samples Classified Into Urban	Water	Wetland	Wooded	Agricl	Beach	Threshold
NWTEST2	Urban	98	94.9	93	0	0	0	5	0	0
NWTEST3	Urban	48	93.8	45	0	0	0	2	1	0
NETEST4	Urban	32	93.8	30	0	0	1	0	1	0
NETEST5	Urban	32	93.8	30	0	0	0	1	1	0
NWTEST1	Water	90	94.4	5	85	0	0	0	0	0
NETEST2	Water	156	96.8	3	151	2	0	0	0	0
NETES 3	Water	119	95.8	5	114	0	0	0	0	0
STEST10	Water	24	100.0	0	24	0	0	0	0	0
STEST11	Water	16	100.0	0	16	0	0	0	0	0
STEST12	Water	364	100.0	0	364	0	0	0	0	0
STEST13	Water	231	93.5	10	216	0	0	0	0	5
STEST14	Water	225	95.6	10	215	0	0	0	0	0
STEST1	Wetland	165	81.8	0	0	135	28	0	0	2
NETEST1	Wetland	84	81.0	2	0	68	13	0	0	1
STEST2	Wetland	147	88.4	0	1	130	16	0	0	0
STEST3	Wetland	60	96.7	0	0	58	2	0	0	0
STEST5	Wetland	96	77.1	0	0	74	22	0	0	0
STEST6	Wetland	90	96.7	2	0	87	1	0	0	0
STEST7	Wetland	136	94.9	3	1	129	3	0	0	0
STEST8	Wetland	49	91.8	0	0	45	4	0	0	0
STEST53	Wooded	36	94.4	0	0	1	34	0	0	1
STEST50	Wooded	12	100.0	0	0	0	12	0	0	0
NWTEST51	Wooded	24	37.5	15	0	0	9	0	0	0
NWTEST4	Agricl	130	99.2	0	0	0	0	129	0	1
STEST18	Agricl	54	92.6	0	0	0	1	50	0	3
STEST19	Agricl	77	100.0	0	0	0	0	77	0	0
STEST20	Agricl	72	98.6	0	0	0	1	71	0	0
STEST21	Agricl	70	95.7	0	0	0	2	67	0	1
STEST22	Agricl	240	97.5	1	0	0	1	234	0	4
SBTEST1	Beach	20	100.0	0	0	0	0	0	20	0
SBTEST3	Beach	12	100.0	0	0	0	0	0	12	0
SBTEST4	Beach	16	100.0	0	0	0	0	0	16	0
TOTAL		3025		254	1187	729	150	636	51	18

OVERALL PERFORMANCE (2840/ 3025) = 93.9

TRAINING CLASS PERFORMANCE

GROUP	NO OF SAMPS	PCT. CORCT	NUMBER OF SAMPLES CLASSIFIED INTO URBAN	WATER	WETLAND	WOODED	AGRICL	BEACH	THRSHOLD
1 URBAN	237	99.6	236	0	0	0	1	0	0
2 WATER	2937	99.2	18	2914	0	1	0	0	4
3 WETLAND	761	93.2	7	1	709	43	0	0	1
4 WOODED	174	92.0	0	0	14	160	0	0	0
5 AGRICL	618	98.4	9	0	0	0	608	0	1
6 BEACH	127	100.0	0	0	0	0	0	127	0
TOTAL	4854		270	2915	723	204	609	127	6

OVERALL PERFORMANCE(4754/ 4854) = 97.9

AVERAGE PERFORMANCE BY CLASS(582.3/ 6) = 97.0

Table 8. Training class performance in the final supervised classification.

TEST CLASS PERFORMANCE

GROUP	NO OF SAMPS	PCT. CORCT	URBAN	WATER	WETLAND	WOODED	AGRICL	BEACH	THRSHOLD
			NUMBER OF SAMPLES CLASSIFIED INTO						
1 URBAN	210	94.3	198	0	0	1	8	3	0
2 WATER	1225	96.7	33	1185	2	0	0	0	5
3 WETLAND	827	87.8	7	2	726	89	0	0	3
4 WOODED	72	76.4	15	0	1	55	0	0	1
5 AGRICL	643	97.7	1	0	0	5	628	0	9
6 BEACH	48	100.0	0	0	0	0	0	48	0
TOTAL	3025		254	1187	729	150	636	51	18

OVERALL PERFORMANCE(2840/ 3025) = 93.9

AVERAGE PERFORMANCE BY CLASS(552.9/ 6) = 92.1

Table 9. Test class performance in the final supervised classification.

BTLARSYS
VICTOR ODENYO

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY

JUNE 16,1975
04 19 35 PM
LARSYS VERSION 3

CLASSIFICATION STUDY 516749116	CLASSIFIED JUNE 16,1975
RUN NUMBER............ 73120101	DATE DATA TAKEN... AUG 30,1973
FLIGHT LINE... 140315132 VL	TIME DATA TAKEN..... 1013 HOURS
DATA TAPE/FILE NUMBER.. 1822/ 1	PLATFORM ALTITUDE..3062000 FEET
REFORMATTING DATE, AUG 17,1974	GROUND HEADING..... 180 DEGREES

CLASSIFICATION TAPE/FILE NUMBER ... 167/ 2

CHANNELS USED

CHANNEL 1	SPECTRAL BAND	0.50 TO 0.60 MICROMETERS	CALIBRATION CODE = 1	C0 = 0.0
CHANNEL 2	SPECTRAL BAND	0.60 TO 0.70 MICROMETERS	CALIBRATION CODE = 1	C0 = 0.0
CHANNEL 3	SPECTRAL BAND	0.70 TO 0.80 MICROMETERS	CALIBRATION CODE = 1	C0 = 0.0
CHANNEL 4	SPECTRAL BAND	0.80 TO 1.10 MICROMETERS	CALIBRATION CODE = 1	C0 = 0.0

CLASSES

SYMBOL	CLASS	GROUP	THRES PCT	SYMBOL	CLASS	GROUP	THRES PCT
+	URBAN1	URBAN	0.10	S	WETLAND3	WETLAND	0.10
2	URBAN2	URBAN	0.10	*	WETLAND4	WETLAND	0.10
-	URBAN3	URBAN	0.10	/	WETLAND5	WETLAND	0.10
$	URBAN4	URBAN	0.10	Y	WOODED2	WOODED	0.10
L	WATER1	WATER	0.10	Z	WOODED3	WOODED	0.10
K	WATER2	WATER	0.10	R	WOODED4	WOODED	0.10
B	WATER3	WATER	0.10	A	AGRICL1	AGRICL	0.10
Q	WATER4	WATER	0.10	C	AGRICL2	AGRICL	0.10
W	WATER5	WATER	0.10	#	AGRICL3	AGRICL	0.10
M	WATER6	WATER	0.10	I	AGRICL4	AGRICL	0.10
X	WETLAND1	WETLAND	0.10	*	BEACH1	BEACH	0.10
F	WETLAND2	WETLAND	0.10	.	BEACH2	BEACH	0.10

Fig. 12. Part of the final supervised classification map.

asphalt streets; concrete drives, patios, and stairs; roofs and walls of various colors; varying stages of maturity of landscaping; churches; schools; and an assortment of tennis courts and swimming pools. Even when the single family class is subdivided on the basis of density, a measure of units per land area, the interplay of these components is not minimized.

Successful classification of the urban class is largely accounted for by the general tendency for a specific urban function to be conducted in a specialized urban environment which may yield a unique spectral signature. Industry, for example, is nearly always found in buildings or clusters of buildings with flat roofs. Many retail centers also have similar structures. These structures are usually accompanied by large asphalt parking areas. These surfaces are spectrally distinct from a residential area with pitched roofs, landscaping, and accompanying streets.

In the City of Virginia Beach, many residential areas are under construction, which adds piled bricks, lumber, mud, sand, and other construction material to the usual factors of residential areas. In some of these areas, where the sandy subsoil has been exposed for some time and is dry, the spectral characteristics are similar to those of open sandy beaches.

Some of the training fields for the urban class were obtained from the eastern part of the City of Norfolk. The fourth subclass, derived from some of these samples, was of highly weathered industrial areas, including some railway marshalling yards, harbor, refineries, and large warehouses. While there are no shipping harbors and railroad yards in the City of Virginia Beach comparable to those in Norfolk, refineries and warehouses are present. Apparently, these are relatively new compared to those in Norfolk, and they have not weathered into the same spectral class. Thus, this subclass was not represented in the classified area. Instead, many mudflats and tidal flats, which are abundant in the classified area, fell into this subclass. This suggests that they have highly similar spectral characteristics with old, weathered, industrial sites. This subclass is therefore listed under the Bare Land class. The other three spectral subclasses of the urban class corresponded to the functional units described below. The symbol "U" indicates "Urban".

4.2.1.1.1 Urm - Medium density residential

These are medium density, single family residential areas with 15 to 22 single family units per hectare (7 to 10 per acre). In a vertical perspective, the man-made structures, rooftops and pavements, cover an average of 30 to 50 percent of the surface and are predominantly light brown in color. Ornamental plants are varied, but they are generally shorter than 7 m and are few and scattered. Predominantly well-kept lawns comprise the rest.

4.2.1.1.2 Uc - Commercial centers

These are mostly commercial and service urban centers, conducting sales of products and services. It includes the central business district (CBD) of the city, which in this area, is an extensively developed vacation-oriented recreational facility. Also included are large, recently built warehouses, drive-in theatres, and very closely built two-family, one floor, low, wide houses in new developments, usually bordering the retail commercial areas. These areas are characteristically extensively paved, mostly with light brown concrete surfaces. Many rooftops are also concrete. Man made structures, including the pavements, cover more than 90 percent of the surface and hardly any vegetation interferes.

4.2.1.1.3 Url - Low density residential

These are low density residential areas, ranging from 4 to 14 single family units per hectare (2 to 6 units/acre). It includes two-floor multiple-family units with four apartments 4 to 9 units per hectare (2 to 4 units/acre). The lawns are large, and the various ornamental trees are mostly taller than 7 m. They overhang houses and hedges and, from a vertical perspective, cover on the average more than 50 percent of the surface.

4.2.1.2 THE AGRICULTURAL CLASS

In contrast to urban land uses, agricultural land uses, except for the problems of seasonal change and variations of stand, are reasonably homogenous. The usual goal in agricultural land use classification is discrete crop identification. Thus, the remote sensing data taken specifically for this purpose would be taken at the time the different agricultural crops exhibit maximum spectral homogeneity. This is usually in early summer or late spring when the crops are several weeks old and the leaf area index is one or higher. The aim is to minimize the interplay of bare ground in those fields that are planted to crops.

In general, many factors must be considered in classifying agricultural areas on the basis of their spectral response characteristics. The factors include (LARS, 1968) plant geometry, planting technique, row direction, date of planting, date of harvest, variety of crop species, species and crop use, and other agricultural patterns. Some of these may be less or more important depending on the time in the growing season the data are obtained. Early in the growing season, there may be more or less ground cover depending on plant geometry, row spacing, or date of planting. In midseason, some varieties of a given crop may flower earlier than others. Late in the season, mature crops invariably turn light gray as the harvesting time approaches. Stubble of one crop may cover more ground surface than that of another. Harvested barley stubble may be hardly distinguishable from stubble of harvested wheat. Weeds in a field may interfere with the spectra of a crop to an extent they may cause the crop to be misclassified. Furthermore, any factor which causes a variation in plant population or plant stand may cause errors in classification. Such factors as depth of planting, machine failures, insect damage, disease, birds, moisture imbalance, soil types, and fertilizer spills can cause variation in the plant stand.

The most important field crops in the study area are corn, soybeans, and wheat. Wheat is generally planted in late fall or in winter. By midsummer, most of the wheat is harvested and many of the same fields are planted to no-till soybeans. In the next growing season, the same field is commonly planted to corn. There are various exceptions to this cropping sequence.

In late August, most of the no-till soybeans have overgrown the wheat stubble, but in wet, or otherwise late years the wheat stubble may still be a factor in the spectral reflectance. Most of the corn has tassled and is fruiting, and in a few cases the first signs of maturity are evident by August. Four agricultural subclasses were delineated in the study area according to spectral reflectivity. These are corn, soybeans, areas in transition from wheat to soybeans, and pasture and other grassland areas. Crops such as sweet potatoes, irish potatoes, strawberries and other vegetables are included in one or more of these classes. Cattle, hogs, and horses are also kept in the study area, and ornamental tree nurseries are present. The symbol "A" indicates Agriculture.

4.2.1.2.1 Aw - Areas in cropping transition

These are areas in transition from wheat to no-till soybeans. In the majority of cases the soybean seedlings had emerged, but the wheat stubble and stalks were still relatively dominant in spectral reflectivity. The spectral class thus reflects the interplay between these and any bare soil that may be visible.

4.2.1.2.2 Ac - Corn fields

Most of the corn at this time of the year (August 30) had tassled and fruiting had began. The corn fields were fairly uniform.

4.2.1.2.3 As - Soybean fields

These were no-till soybean fields in which the soybean crop was dense, green and leafy and uniformly covered the wheat residue. The spectral characteristics in this case were thus due to the soybean crop and other relatively minor variations.

4.2.1.2.4 Ap - Pasture and other grasslands

This was the functional class that closely approaches a well-managed pasture. It included the few cattle and horse pastures in the city, and golf courses, playing fields, and lawns, especially of those relatively recent subdivisions where the ornamental trees were young and did not overshadow the lawn grasses. Any open field with dense, continuous, short grass cover and annual weeds, and in which shrubs do not dominate, fell into this class.

4.2.1.3 THE WOODED CLASS

For the purpose of land use classification with remote-sensor data, Anderson et al. (1972) defined Forest Land (Level I) as "lands that are at least 10 percent stocked by trees capable of producing timber or other wood products that exert an influence on the climate or water regime". At Level II, they divided the class into Deciduous Forest Land, Evergreen Forest Land, and Mixed Forest Land (Table 3), according to the dominant type. In addition, they recommended that when criteria for more than one category were met, "the Urban and Built-up Land category takes precedence over others . . . Thus, residential areas that have sufficient tree cover to meet Forest Land criteria will be placed in the Residential category." Also, forested wetland was classified, at Level I, as Forest Land because the latter is a higher category.

These recommendations were considered in this study. In the study area, due to its geographical location, the land's wetness is more limiting in terms of use options than the fact that it is forested. Further, in the machine processing of remote-sensor data, especially that based on pattern recognition, the ultimate land cover of an area is that whose spectral characteristics dominate the reflectance of that area. Thus, for a residential area which not only has enough tree cover to meet Forest Land criteria but in which the vegetation also almost completely covers the urban features, the ultimate land cover is forest vegetation. Therefore, while the Wooded class as adopted in this study corresponds approximately to the Forest Land of Anderson et al. (1972), Forested Wetland was separated from it and included in the Wetland class (discussed below), and a large forested residential area meeting the requirements of a Forest Land was designated as Level II of the Wooded class.

Except in a few places where a loblolly pine-dominated stand may be found, most of the forested areas of the City have mixed species of various hardwoods and evergreens. Thus, segregation according to species would require imagery of a larger scale and resolution than that used in this study. It seems, however, that the spectral characteristics of these forested areas are related to their age, height, and amount of understory. Those stands which are taller than 12 m (40 ft.) characteristically are less branched and have sparse understory while the opposite is generally true in shorter stands. Three subdivisions of the Wooded class were recognized. The symbol "F" indicates "Forest".

4.2.1.3.1 Fy - Young forests

These were young forests, mostly in recently abandoned agricultural lands. They were typically younger and had less dense undergrowth than those in the wetland periphery (Mp) discussed below.

4.2.1.3.2 Ft - Transitional forest lands

These were more recently abandoned agricultural areas dominated by short stands of brushy vegetation and tall grasses. Most of these were transitional areas in which land was passing from agricultural use to urban use, and which had not been idle long enough to show signs of forest regeneration.

4.2.1.3.3 Fr - Forested residential areas

These are old residential subdivisions mostly in the northern quarter of the study area, bordering Broad Bay, Linkhorn Bay, Crystal Lake, and the Eastern and Western branches of Lynnhaven River. Typical examples are Alanton, Bay Colony, Bird Neck Point, and Linkhorn Park subdivisions. They contain a variety of ornamental and climax vegetation which almost completely cover the urban features such that the influence of the latter in total spectral characteristics is limited.

4.2.1.4 THE WATER CLASS

The study area is surrounded by water in its northern and eastern boundaries. The major industry, tourism, is water-based. However, the Atlantic Ocean and Chesapeake Bay are not the only water bodies. A substantial part of Back Bay juts nearly 20 km (12 miles) into the southern part of the City and it exerts a dominant influence on the land using activities of the surrounding land. Lynnhaven Bay, Broad Bay, Little Creek, Stumpy Lake, and Lake Tecumseh are also significant water bodies. For part of its course, the North Landing River forms part of the Intracoastal Waterway. Several small creeks are also present, and numerous canals have been and are being dug to facilitate drainage as a part of the land development process. In addition, ponds have developed in many excavated areas where sand has been mined for use in urban construction.

The depth and turbidity of the water, the salt content, the degree of algal and other pollution, and the relative calmness all seem to influence the spectral reflectance characteristics of water bodies. Six subdivisions of the Water class were recognized in the area. The symbol "W" indicates "Water".

4.2.1.4.1 Ws - Shallow water

This included the shallow water along the coastline through which the bright sandy bed was visible, and shallow submerged shoals and sandbars. Most of the thin cloud that was present in the area around the southern end of the Chesapeake Bay Bridge-Tunnel also was included.

4.2.1.4.2 Wr - River water

This included river and canal water in North Landing River, West Neck Creek, and Intracoastal Waterway.

4.2.1.4.3 Wb - Bay water

This was the Bay water in Chesapeake Bay, and included Lynnhaven Bay, Broad Bay, and the waters of Little Creek. This water class had a narrow extension around Cape Henry and southward approximately to the Rudee Inlet.

4.2.1.4.4 Ww - Weeded water

These were areas of Back Bay which had a thick growth of water milfoil (Myriophyllum) weeds. The growth was thick enough to be detrimental to outboard motors, but the area covered by the weed varies with time.

4.2.1.4.5 Wc - Clear water

This was clear, non-ocean water of Stumpy Lake and other small inland ponds, and of those areas of Back Bay that did not have the thick growth of weeds.

4.2.1.4.6 Wo - Ocean water

This is open water of the Atlantic Ocean excluding the shallow part along the coastline and the narrow stretch south of Cape Henry that had similar spectral characteristics as the waters of Chesapeake Bay.

4.2.1.5 THE WETLAND CLASS

The Virginia Wetland Act of 1972 defined "Wetlands" as " . . . all that land lying between and contiguous to mean low water and an elevation above mean low water equal to the factor 1.5 times the mean tide range at the site . . . and upon which is growing on July one, nineteen hundred and seventy-two and grows thereon subsequent thereto, any one or more of the following: (here 35 species of plants are named --- author's note)", (Marcellus et al., 1973). Thus, the term is legally defined both in terms of the tide range and the vegetation, and seems to refer only to coastal wetland areas. A separate definition applies to the wetlands of Back Bay.

All the wetland areas in the study area do not satisfy this definition. Most of these are, in coastal zone, sometimes referred to as "Upland

Wetlands". They occupy areas that are above the tide range, but which are low and are flooded for a significant part of the year by surface runoff from inland precipitation. Some of these are permanently submerged, others may have a ground water table that seasonally falls a few centimeters below the soil surface. Examples of such areas are found in the Seashore State Park and in the upland reaches of the North Landing River. Some of these areas meet the definition (Anderson et al., 1972) of Forest Land, but were included in the Wetland class in this study for reasons explained in Section 4.2.1.3 above.

As mapped in this study, all the wetland areas were vegetated. Thus, the spectral characteristics of these areas were influenced by the spectral characteristics of the dominant vegetation. In those wetland areas within the tide range, the vegetation types and species vary with distance from the seashore, and the spectral reflectance seemed to be related to these. In upland areas, most stands are the same forest tree mixtures described earlier, and their spectral response seemed to be related to different phenomena. These included age and thickness of the stand. In all, five wetland subclasses were delineated, and they included saltwater wetlands, the wetlands of the brackish Back Bay, and the fresh-water wetlands along the streams and some inland lakes of this area. The symbol "M" rather than "W" was adopted to indicate "Marshland" and to differentiate it from "Water".

4.2.1.5.1 Mp - Peripheral wetlands

These are in the periphery of the often flooded upland wetlands and the mostly dry young forest areas (Fy) described earlier. They contain the same tree species as the forested wetlands on their lower sides, but the stands are typically younger and shorter, highly branched and leafier, and have thicker undergrowth.

4.2.1.5.2 Mf - Forested wetlands

This is the thickly forested wetland mainly along the North Landing River and its tributaries. It is dominated by tall, mature, hardwood-pine mixture. The stand is stemy and the understory is thin.

4.2.1.5.3 Ms - Seashore State Park

This class is typified by the Seashore State Park, which is dominated by mature stands of Bald Cypress (Taxodium districhum), Sweet Gum (Liquidambar styraciflua), Red Maple (Acer rubrum), and Black Gum (Nyssa sylvatica) in lower wet grounds, and Loblolly Pine (Pinus taeda), White Oak (Quercus alba), Black Oak (Quercus velutina), Southern Red Oak (Quercus falcata), and White Hickory (Carya alba) in the higher dunes. The lower wet areas are also characterized by a thick understory of various species.

4.2.1.5.4 Mb - Bushy wetlands

This is characterized by short, thick, discontinuous patches of salt-tolerant bushes. The bushy vegetation is typically thick and 2 to 5 m tall. They occupy the areas with elevations just above the limit of Virginia's legal definition of a wetland.

4.2.1.5.5 Mn - Nonforested wetlands

These are the lowest in elevation of the wetland areas. They are typified by the dominance of Saltmarsh Cordgrass (Spartina alterniflora), with some Saltmeadow Hay or Saltmeadow Cordgrass (Spartina patens), Salt Grass (Distichlis spicata), Black Needlerush (Juncus roemerianus), Marsh

Elder (Iva frustescens), and a few other species. These areas are within an elevation equal to 1.5 times the tide range.

4.2.1.6 THE BARE LAND CLASS

There was hardly any bare agricultural land at the time the imagery used in this classification was taken (August 30, 1973) and thus, most of the bare land recognized consists of the sandy beaches, mudflats, and otherwise exposed soil or sediment. One interesting feature to note is that the mudflats have similar spectral characteristics as the highly weathered industrial areas typical of the railway and shipping yards of eastern Norfolk (see discussion in Sec. 4.2.1.1). The sandy beaches were bright and highly reflective in all channels; the reflectivity of the mudflats was much more subdued. Three subclasses were recognized. The symbol "B" indicates "Bare".

4.2.1.6.1 Bs - Sandy beaches

These were highly reflective sandy beaches devoid of any vegetation, and included those inland areas in which the sandy C soil horizon had been exposed and was dry and bright. Some blowouts in the Cape Henry area, sand pits, and those areas in the Fort Story Military Reservation which had been disturbed by military vehicles, were also included.

Certain features, due to their very high reflectivity, have been misclassified into this class. These include several trailer parks in areas where the trailer homes were very dense and the vegetation practically absent (for example Powells Crossroads Trailer Park), and the aircraft hangers at Oceana Naval Air Station.

4.2.1.6.2 Bl - Leewards of beaches

These were mostly leeward sides of beaches and dune tops which had a scattering of salt-tolerant grasses standing in single bundles, and also included those areas in the Fort Story Military Reservation in which military traffic had not completely destroyed these grasses.

4.2.1.6.3 Bm - Wet mudflats

These are wet mudflats and tidal flats with very sparse vegetation bordering the wetlands and certain other water bodies.

4.2.1.7 OTHER AREAS

These are isolated areas of unique land uses whose spectral characteristics were dissimilar to all samples used in the training fields. These were the blank areas in the computer printout map (see Fig. 16), and have the symbol "Thr" in the Land Use and Land Cover Map.

4.2.2 CHARACTERISTICS OF THE MACHINE PROCESSED MAP

Land use mapping and data collection has traditionally been based either on conventional aerial photo interpretation, which utilizes low and medium altitude panchromatic or color photography, or on surface and statistical unit mapping. The combination of the satellite-borne multispectral scanner and machine processing thus provides a different tool. Each of these methods produces a somewhat different product. Each has advantages and disadvantages. These have been well documented for aerial photo interpretation and for ground methods. The machine processed satellite data, however, are recent and have not been exhaustively investigated and discussed.

While in the traditional methods functional classes are assigned on the basis of recognition and interpretation of the scene, in machine processing the classification is based solely on similarity in spectral reflectance characteristics. Spectral classes do not always correspond to functional classes. Relative homogeneity in spectral characteristics is best achieved in agricultural fields during the growing season (LARS, 1970). At the other end, maximum diversity is obtained in urban areas. In all cases, the class based on spectral characteristics incorporates an interplay of all the spectral characteristics of all the component members of the class population. Contribution to the intergrated "picture" depends on the frequency of the members of the population and on their other physical characteristics. The members of the population will depend on the area being classified. Some of the components of the classes identified in this study are summarized in Table 10.

The U.S. Geological Survey (Anderson et al., 1972) proposed a land use classification system for use with remote sensor data (Table 3).

Table 10. Spectral response components of the major land use classes

Functional Classes	Spectral response component sources
Urban	Highly reflective concrete surfaces, light brown to white walls and roofs; low reflective asphalt surfaces, dark brown to black roofs and walls. Red walls, landscaped lawns and playgrounds, and numerous species of ornamental trees of all ages. Automobiles, shipping harbors and railroad yards.
Agricultural	Various agricultural crops: corn, soybeans, wheat and wheat stubble, barley, oats, and potatoes. Nurseries, lawns, playing fields, golf courses, pastures, and parks. Scattered areas of vegetable and truck crops. Isolated farmhouses, barns and other farm structures.
Wooded and Wetland	Numerous species of hardwoods and evergreens, brushes and grasses of various heights and ages, leaf geometry, and leaf area indexes. Flowers of various pigmentations.
Water	Suspended mineral and organic sediment, water weeds, algae, oil slicks, and sandy beds.
Bare Land	Highly reflective bare sand, low reflective organic and mineral mudflats, and clumps of salt-tolerant grasses.

The system has levels of generalization I, II, III, and IV; the more discrete higher level use categories are collapsible into the more general lower classes. The system was developed on the assumption that different sensors will provide information for different levels of classification. It was anticipated that Level I would require "satellite imagery, with very little supplemental information"; Level II would require "high-altitude and satellite imagery with topographic maps"; Level III would require "medium-altitude remote sensing (1:20,000) combined with detailed topographic maps and substantial amounts of supplemental information"; and Level IV would utilize "low-altitude imagery with most of the information derived from supplemental sources". Manual methods of imagery interpretation were assumed. Indeed, the authors asserted that ". . . classification of land use from imagery will remain a personal task for an indefinite period of time and will only gradually become a semiautomatic process and perhaps eventually a fully automatic procedure".

For manual interpretation, the LANDSAT-1 imagery is prepared at an enlarged scale of 1:1,000,000. However, when machine analyzed directly from the computer compatible tapes (CCT) without first being converted into a photographic image, each resolution pixel of the multispectral scanner (MSS), which is 0.45 hectares (1.1 acres), can be discreetly classified. When every data point (pixel) is printed, the scale of the printout map is 1:24,000 and overlays the standard U.S.G.S. 7.5 minute quandrangles. Thus, as long as the spectral classes can be related to functional land use classes, more detailed information can be extracted from these data by machine processing. Comparison of the results of this classification with the recommended scheme (Table 11) demonstrates that, at least for the area studied, this assertion can be substantiated.

Table 11. Comparison of a Land-Use Classification Derived from Machine Processing of LANDSAT-1 MSS CCT Data with U.S.G.S. Proposed Land-Use Classification System for Use with Remote Sensor Data.

Machine-processed LANDSAT-1 Data	U.S.G.S. Proposed System Level I	U.S.G.S. Proposed System Level II
1. Urban	01. Urban and Built-up	
Medium Density Residential	"	01. Residential
Low Density Residential	"	"
Commercial	"	02. Commercial and Services; 03. Industrial; 04. Extractive; 05. Transportation, Communications, and Utilities; 06. Institutional; 07. Strip and Clustered Settlement; 08. Mixed.
2. Agricultural	02. Agricultural	
Wheat Stubble	"	02. Cropland and Pasture
Corn Fields	"	"
Soybeans	"	"
Pasture	"	"
3. Wooded	04. Forest Land	
Young Forests	"	01. Deciduous; 02. Evergreen (Coniferous and Other); 03. Mixed.
Transitional Areas	"	"
Forested Residential	01. Urban and Built-up	01. Residential
4. Water	05. Water	
River and Canal	"	01. Streams and Waterways
Lakes, Ponds	"	02. Lakes; 03. Reservoirs
Bays	"	04. Bays and Estuaries
Shallow Coastline Water	"	05. Other
Ocean	"	05. Other

Table 11 Continued

Machine-processed LANDSAT-1 Data	U.S.G.S. Proposed System Level I	U.S.G.S. Proposed System Level II
5. Wetland		
Peripheral	04. Forest Land	03. Mixed
Forested	"	"
Seashore State Park	"	"
Salt Bushes	06. Nonforested Wetland	01. Vegetated
Nonforested Wetland	"	"
6. Bare Land	07. Barren Land	
Mudflats and Tidal Flats	"	01. Salt Flats
Bare Beaches	"	02. Beaches
Partially Vegetated Beaches	"	"

The major advantage in machine processing is the high speed realized. The most time-consuming step in the supervised approach analysis is the selection and coding of the training and test fields. They usually have to be refined at least once. All other steps are much less time-consuming. Other advantages realized are frequently obtained new data, especially if the source is LANDSAT which has an 18-day repetitive coverage; and uniformly repetitive and unbiassed classification. Once operational, the printout maps can also be produced at less cost than with conventional methods. The inherent digitizing of the data facilitates data storage and variable forms of retrieval.

The major disadvantage with the machine processing system is that the classification algorithm cannot discriminate between spectrally similar but functionally dissimilar land uses. Also, the level of generalization cannot be smaller than the resolution element, and this overshadows many details in complex land use in urban areas. Inability to identify parcel ownership, uncontrollable incidence of cloud cover, and seasonal variation due to vegetation are other disadvantages.

Generally, it seems that the satellite/machine processing system has important advantages which will be welcomed as a powerful tool in the spatial analysis work. Further research and improvements will no doubt reduce the list of disadvantages. The necessity for at least sample ground truth verification, however, may never be eliminated.

4.2.3 THE UNSUPERVISED APPROACH

The same set of LARSYS functions is used in both the supervised and unsupervised classification, but the sequence in which the algorithms are used differs. In the supervised approach, data points corresponding to known types of ground cover are used for training samples in the classification algorithm. If the several known classes are also spectrally distinct, the classification will be "successful". In the unsupervised classification, on the other hand, the analyst first determines spectrally distinct classes without regard to the actual ground cover type, performs a classification, and then attempts to draw a correspondence between spectrally distinct classes and cover types (Lindenlaub, 1973).

Thus, the "unsupervised" approach implemented in this study straddles both approaches. First, it was implemented after the conclusion of the supervised classification, during which time the author had become thoroughly acquainted with the nature of the study area. Secondly, the argument is presented that except in unique, miscelleneous cases, the analyst always has some notion of what to expect in an area he selects to study. Thus, the author principally sought to reduce the time spent in selecting, coding, punching, *CLUSTER-ing, refining, re-coding, re-punching, and re-*CLUSTER-ing training fields for the supervised approach.

An example of a typical training field, and the refining process used in the supervised approach is shown in Fig. 13. From this field, samples for two subclasses of the Urban class, Urban 3 (E), and Urban 4 (M), were derived. This process is repeated for many training fields until sufficient samples for each subdivision are obtained.

Part of a "training field" used in the unsupervised approach is shown in Fig. 14. The size of each field is limited only by the number of data

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WAL105                LABORATORY FOR APPLICATIONS OF REMOTE SENSING        MAR 19,1975
ODENYO                             PURDUE UNIVERSITY                       10 39 55 AM
                                                                           LARSYS VERSION 3

                                  FIELD INFORMATION
                              -------------------------

FIELD NWTRAN40                          TYPE  URBAN                LINES   2138- 2149  (BY   1)
RUN NO.   73120101                      NO. OF SAMPLES   144       COLUMNS 1462- 1473  (BY   1)
OTHER INFORMATION  COMMNELK

                                        111111111111
                                        444444444444
                                        666666667777
                                        234567890123

                                 2138   IIIIIIIMMIII
                                 2139    EEIIIMMMIIE
                                 2140   EEEEEMMMMEIM
                                 2141   EEEMMMMMMMMM
                                 2142   EEEMMMMMMMMM
                                 2143   EEIIMMMMMMMM
                                 2144   EEEIIIMMMMMM
                                 2145   EEEEEEMMMMMM
                                 2146   EEEEEEIIMIII
                                 2147   EEEEEEEEMEEM
                                 2148   EEEEEEMMMMMM
                                 2149   EMMIEMMMMMMM

                            NUMBER OF POINTS PER CLUSTER
                          --------------------------------

                CLUSTER      1      2      3      4
                 SYMBOL             I      E      M
              --------------------------------------------

                 POINTS      1     27     50     66
```

Fig. 13. Refining of a typical candidate training field used in the supervised classification.

WAL105 [struck-out] ODENYO

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY

APR 21,1975
12 13 27 PM
LARSYS VERSION 3

FIELD INFORMATION

FIELD N1
RUN NO. 73120101
OTHER INFORMATION SUBDIVIDE

TYPE ALL
NO. OF SAMPLES 1500

LINES 2171- 2190 (BY 2)
COLUMNS 1630- 1851 (BY 2)

```
     111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111
     666666666666666666666666666666666667777777777777777777777777777777777777777777777777778888888888888888888888888
     333334444455555666667777788888999990000011111222223333344444555556666677777888889999900000111112222233333444445
     024680246802468024680246802468024680246802468024680246802468024680246802468024680246802468024680246802468024680

2171 L2GHCCC2AAAAANCL)APCC2LAAA)).)))'JGRJJLJLL)...NNNNNNNNAAAAAAAAAAAAAAAAAAAAAAAAAWWWWWWWWWWWWWWWWWWWWWWWWWWWWW.)
2173 JLLG2LL2CCC))AAAAAACNAAAAN))).)J'J'JJJJGGGCCC)..)NNNNNAAAAAAAAAAAAAAAAAAAAAAAAAWWWAWWWWWWWWWWWWWWWWWWWWWWWWW))L
2175 JJCCLJ)JJ))C)AAWWWAAH2CNN))))JCCJJ'LJJZCHARHAAAN...NNNNAAAAAAAAAAAAAAAAAAAAAAAWWWAWWWWWWWWWWWWWWWWWWWWWWWWWA..CGG
2177 )CCCCCCCNC)JNAAWWWACLLGLCJ)J)JJ)J2J)L)LCGAARGHNGLJ)..NNNANAAAANAAAAAAAAAAAAAAAWWWWWWWWWWWWWWWWWWWWWWWWWWWWN.)CGFH
2179 LLGCCNCCCJCCCAAAAAN))C)NCC)CJJZJL22C)))LHHARAGLGCLNCC)..NNNAAAAAAAAAAAAAAAAAAAAWAAAAWWWWWWWWWWWWWWWWWWWAA)CLGGGHH
2181 JJJJCCCC)CCC)AAWWWAAAAAAAAAJJJZLLC))))CGR2LHAH&ZLLJJLCLC...)AAAAAAAAAAAAAAAAAWWWAAWWWWWWWWWWWWWWWWANA))CLG88GHHH
2183 LLJJZZLJ)CNAAWWAAWAWAAAAAWWA)LLJ))C))LNCCG8GHRAG82LCJLLLL).)...NAAAAAAAAAAAAAAAAWWWWAWWWWWWWWWWWWANACC)CCCGGG88GG88
2185 HRPHLLLLJCNAAANNAAAARL2AAAAH2GZLJC).J'JCCGGGHAHH8LCCJJLGGRL)))...NNNAAAAAAAAAAAAAWWWWWWWNN)C)L).L2CCGGHGCCGLG&&8
2187 RAAAAAJAACCNNAHH).LJCL2C)CGHG88G22LCCCCCLLCL)A8G2LC2GHGAAHALCJLCL....NAAAAAAAWWWWWWWA)C))2GLGCCGGGGGGCCLCCG88F
2189 HAAARAAAAHCLCCNC)LCJCL2LCCGL2GHG2GL82JGGC))CNAG82GL22HGRHGRHLLLGLLLCCC).NAAAAAAAAA)))CCGGLCGCCGGGGCGGL)CCL)HAHR
```

NUMBER OF POINTS PER CLUSTER

CLUSTER	1	2	3	4	5	6	7	8	9	10
SYMBOL		'	.	=	)	J	C	L	2	Z
POINTS	0	5	36	0	84	58	125	85	27	7

CLUSTER	11	12	13	14	15	16	17	18	19	20
SYMBOL	3	&	T	8	F	G	H	N	R	D
POINTS	0	2	0	19	2	77	35	58	16	0

CLUSTER	21	22
SYMBOL	A	W
POINTS	277	197

Fig. 14. Part of a "training field" used in the unsupervised classification.

points the *CLUSTER classifier can accomodate and by the number of such fields the analyst selects as adequate for the area to be classified. In this case, six such fields were selected.

A refinement of the clusters is achieved by examining the Separability Information Listing, a table of statistics indicating the degree of separability of all pairs of clusters. The number of cluster classes are thus modified accordingly. The *CLUSTER function is then re-run, specifying the modified number of cluster classes. At the same time, a "PUNCH STAT" card, which causes binary statistics to be punched, is included in the deck. The statistics deck thus obtained is used to *CLASSIFYPOINTS in the same way as in the supervised approach.

The major disadvantage in the unsupervised approach is the inability to quantitatively evaluate the classification performance. However, where a map printout of the supervised approach of the same area is available, a qualitative comparison is possible. This facilitates a qualitative comparison between functional and spectral maps. Fig. 15 shows part of the unsupervised classification map. There is substantial similarity between this map and that in Fig. 12, considering the fact that the former has 22 subclasses and the latter 25. A useful feature of the unsupervised classification map is that there are fewer unclassified (thresholded) data points. The preparation of the training statistics for the unsupervised approach required less than one quarter of the time needed for preparation of similar statistics for the supervised approach. It is the opinion of the author that as long as the few large "training fields" and the number of cluster classes are selected with careful consideration for the range of land uses in the study area, this approach can provide equally usable data as the traditional supervised approach at

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BTLARSYS                LABORATORY FOR APPLICATIONS OF REMOTE SENSING         JUNE 17,1975
VICTOR ODENYO                      PURDUE UNIVERSITY                          09 30 40 AM
ERTS UNSUPERVISED CLASSIFICATION VA BEACH VICTOR ODENYO 1975                  LARSYS VERSION 3

        CLASSIFICATION STUDY  511145405              CLASSIFIED          APR  21,1975
        RUN NUMBER............ 73120101              DATE DATA TAKEN... AUG  30,1973
        FLIGHT LINE... 140315132     VA              TIME DATA TAKEN..... 1013 HOURS
        DATA TAPE/FILE NUMBER.. 1822/ 1              PLATFORM ALTITUDE..3062000 FEET
        REFORMATTING DATE. AUG  17,1974              GROUND HEADING..... 165 DEGREES

                 CLASSIFICATION TAPE/FILE NUMBER ...  867/  1

                              CHANNELS USED
                              *************

   CHANNEL  1    SPECTRAL BAND  0.50 TO  0.60 MICROMETERS    CALIBRATION CODE = 1    C0 = 0.0
   CHANNEL  2    SPECTRAL BAND  0.60 TO  0.70 MICROMETERS    CALIBRATION CODE = 1    C0 = 0.0
   CHANNEL  3    SPECTRAL BAND  0.70 TO  0.80 MICROMETERS    CALIBRATION CODE = 1    C0 = 0.0
   CHANNEL  4    SPECTRAL BAND  0.80 TO  1.10 MICROMETERS    CALIBRATION CODE = 1    C0 = 0.0

                                 CLASSES
                                 *******

     SYMBOL    CLASS                               SYMBOL    CLASS

       1       NS-  1/                               M       NS- 12/
       2       NS-  2/                               F       NS- 13/
       .       NS-  3/                               S       NS- 14/
       4       NS-  4/                               Y       NS- 15/
       -       NS-  5/                               B       NS- 16/
       =       NS-  6/                               +       NS- 17/
       /       NS-  7/                               I       NS- 18/
       $       NS-  8/                               J       NS- 19/
       X       NS-  9/                               *       NS- 20/
       #       NS- 10/                               G       NS- 21/
       L       NS- 11/                               H       NS- 22/
```

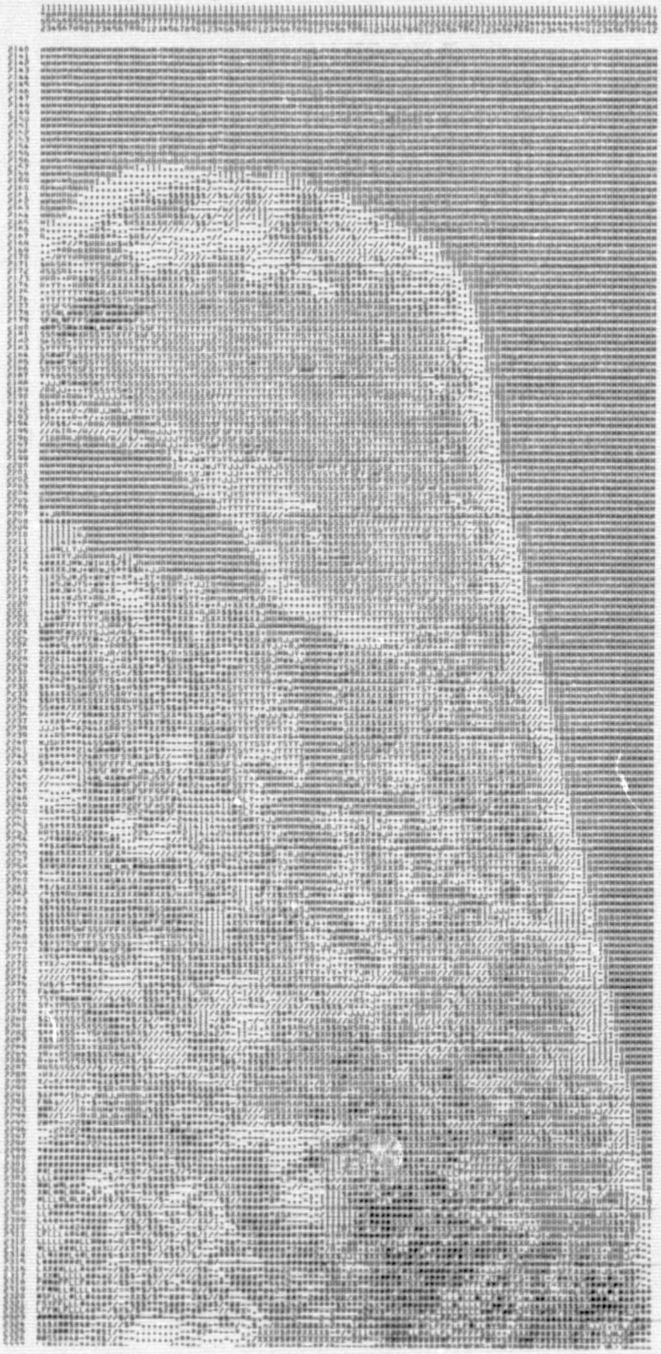

Fig. 15. Part of the unsupervised classification map.

less than half the cost in time. This approach would also be more suitable when a large area, for example one whole LANDSAT frame, is to be machine processed en block, a situation not unlikely in a regional analysis.

4.3 HIGH ALTITUDE (U-2) DATA

The printout map obtained from the digitized U-2 data, when every line and column are printed, is at a very large scale, measuring 11.2m by 14m. Each data point on the map represents 0.0044 hectares (0.011 acres) on the ground; that is, 100 data points represent 0.45 hectares (1.1 acr.). Put another way, every acre of land can be classified into almost 100 land uses or land cover types. It is conceivable that in non-urban and non-agricultural areas more than one hundred species may be present in one acre of surface. In urban areas, it may be possible to obtain one hundred spectral classes. But, in both cases, the extent of field verification required may not be justifiable in terms of practical benefits. Besides, the funtional classes cannot be stretched that far without a concomitant loss in meaning.

Two small areas were sample-classified using the unsupervised approach in the same manner as previously described. One area was predominantly agricultural, the other was predominantly urban. The field verification for these data were not detailed.

The agricultural area was that immediately west of the Princess Anne Court House (Fig. 8). The classification isolated very much detail in the whole area, delineating drainage canals in Winn's Ornamental Tree Nursery and even large isolated trees on the edges of the agricultural fields. At the time the imagery was taken (November 1, 1973) all of the corn had been harvested and the same fields disked and seeded to winter wheat. Thus, most of these fields show bare soil, and so facilitate the delineation of drainage classes. The soybean crop was mature and predominantly light brown, and a considerable portion of the earlier-planted fields were also harvested. Most of the hardwoods had shed their leaves with the onset of the fall weather and thus easily delineated from the evergreens. However, within these two broad groups, the complexity of the actual local species mixtures is borne out in the classification. This complexity was hardly reduced when the classification classes for the sample area was reduced to ten.

The urban sample-classification area was that north of Hwy 58 and between the Eastern and Western Branches of Lynnhaven River (Fig. 7). Independence Boulevard in the Pembroke Manor area, Witch Duck Road, and Little Neck Road, were clearly visible even when the map was printed every two lines and columns. Clusters of ornamental trees, and backyard lawns in the residential areas were delineated. The Kingston Elementary School and the traffic circle to the east of it were clearly defined.

It seems that these data could be useful for a very detailed investigation, though they would still be subject to the same disadvantages of the machine processed map.

4.4 THE I^2S ANALYSIS RESULTS

The filter/illumination combination used to accentuate certain land cover types were previously summarized in Table 4. The first combination renders the highly reflective urban and built-up areas, bare beaches, and clouds bright red (Fig. 16), but the separation between these and neighbouring classes is not well defined. The forested areas including forested wetlands are easily distinguishable as dark green rendition.

The agricultural areas are well separated as bright red or pink areas in combination 2 (Fig 17). The urban areas are rendered grayish brown and clearly delineated in this combination. The Oceana Naval Air Station and the commercial and residential areas south of Hwy 58 are particularly recognizable.

The third combination (Fig. 18), in which the spectral band 7 (0.80 - 1.10 micrometers) is eliminated and band 5 (0.60 - 0.70 micrometers) is combined with a clear filter, also accentuated the forested areas and forested wetlands as dark green and built-up areas, bare land, and clouds, as light gray.

Reducing illumination and cutting out the green from band 6 (0;70 - 0.80 micrometers) as in combination 4 (Fig. 19), again renders agricultural areas bright pink and accentuates the land/water boundaries. The forested areas are more blurred in this rendition.

The I^2S analysis seems to be fairly effective in delineating the major classes. It is also an informative first step to the machine analysis of LANDSAT data. Because the instrument can accomodate one whole LANDSAT frame it seems to be also suitable for regional analysis. The major drawback in the use of this instrument is the loss in fidelity during the processing of the photographs taken from the screen.

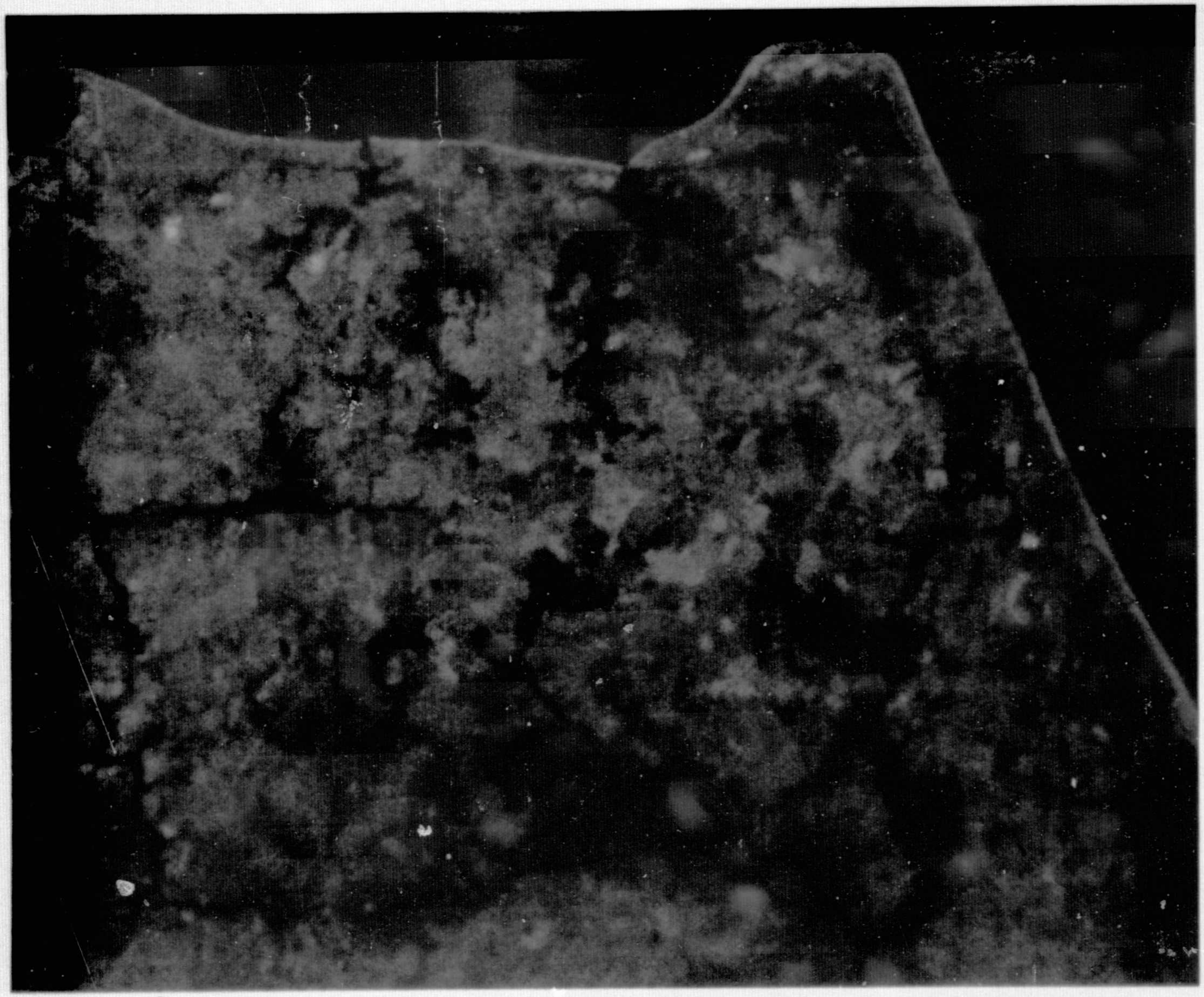

Fig. 16. I^2S additive color image of combination 1. Bands 4 and 7 had blue filters with max. illumination, band 5 had red filter with max. illumination, and band 6 had green filter with 7.5 illumination.

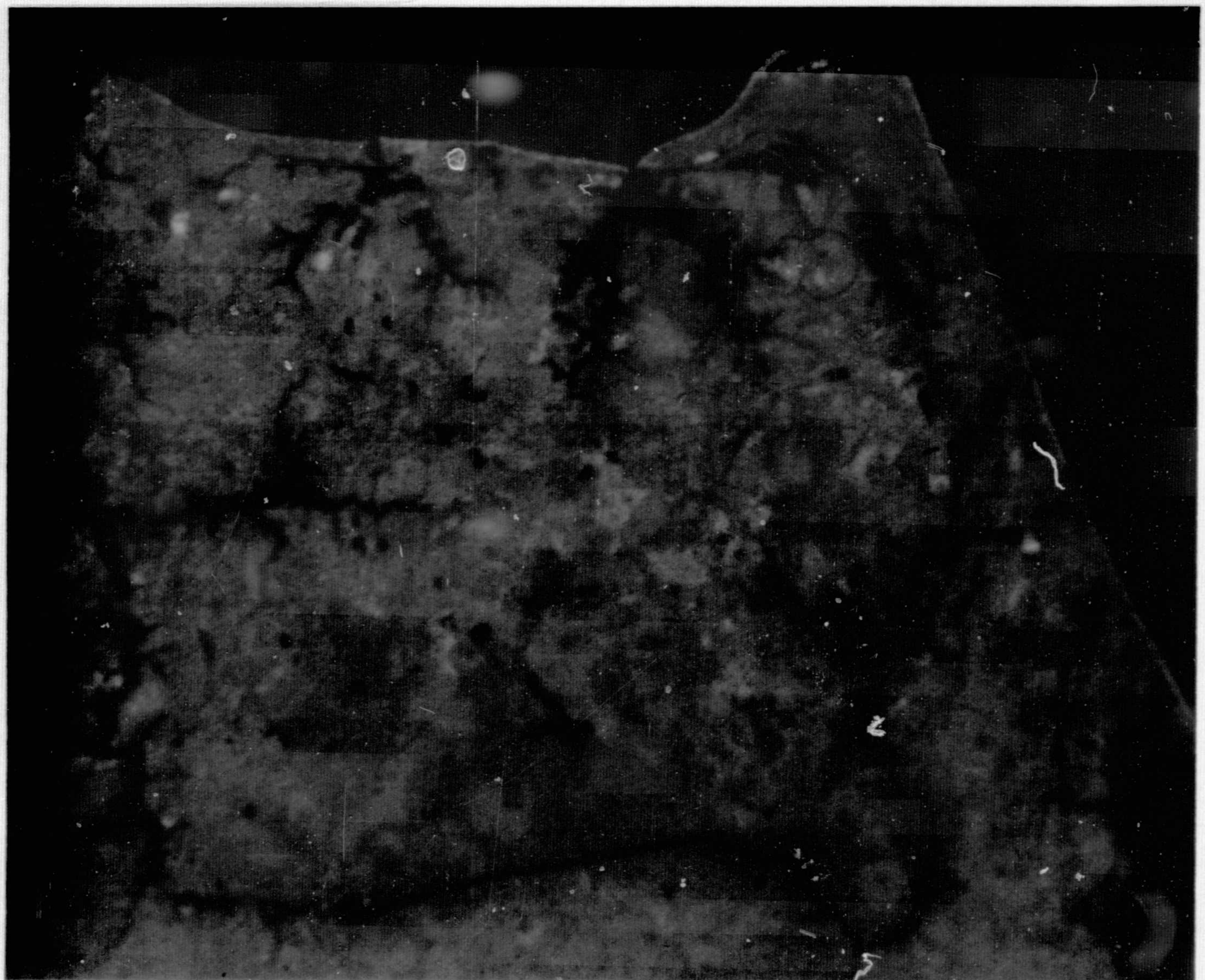

Fig. 17. I^2S additive color image of combination 2. Bands 4 and 5 had green filters with 7.7 and 8.0 illumination respectively, band 6 had blue filter with 8.0 illumination, and band 7 had red filter with maximum illumination.

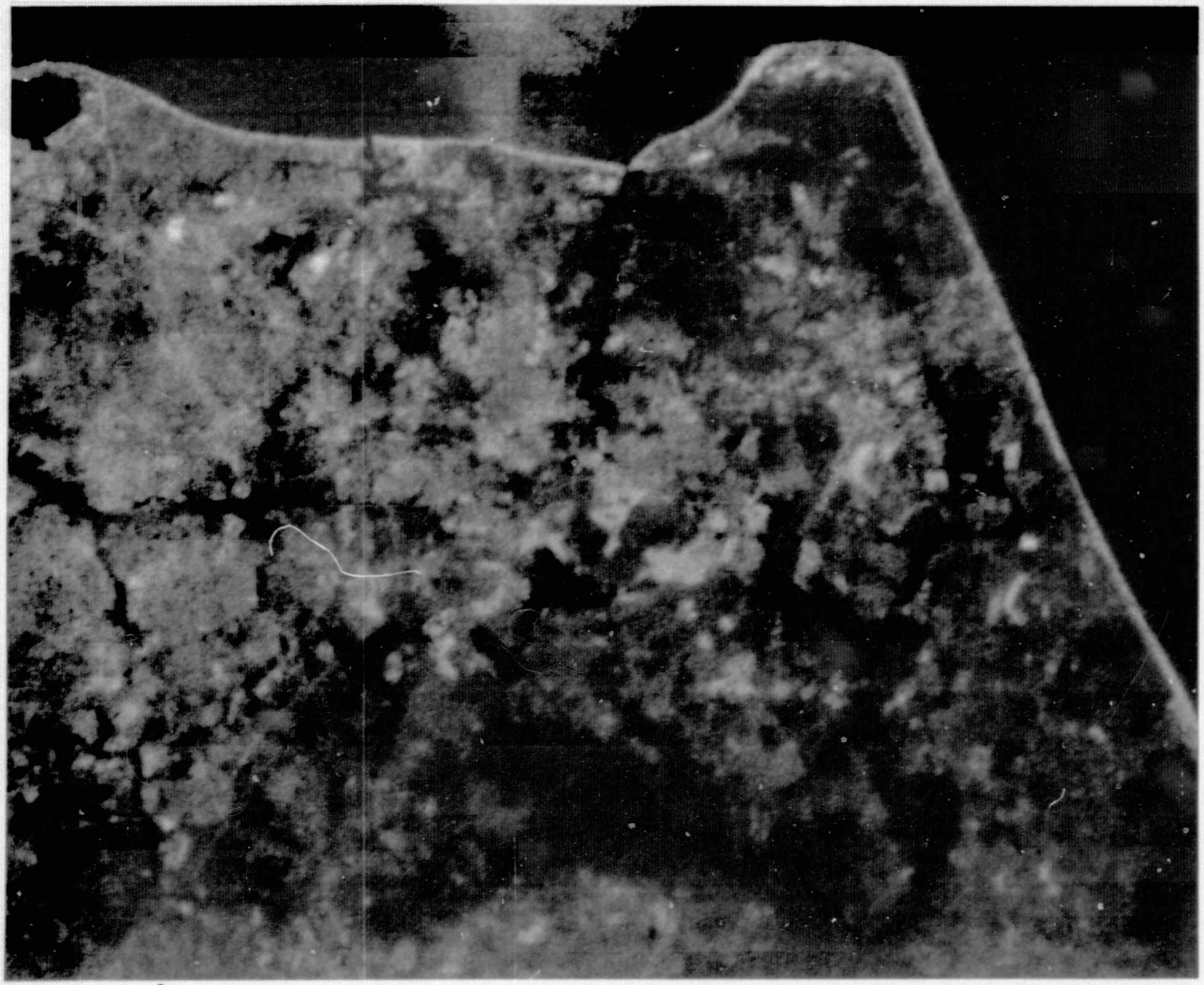

Fig. 18. I^2S additive color image of combination 3. Bands 5 and 7 had clear filters with maximum and minimum illumination respectively, and bands 4 and 6 had green filters with maximum illumination.

Fig. 19. I^2S additive color image of combination 4. Bands 5 and 6 had green filters with maximum and 4.0 illumination, respectively, and bands 4 and 7 had respectively blue and red filters with 7.5 illumination.

4.5 RESPONSE OF LAND USE TO SOIL LIMITATIONS

According to the Soil Conservation Service (SCS, 1961) the various types of soil limitations are erosion, wetness, soil rooting zone, and climate. To this may be added slope. In the City of Virginia Beach, the major problem is wetness, and this affects agricultural as well as non-agricultural land uses. Slope is a conspicuous problem--by its absence, and is, indirectly, the cause of wetness.

In "Urban Land Use Planning", Chapin (1965) does not include the intrinsic characteristics of the land at any level in his enumeration of the land use determinants. It is not considered in the determination of the land value. Whereas this omission may make sense to the land economist, it is an inexcusable oversight to the soil scientist and civil engineer.

Of the total area of 80,352 hectares (198,400 acres), 67,055 hectares (165,568 acres), or 83.4 percent is land (Va. Beach Dept. Econ. Dev., 1973). As of 1969 (Vepco, 1969) 25,516 hectares (62,998 acres), or 32 percent of these were "agriculturally productive" compared to 30 percent in 1945; and 19,560 hectares (48,300 acres) were in commercial forest. Statistics available for 1974 (Earl Williamson, Soil Conservationist, Soil Conservation Service, City of Virginia Beach, Virginia--personal communication) indicate that 69 percent of the total land area was farmland, of which 34 percent was cropland, 26 percent was forest, and 9 percent was pasture and other land. Some of the discrepancies in these data are probably due to different methods of inventorying. However, the apparent slight increase in percent of agricultural land between 1945 and 1974 may be partly due to improved technology in agriculture that has enabled the utilization of some poorly drained soils.

Simmons and Shulkcum (1945) reported that as of that year, about ten percent of the total area was in marsh and about 5 percent in dune sand and coastal beach. These figures probably have not changed sustantially, but urban development, for example in Sand Bridge, is utilizing some of these areas. Most of the coastal beaches, however, are used for recreation, and some of the wetland areas have been made into wildlife reserves and parks.

By its very nature, agriculture is more sensitive to soil limitations than any other land use. Only a few specialized agricultural crops are adapted to saturated soil conditions, but none of these are grown in the study area. In fact, the major field crops grown in the study area, corn, wheat, and soybeans are quite sensitive to even short periods of soil saturation. Thus, agricultural and horticultural crops are restricted to at least somewhat poorly drained and , in a very few cases, some poorly drained soils. It is not only the sensitivity of the crops that limits the use of the poorly and very poorly drained soils--the soil structure is very greatly compromised by plowing at high moisture contents. Thus, most of the poorly drained and very poorly drained soils are under forest. There are a few somewhat poorly drained soils also under forest.

According to the 1945 soil survey (Simmons and Shulkcum, 1945) there were 12,260 hectares (30,272 acres) of well drained soils, mostly in the northern part of the city and along the Pungo and lesser ridges. The economic study committee (Vepco, 1969) reported 25,516 hectares of agriculturally productive land "primarily located in the Princess Anne, Pungo, and Blackwater boroughs". These are all located in the southern part of the city.

4.5.1 RESPONSE OF URBAN LAND USE TO SOIL LIMITATIONS

Following on the steps of Adam Thoroughgood, the people who settled in this area occupied the well drained and moderately well drained soils first (Simmons and Shulkcum, 1945). Most of the older residential subdivisions were built on these soils. Examples of these are Alanton, Bay Colony, Bird Neck Point, Thoroughgood, Smith Lake Terrace, and Laurel Manor subdivisions north of Virginia Beach Boulevard. Relatively small areas of these soils in this part of the City are still in agriculture, and these are changing rapidly to residential subdivisions. As of 1974 6,400 hectares (15,800 acres) were in urban and built up areas (Williamson -- personal communication). Similar data for earlier periods were not readily available, but with an increase in population from 19,984 in 1940 (Simmons and Shulkcum, 1945) to 85,218 in 1960 and 158,506 in 1968 (Vepco, 1969); and from 172,106 in 1971 to an estimated 209,200 in 1974 (Blume, 1975), the change in urban acreage has apparently been quite substantial.

Many of the older residential subdivisions built on the well drained and moderately well drained soils have large lots, 4 to 9 single units per hectare (2 - 4 units per acre) and thus had enough room for septic drainfields. However, these soils, Sassafras, Norfolk, Craven, and Woodstown (Simmons and Shulkcum, 1945), are not the ideal soils for effluent disposal. Sassafras has clay loam, sandy clay, or silty clay loam at depths between 70 and 90cm (25 and 35in); Craven has clay loam or clay between the same depths; and Norfolk has fine sandy loam or clay loam between 76 and 102cm (30 and 40in). Woodstown has mottles between 90 and 112cm (36 and 44in). The recommended minimum depth for absorption trenches is 61cm (24in) (US Dept. of Health, Education and Welfare, 1967).

A large area, nearly 500 hectares due west, south, and south-west of the Oceana Naval Air Station has been designated for an industrial park. Several factors have been considered in this designation, among them the proximity of the air station. Wooded land has been preserved along the approach alleys to serve both as buffers in case of aircraft crushes and against jet noises. The soils of this area are also mostly poorly drained, and a large drainage canal is being constructed to facilitate the development of the industrial park.

Many of the more recent developments south of Virginia Beach Boulevard are on poorl drained and somewhat poorly drained soils. Princess Anne Plaza and Windsor Woods are two examples of these. A substantial part of both of these subdivisions is built on poorly drained Roanoke silt loam and Myatt silt loam. The soils have mottles within 25cm (10in) of the surface and are both typic ochraquults (Jim Belshan, party chief, Cooperative Soil Survey, City of Virginia Beach, Virginia -- personal communication). Characteristics of these soils are described in appendixes 2 and 3. In both of these areas, as in other developments in poorly drained areas, relevant precautions are being taken to overcome urban problems arising from the poor natural drainage conditions.

5. SUMMARY AND CONCLUSIONS

Since the advent of the application of space technology to natural resource investigations the amount of remote sensing data available has not only increased, it has also acquired different forms, partly due to the sophistication in the sensing instruments. This has, in turn, made it necessary that the interpretation techniques move to higher levels--thus more sophistication and automation.

The research reported herein attempted to apply one of the recently developed machine processing techniques for remote sensing analysis. The LARSYS software system was applied to land use classification and mapping of the City of Virginia Beach, Virginia, with space remote sensing data (LANDSAT-1) and high altitude aerial imagery (U-2). An additional objective was to determine the extent the land uses, as mapped, were related to the soils of the area.

5.1 TECHNIQUES OF ANALYSIS

The LANDSAT data were subjected to both supervised and unsupervised classification. They were also analyzed with the International Imaging Systems (I^2S) Additive Color Viewer. After detailed field examination, six major land use classes were derived. In the supervised classification, 119 training fields with a total of 4854 data samples, and 32 test fields with a total of 3025 data samples, were developed for the six classes. In the unsupervised classification, six large fields, which included as many of the land use units as possible, were selected and used for deriving statistics for classification.

A map printout of the supervised classification was overlayed with glazed acetate and a land use/land cover map was prepared. The subclasses of the six major land use classes formed the units for this map. The units were designated on the map by two- or three-letter symbols, each letter symbolizing the major components of the different subdivisions of the major class.

The U-2 data was digitized with either two or four filters, reformatted, and filed at the LARS-Purdue computing center. Two areas, one predominantly agricultural and the other mostly urban, were selected for sample classification. The unsupervised approach for the LARSYS was applied in both areas.

5.2 RESULTS

The six major land use classes derived for the study area were "Urban", "Agricultural", "Wooded", "Water", "Wetland", and "Bare Land". These formed the Level I classes. In the supervised classification, performances of 97.7 percent for the training fields and 93.9 percent for the test fields were obtained in the final attempt. The average performance by class for the training class was 97.0 percent, ranging from 92.0 percent for the "Wooded" class to 100 percent for the "Bare Land" class. The average performance by class for the test class was 92.1 percent, ranging from 76.4 percent for the "Wooded" class to 100 percent for the "Bare Land" class.

Separation at Level II was achieved for all the Level I land use classes, and Level III was also achieved for a few of the classes. The subdivisions of the various Level I classes were achieved on the basis of the characteristics summarized below:

1. The Urban class was found to contain a wide variety of cover types with various optical reflectance characteristics. These included

concrete and asphalt surfaces; black, white, red and green walls and roofs; lawns and ornamental trees; and both highly weathered and relatively new industrial sites. The subclass separation was achieved on the basis of the extent and density of man-made structures.

2. The Agricultural class consisted of field crops and some ornamental and truck crops. The field crops were extensive enough to form subdivisions of this class, while the truck and ornamental fields were generally less extensive.

3. Wooded and Wetland classes were subdivided on the basis of the age, amount of branching and leafiness, and the amount of understory vegetation. Forested and non-forested wetlands were delineated.

4. Water was subdivided on the basis of its turbidity with respect to suspended inorganic and organic sediment, degree of clarity, presence or absence of substantial algal growth, extent of weed growth, and salt content.

5. Bare Land consisted of bare sandy beaches, partially vegetated beaches and inland sand, and bare tidal mudflats.

A comparison between the land use classification derived in this study and the USGS proposed system (Anderson, et al., 1972) revealed a close correspondence between the two.

The printout map resulting from the unsupervised classification had close similarity to that obtained via supervised classification. Time needed for the unsupervised classification was less than 25 percent of that required for the supervised classification.

Very detailed maps were obtained from the U-2 data. Each data point in the map represented approximately 6.5 by 6.5 m on the ground, which permitted the delineation of single large tree stands in the edges of agricultural fields, and of drainage canals. In the urban area single stands of mature ornamental trees in lawns were delineated. Schools, churches, and single residential houses were separated.

Four combinations of filter and illumination intensity with the I^2S Additive Color Viewer enabled the major land use classes (Level I), urban, water, agricultural, forested and nonforested wetland, and wooded areas to be delineated in color. The viewing screen of the instrument was photographed and prints made.

In the investigation of the response of land use to the soil limitations, agriculture was found to be restricted mostly to well drained, moderately well drained, and somewhat poorly drained soils. Forest or wooded areas were found to be devoted to poorly drained and some very poorly drained soils. Most wetland areas were found to be used for wildlife or for recreation activities.

Urban development was found to have utilized most of the well drained and moderately well drained soils of the northern quarter of the City, and it appeared to be spreading into the somewhat poorly and poorly drained soil areas. It appears that more alterations to the land surface are being effected in the more recently developed urban areas, mostly to overcome the adversity due to poor natural drainage conditions.

5.3 CONCLUSIONS AND FORECAST

Results of this study demonstrate:

1. That machine analysis of LANDSAT data to produce land use maps is feasible.

2. That the LARSYS software system can be utilized for land use in relatively complex areas.

3. That high levels of accuracy can be attained in the supervised approach with machine analysis.

4. That a saving in investigation time, without loss in accuracy, can be achieved with the machine analysis approach.

Other possibilities are also indicated by the results of this study. Because the land area of the pixel is known (or can be calculated from the scale), quantification of the land use data or changes in land use seems to be feasible. The high speed attained in the interpretation of data is likely to make temporal comparisons easier and faster, especially with the repetitive coverage of the LANDSAT. The work of the natural resource analyst is likely to be accelerated without compromising accuracy.

Although the traditional supervised approach is relatively tedious, it is preferred where the area to be analyzed is small, and detailed information is desired. The partially supervised approach implemented in this research seems to be applicable in cases where the area to be analyzed is large, as in regional analysis. It is capable of providing the same level of detail as the traditional supervised approach in a much shorter time.

The Land Use/Land Cover map produced by these procedures seems to compare favorably with the maps produced by conventional means, except for the misclassifications due to the inability of the machine to distinguish between functional and spectral classes. This can be conclusively determined only by the use and testing of the machine produced map.

The Land-Use Classification System for Use With Remote-Sensor Data proposed by USGS was found, with minor modifications, to adequately cover the land uses of the area studied. Its numerical designation of classes and subclasses were not used mainly because the result was not intended to be stored in retrievable cell-by-cell form. Results obtained in this study indicate this classification system and the LARSYS software system would be usable for natural resource inventorying on a state-wide basis.

Of equal value, this study suggests the route for follow-on work. The reliability of land-use recognition and classification needs improvement. A systematic study of the relationships between spectral characteristics and functional land use classes would contribute to this. In the same way, the development of algorithms that would enable the computer to make distinctions between functionally different but spectrally similar land uses would increase the reliability.

Studies and experimentation aimed at developing an optimal land use classification scheme applicable to the major part of the United States should be continued. Such a scheme, unlike the current one, should take into consideration the machine analysis of remote-sensor data, especially of LANDSAT data. Data from other sources, for example skylab, aircraft-borne scanners from varying altitudes, side-looking airborne radars, and thermal bands, should be duly considered in the modified scheme.

With respect to the Commonwealth of Virginia, studies should be initiated to facilitate production of a state-wide land use/land cover map by machine analysis of LANDSAT data. The know-how and the data are available, and machine classification at Level II and storage of the data on a retrievable cell-by-cell format seems feasible.

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APPENDIX

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LARS FIELD COORDINATE CODING SHEET (AIRCRAFT SCANNER DATA)

RUN NUMBER (1-8)	FIELD DESIGNATION (11-18)	FIRST LINE (21-25)	LAST LINE (26-30)	LINE INTERVAL (31-35)	FIRST COLUMN (36-40)	LAST COLUMN (41-45)	COLUMN INTERVAL (46-50)	FIELD TYPE (51-58)	ADDITIONAL INFORMATION (59-72)

NASA WI-1306 (9-73)

71A Roanoke silt loam (high base variant)

Classification: A member of the clayey, mixed, thermic family of Typic Ochraquults.

Location: Approximately 600 feet W. of Nimmo Methodist Church, 200 feet N. of Princess Anne Road, in mixed hardwood and pine forest.

Physiography: Lower Coastal Plain, Flat Woods Section; elevation 12 feet.

Parent Material: Marine sediments

Drainage: Poorly drained

Sample Numbers: S73Va-76-3-(1-8*)

O_1	1/2-0"	Mixed hardwood and pine leaf litter
A_1	0-2"	Very dark brown (10YR2/2) silt loam; weak fine granular structure; friable, slightly sticky, non-plastic; many fine, medium and coarse roots; common fine bleached white sand grains; very strongly acid (pH 4.3); abrupt smooth boundary.
A_2	2-7"	Very dark grayish brown (10YR3/2) silt loam; weak fine granular structure; friable, slightly sticky, non-plastic; common fine, medium and coarse roots; few worm ducts up to 1 cm in diameter; few to common white washed sand grains; very strongly acid (pH 4.5); abrupt smooth boundary.
B_1tg	7-14"	Light brownish gray (2.5Y6/2) silty clay loam, with common medium prominent strong brown (7.5YR5/6), and yellowish brown (10YR5/6) and few to common fine and medium, faint grayish brown (10YR5/2) mottles; weak fine and medium subangular blocky structure; friable; slightly sticky, slightly plastic; common fine and medium roots; thin discontinuous clay films; medium acid (pH 5.5); clear wavy boundary.
$B_{21}tg$	14-28"	Gray (10YR5/1) silty clay; with common medium distinct yellowish brown (10YR5/6) mottles; moderate medium subangular blocky structure; firm, sticky, plastic; few to common fine and medium roots; thick continuous clay films on ped faces; few moderately thick discontinuous silt coatings; few krotoivina up to 1 inch; very slightly acid (pH 6.3); clear wavy boundary.

$B_{22}tg$	28-43"	Gray (10YR5/1) silty clay; few fine and medium distinct yellowish brown (10YR5/6) and few fine and medium distinct very dark brown (10YR2/2) mottles; moderate medium subangular blocky structure; firm, sticky, plastic; few fine roots; thick continuous clay films on ped faces; few krotovina up to 1/2 inch filled with highly decayed root fiber; newtral to alkaline (pH 7.5); clear wavy boundary.
C_1g	43-92"	Gray (5Y5/1) silty clay loam; with common medium distinct yellowish brown (10YR5/6) and few fine distinct pale brown (10YR6/3) and few fine distinct (blue'green" mottles; massive; friable, slightly sticky, slightly plastic; few krotovina up to 1/2 inch in diameter; common fine mica flakes; alkaline (pH 8.0); few black mineral concretions.
C_2g	92-134"	Dark gray (2.5 Yn/4) silty clay, massive (from auger) firm; very sticky, plastic; strata appears to be permanently saturated; neutral (pH 7.0).

Vegetation: Hornbeam, oaks, loblolly pine, beech, sweet gum, and light understory of reeds and greenbriers.

Remarks: Mica flakes first thought to be quartz grains, and are fairly resistant to breakdown with thumbnail. Pit dug to 76 inches - auger boring to 134 inches.

65A Myalt silt loam

Classification: A member of the fine-loamy, mixed, thermic family of Typic Ochraquults.

Location: Approximately 125 feet S. of old Potters Road and 250 feet E. of junction of old Potters Road and Lynhaven Parkway and approximately 500 feet SE. of overpass of Route 44 over Lynhaven Parkway.

Physiography: Lower Coastal Plain; Flat Woods section; elevation 11 feet.

Drainage: Poorly drained.

O_1	1/2-0"	Pine needles and hardwood leaf litter.
Ap	0-7"	Brown (10YR5/2) silt loam; weak fine granular structure; friable; slightly sticky non plastic; many fine and medium and few coarse roots; very strongly acid (pH 5.0); abrupt smooth boundary.
B_1tg	7-15"	Light brownish gray (10YR6/2) light clay loam, mottled with common medium, prominent, yellowish brown (10YR5/6) mottles; moderate medium subangular blocky structure; friable; sticky, slightly plastic; common fine and medium and few medium roots; few thin discontinuous clay films; very strongly acid (pH 5.0); clear smooth boundary.
B_{21}tg	15-26"	Gray (10YR5/1) clay loam, mottled with common, medium, prominent, yellowish brown (10YR5/6) and few, medium, distinct, light brownish gray (2.5Y6/2) mottles; strong medium subangular blocky structure; firm; sticky, plastic; few fine roots; many thin continuous clay film; very strongly acid (pH 5.0); gradual smooth boundary.
B_{22}tg	26-52"	Gray (10YR5/1) clay loam, mottled with common, medium, prominent yellowish brown (10YR5/6) and common, medium, distinct, light gray (10YR7/1) mottles; strong moderate subangular blocky structure; firm; sticky, plastic; few fine and medium roots; light gray (10YR7/1) mottles appear as coarse pockets of more silty material (possibly old root channels); many thin continuous clay films (clay films may be silt coatings); very strongly acid (pH 5.0); clear way boundary.

IC_1g	52-80"	Light gray (10YR7/1) loamy sand; mottled with many, medium, prominent, brownish yellow (10YR6/8) mottles; massive; very friable; none sticky and none plastic; few fine mica flakes; three to four inch lenses of sandy loam material; very strongly acid (pH 5.0).

VITA

Victor Agab Omondi Odenyo was born in [redacted]4. He received his elementary education at Regea and Luanda schools and his high school education at Maseno and Sharda High Schools.

From 1965 until 1966 he worked as a clerk in the former National and Grindlays Bank in Nairobi. In 1966 he was awarded a Swedish Government Scholarship to study Earth Sciences at the University of Uppsala, where he enrolled in September of that year. He received the degree of Filosofie Kandidatexamen in 1970, majoring in Soil Science and Geomorphology.

From September 1970 to August 1971 he was employed as a Lecturer in Soil Science at the Egerton Agricultural College in Njoro, Kenya.

A fellowship from the Ford Foundation enabled him to enrol in the graduate school of the University of Minnesota, Minneapolis/St. Paul, in September, 1971. He received the degree of Master of Science in Soil Science in July, 1973.

He entered the graduate school of Virginia Polytechnic Institute and State University in September, 1973, to pursue graduate work leading to the degree of Doctor of Philosophy in Agronomy. He is a member of Gamma Sigma Delta.

He is married to Carina [redacted] and they have two children, Victoria Atieno and Tanya Adero.

REMOTE SENSING APPLICATION

TO LAND USE CLASSIFICATION IN A RAPIDLY CHANGING

AGRICULTURAL/URBAN AREA--CITY OF VIRGINIA BEACH, VIRGINIA

by

Victor A. O. Odenyo

(ABSTRACT)

Remote sensing data on computer-compatible tapes of LANDSAT-1 MSS Frame E-1483-15132 of August 30, 1973, were analyzed to generate a land use map of the City of Virginia Beach. All four bands were used in both the supervised and unsupervised approaches with the LARSYS software system of Purdue University. Color IR imagery of U-2 flight 73-185, November 1, 1973, of the same area was also digitized and two sample areas were analyzed via the unsupervised approach. The I^2S Additive Color Combiner was also utilized with LANDSAT-1 imagery. The relationships between the mapped land use and the soils of the area were investigated.

A Land Use/Land Cover map at a scale of 1:24,000 was obtained from the supervised analysis of LANDSAT-1 data. Major functional classes delineated were "Urban", "Agricultural", "Wooded", "Water", "Wetland", and "Bare Land". Twenty four subdivisions of these classes were spectrally separable. Some of these were subdivisions of Level II of the USGS-proposed system. Extent of man-made structures, unit density, and degree of weathering were important in subdividing the Urban class. Crop type was important in the Agricultural class. Vegetation types, age, extent of branching and leafiness, and thickness of undergrowth were important in Woodland and Wetland areas. The turbidity, depth,

weed growth, and the degree of algal and other pollution determined Water subclasses. Bare Land consisted mostly of beaches and mudflats. Performances of 97.9 percent for training field, 93.9 percent for test field, 97.0 percent for training class, and 92.1 percent for test class were obtained. Construction activities caused many misclassifications.

The printout map from the unsupervised approach compared favorably with that from the supervised approach. The I^2S Additive Color Viewer was found to be very suitable for Level I mapping.

The U-2 classifications exhibited great detail in both the agricultural and urban sample areas. Large, highly branched single trees, drainage canals, neighborhood streets and traffic circles, and ornamental trees were delineated.

A relationship was found to exist between the mapped land uses and the soils. Most poorly and very poorly drained soils, approximately 10 percent of the total city area, were in wetland, forested or sparsely vegetated. Some somewhat poorly drained soils were also under commercial forests. Commercial forests accounted for 1960 hectares (48,300 acres) as of 1968. Most of the 25,515 hectares (63,000 acres) of agriculturally productive land were found to be concentrated on the well and moderately well drained and some poorly drained soils. Early urban/suburban expansion was found to have concentrated on the well drained and moderately well drained soils. Many of the newer urban areas were found to utilize some somewhat poorly and poorly drained soil areas. In the latter case, the streets were increasingly being used to collect and disperse surface runoff. Storm drainage pipes often ran under the streets.

It was concluded that machine analysis of remote sensing data to produce land use maps was feasible; that the LARSYS software system was usable for this purpose; and that the machine analysis was capable of extracting detailed information from the relatively small scale LANDSAT data in a much shorter time without compromising accuracy. The use of this approach for regional analysis is anticipated.