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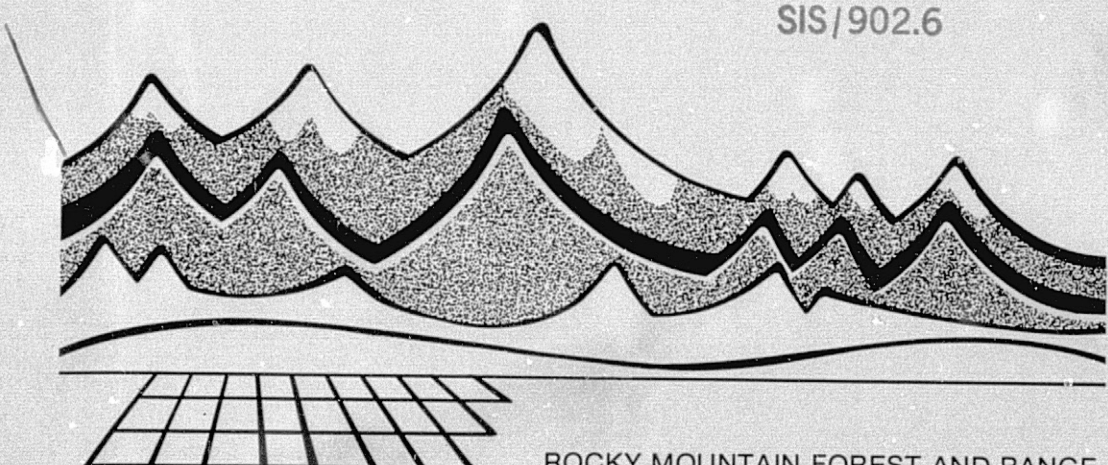

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
FORT COLLINS, COLORADO
FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

INVENTORY OF FOREST RESOURCES (including water) BY MULTI-LEVEL SAMPLING

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16. Abstract Four independent LANDSAT based forest and water resource inventory studies were conducted in nine northern Virginia coastal plain counties. The studies include: (1) a water resource inventory by conventional photo interpretation, (2) a forest inventory by conventional photo interpretation, (3) a forest area inventory by computer assisted techniques, and (4) a study of solar and atmospheric effects on LANDSAT data. In addition, an example is given for using LANDSAT and other information sources in an area decision management plan.

A stratified random sample using LANDSAT band 5 and 7 panchromatic prints resulted in estimates of water in counties with sampling errors less than ± 9 percent (67 percent probability level).

A forest inventory using a four band LANDSAT color composite resulted in estimates of forest area by counties that were within ± 10 percent of operational forest survey figures. Conifer and deciduous areas were highly variable by counties, but for all combined counties the sampling errors were only ± 6.7 percent and ± 3.7 percent respectively (67 percent probability level).

Estimates of forest area for counties by computer assisted techniques were within ± 21 percent of operational forest survey figures and for all counties the difference was only one percent.

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Signature Extension, Timber Volume, Forest Type, Surface Water, Water-Ways, Census Water, Reflectance, Radiance

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16. Abstract (continued from page i)

Correlations of airborne terrain reflectance measurements with LANDSAT radiance verified a linear atmospheric model with an additive (path radiance) term and a multiplicative (transmittance) term. Coefficients of determination for 28 of the 32 modeling attempts, not adversely affected by rain showers occuring between the times of LANDSAT passage and aircraft overflights, exceeded 0.83.

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PREFACE

The quasi operational timber and water resource inventories and related research described within this report are experimental. The results of these experiments are only an indication of what state-of-the-art technology will allow us to accomplish in the future. For instance, since this research was completed, new computer enhancement techniques have improved interpretability of LANDSAT photographic data considerably. This improvement should result in higher accuracies using conventional photo interpretation methods.

The results in this report are compared with known standards (Forest Survey[1] and the United States Bureau of the Census). Each result is discussed objectively from the standpoint of utility, cost and accuracy. Land managers and potential users in renewable resources inventories can use these results to make valuable judgements as to what they might expect to accomplish with LANDSAT data.

Experiments reported in the final report were performed under a Memorandum of Understanding (Contract No. S-54053) between the National Aeronautics and Space Administration, Goddard Space Flight Center (NASA/GSFC) and the United States Department of Agriculture (USDA). The research was conducted by professional staff members of the Renewable Resources Evaluation Techniques Program, Rocky Mountain Forest and Range Experiment Station (RM), Fort Collins, Colorado. When the work was originally contracted, the Principal Investigator, Co-investigators, and other supporting staff members were assigned to the Remote Sensing Work Unit, Pacific Southwest Forest and Range Experiment

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Station, Berkeley, California. The unit was transferred to Fort Collins on July 1, 1976.

The original research proposal was submitted to NASA/GSFC on January 31, 1973 by Robert C. Heller, Principal Investigator. The proposal was entitled "Monitoring Forest and Range Resources with ERTS-B and Supporting Aircraft Imagery". On September 6, 1974, Robert C. Aldrich was named Prinicipal Investigator. From that date the research proposal was revised several times to meet recommendations of the Agriculture, Range, and Forestry Sub-panel of the Missions Utilization Office. The Statement of Work was accepted and the contract begun on March 7, 1975. Due to delays created by the move of Forest Service remote sensing research functions from Berkeley, California to Fort Collins in July 1976, the Period of Performance was extended from 22 to 28 months.

We gratefully acknowledge the helpful assistance, patience and understanding of G. R. Stonesifer who was Technical Officer for NASA for the duration of this contract.

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[1]The Forest Survey, renamed Renewable Resource Evaluation, is a branch of the Forest Resources Economics Research Division, Forest Service, United States Department of Agriculture.

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GLOSSARY

Band: One of the wavelength bands of the electromagnetic spectrum sensed by a multispectral scanner (MSS) or radiometer, or passed by a bandpass filter and recorded by a photodiode or vidicon tube.

Bandpass filter: An optical filter that allows only portions of the electromagnetic spectrum to pass to the sensor surface.

Beam transmittance: Fraction of electromagnetic radiation in a particular wavelength which is transmitted vertically through the atmosphere from the ground to the spacecraft sensor.

Color composite: A false-color reconstruction of LANDSAT data in photographic form, created from two or more bands for one scene.

Computer-compatible tape (CCT): Standard 0.5 inch magnetic tape containing digital LANDSAT video (scene radiance) data along with calibration, identification and annotation data. A full 185 by 185 km frame is stored on four tapes, each segment being a 46 by 185 km strip in the direction of spacecraft heading.

CVF: Circular variable filter used for wavelength selection in ground-based spectrometer.

Data field: Recognizable terrain feature or area over which sampled radiance data were integrated to obtain registered data pairs in the correlation of reflectance to LANDSAT radiance.

Digital counts: Values of radiance data as recorded on computer compatible tapes. For MSS bands 4, 5 and 6 the scale is 0-127. For band 7 the scale is 0-63.

Four channel radiometer: Instrument for measuring LANDSAT MSS-matched radiance.

FET input op amp: Operational amplifier with a high input impedence field effect transistor in the input stage.

Interference filter: Optical filter employing thin metal or dielectric coatings on glass to reflect all unwanted wavelengths and transmit the wavelength band of interest.

Irradiance: The power per unit area of electromagnetic radiation impinging on a surface. Typical units are multiwatts per square centimeter.

Lambertian reflectance: Isotropic reflection from a diffuse surface.

LED display: Numerical readout employing light emitting diodes.

Multispectral scanner (MSS): For LANDSAT, an electronic optical line scanning device that collects reflected radiation in four spectral intervals (bands) of the visible and near infrared regions of the electromagnetic spectrum. The two visible bands are greenish-yellow and red wavelengths.

Normalized spectral response: Relative wavelength response of a sensor system, usually the combined effects of optics and detector.

Path radiance: Remotely sensed radiance from the scattering of solar radiation by atmospheric gases and aerosols.

Photovoltaic: Producing charge carriers (and therefore an electrical current) in a semiconductor without an external voltage bias applied to the device.

Picture element: (also called Pixel) A single element of digital image data recorded on a LANDSAT computer compatible tape. The ground resolution of an element is approximately 56 meters perpendicular to the spacecraft heading and 79 meters along the spacecraft heading.

Pixel: See Picture element.

Radiance: The brightness of an object as seen from a remote obervation point. Specifically, it is a measure of the power radiating from a unit area of a source through a unit solid angle. Typical units of radiance are watts/meter^2-steradian.

Scene: One LANDSAT image covering an area approximately 185 by 185 kilometers (100 nautical miles square).

Stabilene: A trade name for dimensionally stable transparent or translucent overlay material.

Threshold: A beginning value selected from a data array to define a signature for classification. The threshold value can be changed by trial and observation to improve classification.

UTM: Universal Transverse Mercator map projection system.

Zoom transfer scope: An optical instrument for transferring data from a small scale photograph to a larger scale photograph or map. The scale range is from 1X to 13X. (Manufactured by Bausch and Lomb Optical Company.)

SUMMARY

This report covers a 24-month long investigation of applications of LANDSAT data in forest and water resource inventories. The investigation included four separate studies: (1) a water resource inventory by conventional photo interpretation, (2) a forest resource inventory by conventional photo interpretation, (3) an inventory of forest area by computer aided classification, and (4) a study to develop a technique for measuring solar and atmospheric effects in LANDSAT MSS data. The studies were conducted within a nine county area in the northern coastal plain of Virginia. The quasi-operational LANDSAT based inventories were made concurrent with an operational inventory conducted by the U.S. Forest Service Resource Evaluation Unit at the Southeastern Forest Experiment Station in Asheville, North Carolina. Results of the operational inventory are used as a basis for comparing methods and results.

Imagery used in the investigation include U-2 color IR photography, LANDSAT black and white and combined color images, and computer compatible tapes (CCT's). Photographic products were supplied by the Agricultural Stabilization and Conservation Service, Salt Lake City, Utah. Computer tapes were ordered through the Earth Resources Observation System (EROS), Sioux Falls, South Dakota. Enhanced false color images used in the forest inventory section were produced directly from LANDSAT data by the University of California (Berkeley) Space Sciences Laboratory on their Imaging Gang Optical Recorder (IGOR). Maps resulting from computer aided classification were also produced by the IGOR System.

In addition to LANDSAT and aircraft imagery, reflectance measurements were collected from a low flying aircraft with a four-channel radiometer matched to the LANDSAT MSS wavelength bands. Reflectance measurements were related to LANDSAT radiance measurements to develop a method of correcting for changes in solar irradiance and atmospheric interference.

Equipment and methods for interpreting, mapping and analyzing remote sensing data varied considerably between studies. A Bausch and Lomb Zoom Transfer Scope was necessary in all studies to interpret and map information on multiscaled maps, photographs, and computer printouts.[1] An Old Delft Scanning Stereoscope was an aid in stereoscopic interpretation and mapping on U-2 color transparencies. The scanning stereoscope was also used to view two LANDSAT band (5 and 7) simultaneously to map water. An illuminated 2x magnifier was used for monoscopic interpretation of LANDSAT photographs.

Test areas used to relate aerial measurements of reflectance and radiance recorded by LANDSAT were imaged with an airborne video camera. In the laboratory, fields sampled by the non-imaging radiometer were accurately relocated by a replay of the video flight coverage on a TV monitor.

Water Resource Inventory

A stratified-random double sample design was used to estimate water in three counties. LANDSAT photo enlargements (1:125,000) for an

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[1] Trade names and commercial enterprises or products are mentioned in this report solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

October 1975 band 5 image and a November 1975 band 7 image were examined together with a scanning stereoscope to delineate surface water and water-ways. A sample frame of one-kilometer square cells, overlaid upon the LANDSAT band 7 enlargement was stratified into seven strata based on length of water-ways and area of surface water delineated in each cell. A random sample of cells selected from the seven strata were located on CIR photographs (1:120,000) and 1:24,000 USGS map sheets. By viewing the sample cells on both photos and maps simultaneously with the ZTS, individual water sources were identified, measured, and cataloged by size, accessibility, and utility class. Sampling errors for county estimates of water-ways ranged from 8.1 to 9.4 percent.[2] Estimates of surface water in each county resulted in sampling errors that ranged from 10.7 to 59.4 percent. When county totals were combined, however, sampling errors for water-ways and surface water were reduced to 8 and 3 percent respectively. Estimates by type, size, accessibility and utility classes were made from the proportions derived from weighted strata means.

Forest Resource Inventory

A random-systematic double sample was used to estimate deciduous and coniferous forest area in nine counties. Color composites of one May 1975 LANDSAT image were enlarged to 1:125,000 scale and conifer, deciduous, nonforest and water area estimated from a large number of 16-point sample clusters. County estimates of total forest area were within 10 percent of estimates made by a concurrent operational

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[2] All estimates in this study were made at the 67 percent confidence level.

inventory. The difference was only 0.8 percent when total forest area for all nine counties were combined. Deciduous and conifer areas were estimated for each county with sampling errors ranging from 7 to 48 percent. For all counties, the sampling errors were 3.7 and 6.7 percent respectively for the deciduous and the conifer areas. The LANDSAT technique resulted in sampling errors 2 to 3.5 times larger than sampling errors for the operational inventory. Sampling errors for deciduous and conifer cubic-foot volume estimates were 10.2 and 8.7 percent respectively. Cost of the LANDSAT technique was 1.46 times the cost of operational photo interpretation techniques.

Computer Aided Inventory

A computer aided inventory utilizing LANDSAT digital data to determine the area of conifer forest, hardwood forest, nonforest, and water was made for a nine county area of the Virginia coastal plain. The inventory was performed using a combination of unsupervised and supervised classification methods. Unsupervised clustering partitioned the data into clusters such that there is greater spectral similarity within clusters than among clusters, thus defining groups of data that can be differentiated one from another. The clusters were then identified as ground cover types. Statistics from these clusters were input to a supervised classification program which classified the data into those ground cover types. These were then aggregated into conifer, hardwood, nonforest, and water.

For three counties all data was classified. For all nine counties a seventeen percent sample was classified. Sampling errors at the sixty-eight percent confidence level were less than one percent for any county. Forest area estimates by county differed by as much as twenty-one percent from the concurrent Forest Survey estimate. For the nine county area the two forest area estimates differed by less than one percent.

Measuring Solar and Atmospheric Effects

An empirical method was developed to measure solar and atmospheric effects in LANDSAT data by comparing LANDSAT MSS data with terrain reflectance. Terrain reflectance was measured with a Forest Service designed and built four-channel radiometer capable of measuring radiance in the LANDSAT MSS matched wavelength bands. Reflectance of many terrain elements which could be registed to the LANDSAT digital data were measured from a low-flying aircraft. LANDSAT radiance was fitted to reflectance by regression techniques to find coefficients that represent path radiance and the product of solar irradiance on the ground and vertical transmittance T of the atmosphere. The instruments included a digital data logger, a four-channel radiometer, an irradiance meter, and a video camera with recorder.

Five subsites within the Virginia test site were used in the study. All subsites included plowed fields, agricultural crops, conifer, deciduous and mixed conifer-deciduous stands. Clearcut areas were present in all but one subsite. In addition to aerial radiance measurements, concurrent irradiance measurements were taken on the ground at two subsites.

This study concluded that there was substantial evidence for the validity of a linear atmospheric model with an additive (path radiance) term and a multiplicative (transmittance) term. A demonstration of the usefulness of signature extension with this technique requires data sets with greater haze variations than were encountered on the two dates studied.

INTRODUCTION

Recent legislation by the Congress of the United States makes it mandatory that present and potential renewable resources be assessed periodically.[1] The assessment must include a renewable resource inventory, an evaluation of opportunities for improving yields of both tangible and intangible goods and services, and national programs to meet short and long term production goals for meeting the needs of the people.

National assessments require lower resolution resource inventory data than local assessments where management programs must be carried out. Arguments for localized intensive management inventories as opposed to broad based extensive National inventories are irrelevant. Each has its own place. The two inventory systems should, however, compliment one another using multi-level sampling and standard vegetation, soils, and water and land-form terminology.

Multi-level sampling, with LANDSAT or other remotely sensed data providing the first level of information, can be useful in both National and local management inventories. For LANDSAT data to be of value; (1) it must be as accurate as other sources of the same information, (2) it must provide information not available from other sources, and (3) it must be cost effective. This report addresses each of these requirements and attempts to evaluate LANDSAT in quasi-operational situations.

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[1]The "Forest and Rangeland Renewable Resources Planning Act of 1974"; Public Law 93-378, 93rd Congress, S. 2296; August 17, 1974.

Objectives

The primary objective of this investigation was to test the feasibility of using remotely sensed data, i.e., LANDSAT and high-flight aircraft data, with ground data in a multi-stage sampling concept to locate and monitor forest resources. A secondary objective was to integrate resource inventory data into an operational decision-making instrument to assist in the overall management of the forest in the region studied.

To fulfill the primary and secondary objectives of this investigation, several sub-objectives were required. These sub-objectives were as follows:

1. Measure gross and net timber volume for deciduous and conifer types by county and group of counties.
2. Measure forest area and area of water in each county and group of counties.
3. Classify and map land cover types for a portion of the region, delineate forest area, and show residential and industrial encroachment.
4. Use slope, aspect, and elevation, soil type, precipitation near and long-range patterns; and erosion hazard ratings to assess the impact of disturbance in the forest.
5. Inventory water as a function of utility; i.e., recreational, residential, or industrial.
6. Make a cost-benefit analysis comparing current and recommended methods for forest inventory.
7. Determine the optimum combination of man/machine analysis to maximize the efficiency of the overall data analysis.

Several sub-objectives could not be satisfied within the time frame of this investigation. For instance, only net timber volume is reported because we felt that gross volumes would add very little to the management plan. Slope, aspect, and elevation overlays, and erosion hazard ratings were not completed. In defense of this decision we were advised by our Engineering Division that Defense Mapping Agency (DMA) topographic data tapes would have 100-foot horizontal and 50-foot vertical errors. Errors of this magnitude would mask out significant differences in this coastal plain test site (elevation range is from 0 to 250 foot). The study of residential and industrial encroachment on forest land could not be completed. This study required the use of registered LANDSAT temporal data for which we had insufficient time and personnel to assign the developmental work. These incomplete sub-objectives are considered important for monitoring renewable resources. For this reason, the Forest Service will continue research and development in these problem areas.

Background

Interest in renewable resource inventories aided by remote sensing from space and high altitude has increased in recent years. This interest was brought about by a need for more information; (1) to help land managers resolve land use conflicts, (2) to assess the present and potential supply of renewable resources, and (3) to plan programs that will provide a continuing supply of goods and services to meet the public's needs. A literature review will show that there are good possibilities for acquiring some information using multi-level sampling (multi-phase, multi-stage, or combinations of the two) with remote sensing.

In 1969, photographs taken by Apollo 9 astronauts covering 10-million acres in Arkansas, Georgia, Louisiana and Mississippi provided the first level of information to estimate total timber volume in a stratified five-stage variable probability sampling design (Langley and others 1969). In multi-stage, or multi-level sampling designs, aerial photography could provide this first level of information or it could provide one or more links between space acquired data and the ground. Tests of conventional photo interpretation on high altitude color and color infrared (CIR) photographs between 1970 and 1972 (Aldrich and Greentree 1972) indicated that forest land can be separated from non-forest land on 1:120,000 scale CIR photographs with 96 to 100 percent accuracy depending on the season of photography. Also, seasonal separation between pine and hardwood types was 70 to 85 percent successful, but mixed pine/hardwood can not be reliably classified according to strict Forest Service standards. The mixed class must be combined with pine type for the information to be most effectively used by managers.

With the launching of ERTS-1 (LANDSAT-1) in July 1972, a large number of earth resources survey investigations were undertaken under NASA sponsorship. Very few of these investigations were forestry oriented. The forestry oriented investigations for the largest part dealt with evaluating LANDSAT data for resource mapping. Mapping, or delineating class boundaries, is not relevant to the present investigation. Differentiating and classifying cover-classes at systematically spaced sample points, however, is relevant to both this investigation and broad based National renewable resource assessments as well.

Before LANDSAT can find its proper role in national renewable resource inventories, the possibilities and limitations of low resolution data in broad based extensive inventory designs must be fully understood. Several critical evaluations have already been made. For instance, Erb (1974) found that stands of pine 10 acres (4 hectares) and larger were detectable and that the smallest feature of any kind that could be detected on LANDSAT data was 2.5 acres (1-hectare). From his evaluation, Erb made this conclusion, "ERTS data can probably best be used in forestry applications if the data are used for extensive surveys in which broad generalized classes are needed rather than for intensive surveys in which detailed stand conditions must be portrayed". Heller (1975) reported similar results. His evaluations showed that land use classes such as forest, or non-forest and range vegetation classes at the Regional level, were distinguishable with 95 percent accuracy on LANDSAT data. Further break downs of cover types was not successful except where the cover was disturbed. Forest clearings and cutting operations, as small as 2 to 3 acres (.8 to 1.2 hectares), can be detected by comparing LANDSAT temporal data or LANDSAT photographic color composites with six year old aerial photographs (Aldrich, 1975). Both Heller and Erb (1974) indicated that computer aided classification of cover types was the most effective method although human interpretation was equally accurate. The choice of method depends on the availability of trained people and equipment.

The University of California Berkeley has made a number of quasi operational timber volume inventories with multi-stage sample designs and remote sensing (Nichols and others 1975, Titus and others 1975, Colwell and others 1976). In each of these inventories, LANDSAT was used to provide the first level of information for selecting first stage samples. High altitude and large scale photographs provided information at other stages. Two inventory studies conducted on the Plumas National Forest in California were successful in terms of increasing the sampling efficiency. In the third, an inventory of the Sam Houston National Forest in Texas, LANDSAT data were not useful because of extreme homogeniety of topographic and vegetative conditions.

The Skylab (EREP) experiment in 1973, offered the opportunity to use high resolution color photographs in quasi operational inventory studies near Augusta, Georgia (Aldrich and others 1976). In one study, systematic sampling for forest area proportions always resulted in lower variance than simple random sampling. Systematic sampling with post-sampling stratification using digitized Skylab photographic data resulted in the lowest variance. A systematic large area cluster sample on enlarged Skylab photographs, adjusted using regression techniques, resulted in a forest proportion for one county that was 5 percent higher than a Forest Service inventory completed in 1972. The sampling errors of the two inventories, however, were very similar.

Study Area

The study site lies in the northern coastal plain northeast of Richmond and southeast of Fredricksburg, Virginia (fig. 1). It includes nine counties bounded on the north by the Potomac River, on the south by the Mattaponi and York Rivers, and on the east by the Chesapeake Bay. The Rappahannock River and many tributaries cut the area into a gentle landscape of undulating to rolling hills. Most of the elevations lie between sea level and 200 feet (61 meters). Soils are for the greatest part moist, except during the warm season when some may dry out. Most soils have a shallow to deep subsurface of clay accumulations.

The area is approximately 60 percent forested, primarily in farm woodlots and some larger private holdings. Forest cover types include

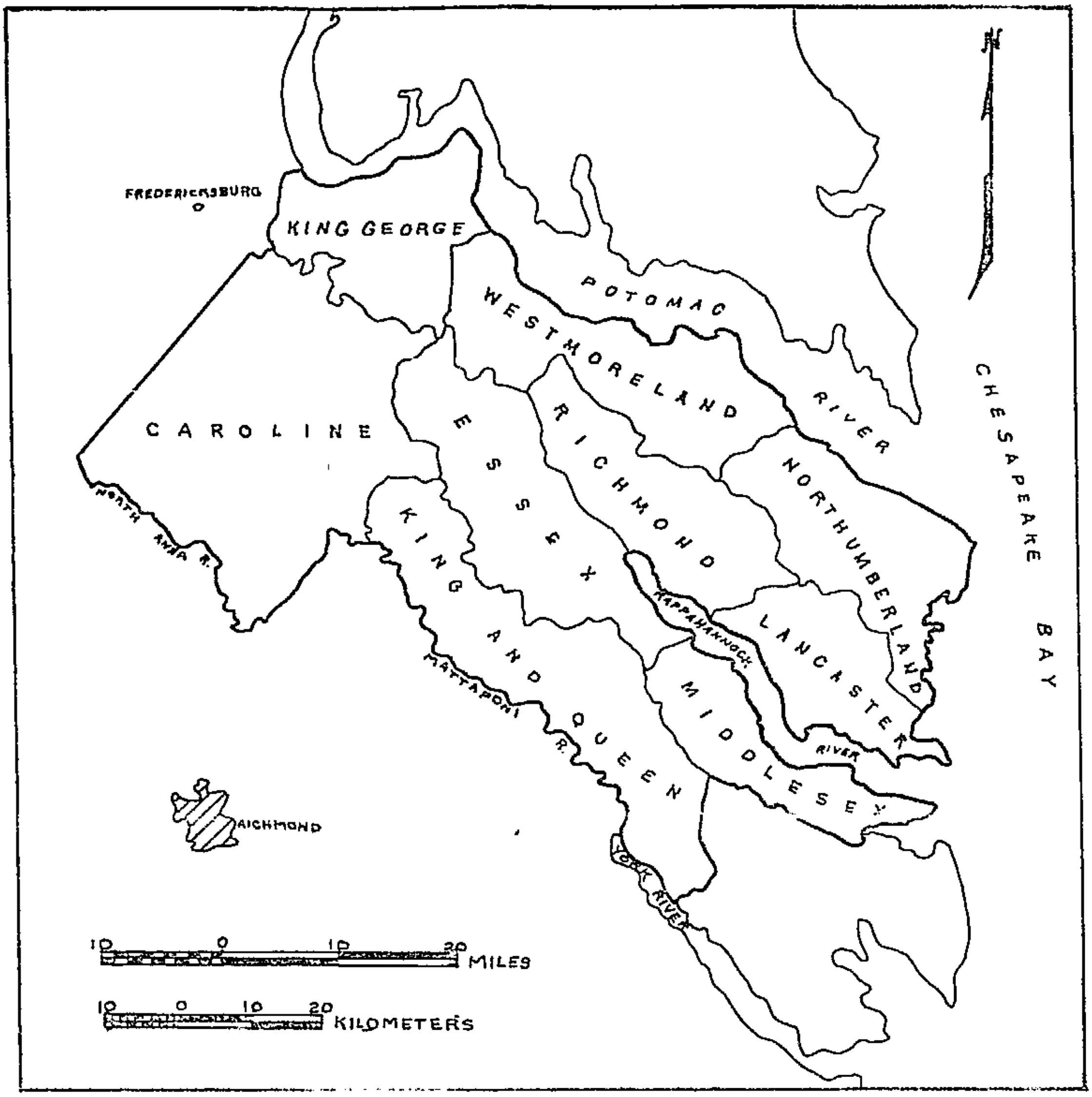

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Figure 1.---The nine county study site is in the northern coastal plain of Virginia. King George, Lancaster and Northumberland Counties were used for computer aided classification of cover types, soil maps, and a water inventory.

loblolly-shortleaf pine, oak-pine, oak-hickory, and oak-gum-cypress. Non-forest areas are primarily pasture with some hay, corn, and small grain crops. Since there are no Federal or State owned forests or parks within the site, recreational opportunities are scarce. However, the Potomac River and Chesapeake Bay do offer opportunities for swimming, boating, and fishing.

Some of the studies reported here were carried out within three counties ---King George, Lancaster, and Northumberland. This was because soils maps needed to develop resource management plans were unavailable for the remaining six counties.

Data Used

Remotely sensed data used in this investigation included bulk LANDSAT I and II MSS photographic and computer compatible tapes, U-2 high altitude CIR photographs, Agricultural Stabilization and Conservation Service (ASCS) photographs, radiance measurements made with a Forest Service airborne four-band radiometer, and field measurements of solar irradiance and sky radiance. Table 1 lists the remote sensing data used by data source, study, date, and quality.

LANDSAT photographic data were either received through a standing order with the Western Photographic Laboratory, ASCS, Salt Lake City or selected from LANDSAT U.S. Standard Catalogs (NASA, Goddard Space Flight Center). To be useful, these data had to (1) conform with timing of the on-going Forest Survey in the area, (2) be within a good season for interpretation and classification, (3) provide complete coverage of the study site, and (4) be cloud free. Also, base date for the investigation had to be within a few days of the high altitude photographic mission (May 8, 1975).

Table 1.--Remotely sensed data used in inventory studies by data source, date, and quality.

Data Source	Date	Inventory Studies	Data Type	Electromagnetic Bands	Quality
LANDSAT I					
5339-14344	March 23, 1976	Water Resource Inventory	Photographic (panchromatic)	.8-1.1 μm (IR)	Good
5340 14395	March 24, 1976	Water Resource Inventory	Photographic (panchromatic)	.8-1.1 μm (IR)	Good
LANDSAT II					
2122-15074	May 14, 1975	Forest Inventory	Photographic (combined color)	.5-.6 μm (Green)	Good
2122-15081			1:125,000	.6-.7 μm (Red)	
			CCT'S	.7-.8 μm (IR)	
				.8-1.1 μm (IR)	
2274-15062	October 23, 1975	Water Resource Inventory	Photographic (panchromatic)	.6-.7 μm (Red)	Good
2275-15065			1:125,000		
2310-15060	November 28,1975	Water Resource Inventory	Photographic (panchromatic)	.8-1.1 μm (IR)	Good
2310-15062			1:125,000		

Table 1.--Continued

Data Source	Date	Inventory Studies	Data Type	Electromagnetic Bands	Quality
2453-14574 2454-15030 15032	April 19, 1976 April 20, 1976	Solar and Atmospheric Corrections	CCT'S	All Bands	Good
U-2 Mission					
75-056A	May 8, 1975	Forest Inventory	Photographic (CIR)	.4-.8 μm	Good
		Water Inventory	1:125,000		
		Solar and Atmospheric Corrections			
ASCS (Aerial Photographs	1969-1972	Forest Inventory	Photographic (panchromatic) 1:20,000	.4-.7 μm	Fair
Forest Service (Ground and Air	October 23, 1975	Solar and Atmospheric Corrections	Radiometer (total ground irradiance and sky radiation)	400-1125 nm	Good
	April 23-24,1976	Solar and Atmospheric Corrections	Radiometer (total ground irradiance and sky radiation)	400-1125 nm	Good
			Four-Band Radiometer	.5-.6 μm (Green) .6-.7 μm (Red) .7-.8 μm (IR) .8-1.0 μm (IR)	Good

All LANDSAT data prior to May 14, 1975 included only small portions of the study site. In many instances the data also included cloud cover. Thus the first opportunity for acceptable data was over two months after the start of the contract. The photographic data and CCT'S, however, were not received until several weeks later.

The high altitude photographic mission was originally requested for the period April 1 to May 31, 1975. This period was considered acceptable for capturing differences in phenological development for ground cover classes. The photographs were taken in early May and color transparencies and prints received from the ASCS Western Photo Lab in August. It was October, however, before the photographs were judged to be acceptable in quality.

Base maps for both area and point control data included USGS 1:250,000 topographic sheets and USGS 7½ minute quadrangle map sheets. General Soils Maps produced by the Soil Conservation Service were used to produce soil association overlays for resource cover maps.

Climatic data were summarized from monthly Climatological Data reports from the Environmental Data Service, National Oceanic and Atmospheric Administration (NOAA).

FOREST AND WATER INVENTORY BY CONVENTIONAL PHOTO INTERPRETATION

by

Robert C. Aldrich and Wallace J. Greentree

Introduction

There is a place in resource management for conventional photo interpretation by highly skilled photo interpreters. Any allusion that machines, trained by machine operators, will inventory and map the resources in the future is pure speculation. Resource managers well versed in resource interpretation will either use machines or conventional photo interpretation to help them inventory and map the resources.

Most resource managers will be disappointed to find that sophisticated computer programs and peripheral computer devices are either not available, are too expensive to use, or their own computers (if they have one) are not compatible with the systems. On the-other-hand, conventional photographic interpretation techniques result in equal or better accuracy, they are less expensive, and they are simple to use. One disadvantage is that conventional interpretation will usually require more time to complete the work (Aldrich 1976). If the information to be obtained is absolutely necessary, however, the additional time will not be that important.

In this portion of the report we will show how photographic interpretation of LANDSAT data was used to measure water and forest resources in two separate inventory schemes.

Water Resource Inventory

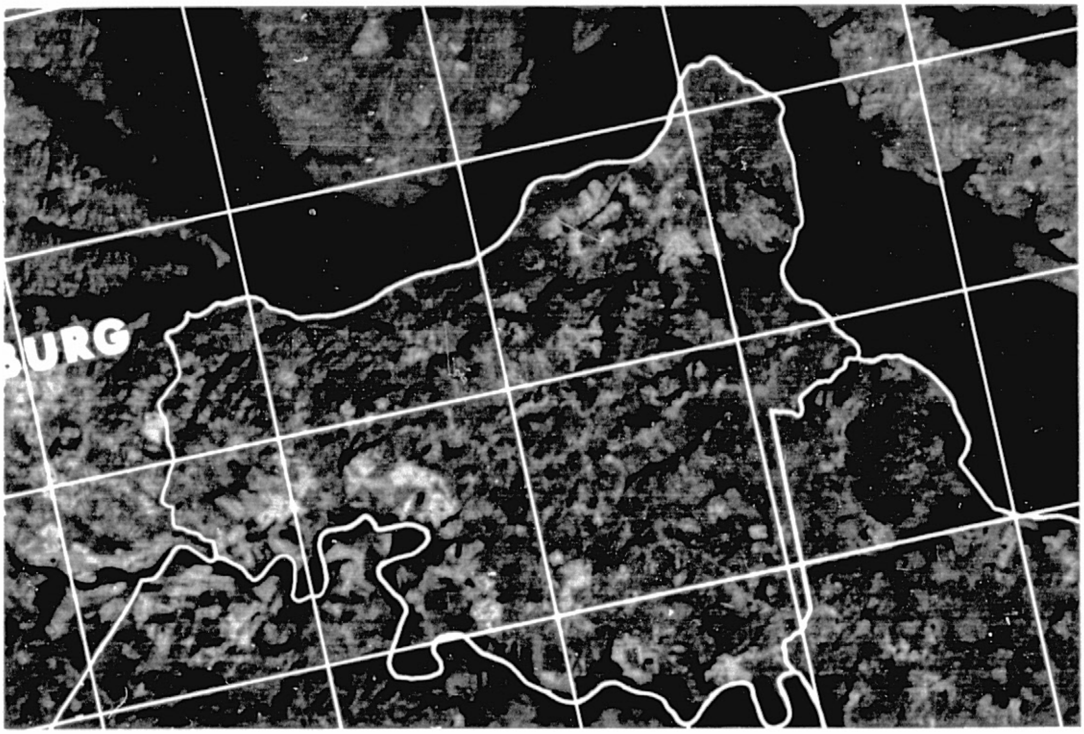
Knowing how much, the quality, the use, and where water resources are located is important information for a water data base. This information should be important in identifying areas desirable for outdoor recreation activities, management of range and wildlife, industrial development, and for monitoring non-point sources of pollution. In other words, availability of water is important in the management of land and in making land-use decision.

The smaller the land management unit the greater the need for in-place resource information. This water inventory study investigated the use of LANDSAT photographic data to inventory water for individual counties. The objective was to provide county managers with information that could be coupled with soils, climate, vegetation, and population information to manage the land and water resources. Three counties are included in the inventory---King George, Lancaster, and Northumberland (fig. 1).

Techniques and Procedures

The water resource inventory sampling design is a stratified random double sample (two phase). All visible bodies of water are enumerated on LANDSAT, stratified by size class, and subsampled on U-2 color infrared (CIR) aerial photographs. Total water estimates were computed by expanding the U-2 subsample means.

All streams and wide water bodies within a county boundary were delineated on 1:125,000 scale enlargements of LANDSAT Band 7 for scenes 2310-15060 and 2310-15062, November 28, 1975 (fig. 2). Band 5 for the November scene was not recorded, therefore Band 5 for scenes 2274-15062



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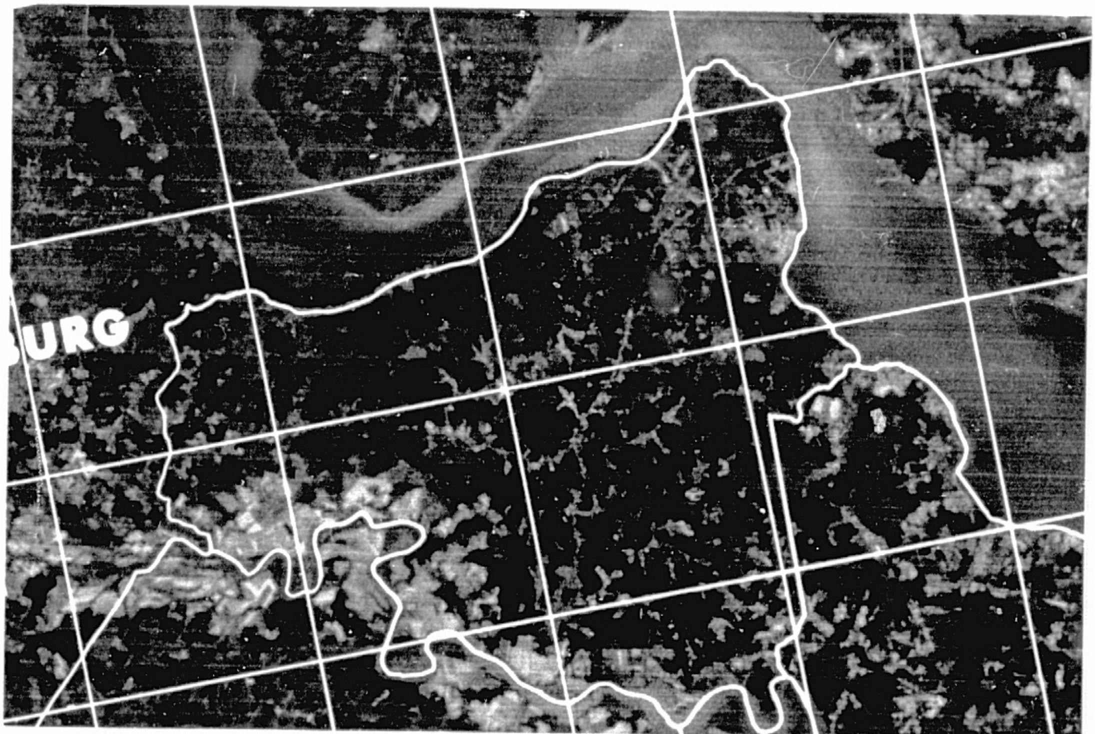

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Figure 2. LANDSAT (Band 7) Scene 2310-15062, November 28, 1975 (a), and (Band 5) Scene 2275-15065, October 23, 1975 (b), were enlarged to 1:125,000 scale for interpretation and mapping water resources; King George County.

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and 2274-15065, October 23, 1975, were substituted for additional thematic and cultural information. County boundaries and 10,000 meter Universal Tranverse Mercator (UTM) grid lines were drawn from 1:250,000 topographic map sheets. The outlines were photographed, enlarged to fit the LANDSAT image and taped in place.

The LANDSAT scenes for the November and October dates were examined together with the aid of a scanning stereoscope. Boundaries of lakes, reservoirs, ponds and other wide surface water bodies were drawn on clear stabilene material in India ink (fig. 3). Streams, canals, and other narrow bodies of water were drawn on the stabilene material using a single dashed line.

The length of streams and area of surface water bodies within 1 kilometer (.62 mile) square cells within 10 X 10 kilometer UTM grid cells were measured using a metric rule. Surface water was measured to the nearest 0.5 mm^2 (0.02 $inches^2$) and stream lengths to the nearest 0.5 mm (0.02 inches). The totals for each cell were recorded and identified by each 10,000 meter UTM cell and grid location. Cell locations were necessary to relocate samples in the second phase of the sample design. The data were punched for computer analysis.

A computer program was written to stratify the total population of sample cells into seven strata based on stream length and surface water area (table 2). Then samples were randomly selected within these strata for the photo interpretation phase of the sample design. The number of samples selected in each strata was arbitrary (table 2). We wanted a sufficient number in each strata to keep sample variation within strata at a minimum yet we could not afford to over sample because of time restrictions.

The samples were located by 1 kilometer (.62 mile) cell number on 1:24,000 map sheets that had been up-dated from May 8, 1975 U-2 CIR

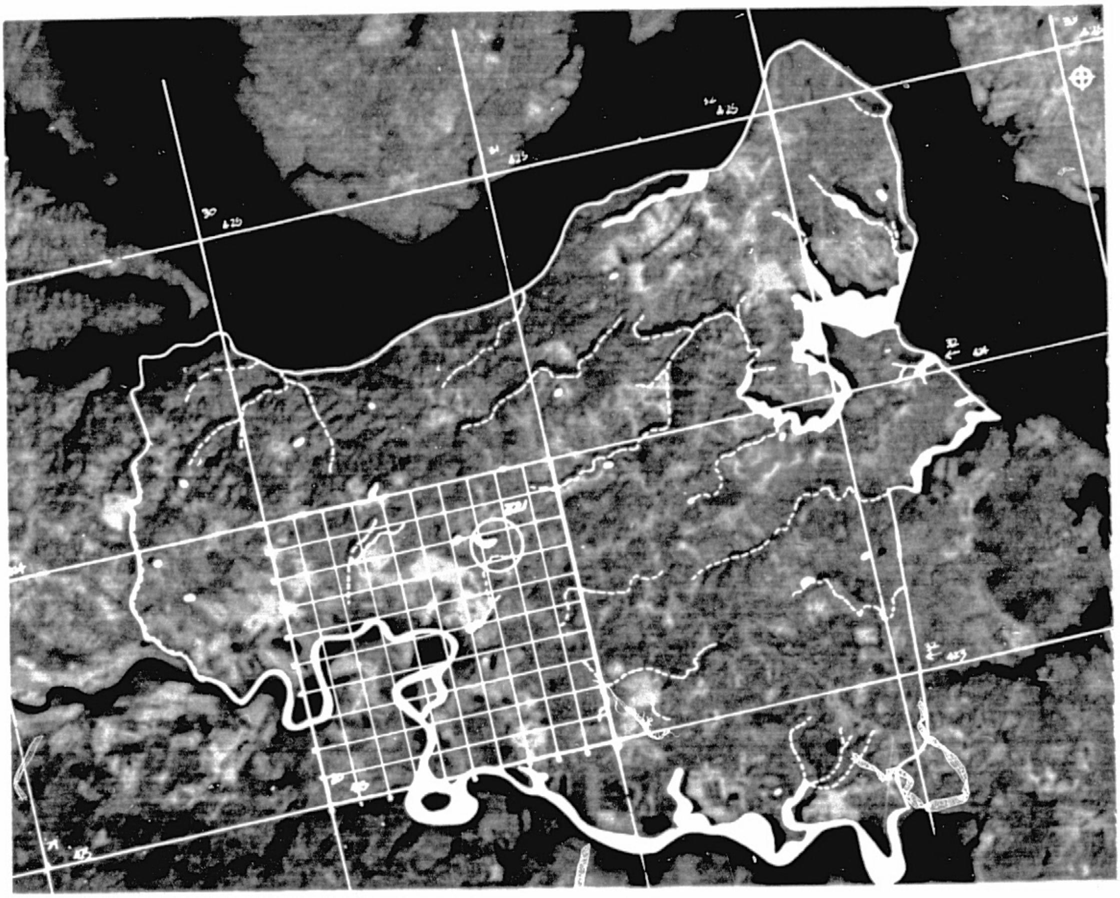

Figure 3. Boundaries of lakes, reservoirs, ponds, estuaries, and rivers as well as streams and canals were delineated on the LANDSAT enlargement using a stabilene material and India ink. The large cells in the illustration are defined by the 10,000 meter UTM projection system; the smaller 1,000 meter cells form the sampling frame. Circled cell number 321 is one of the stratified random samples examined on high altitude CIR photos and USGS maps.

Table 2.--Total number of LANDSAT sample cells (the sample frame) and U-2 photo samples by seven defined water strata; three counties.

Strata	Strata Definition	County							
		King George		Lancaster		Northumberland		All Counties	
		LANDSAT Cells	U-2 Sample	LANDSAT Cells	U-2 Sample	LANDSAT Cells	U-2 Sample	LANDSAT Cells	U-2 Sample
1	No streams and no water bodies	263	30	122	30	190	30	575	90
2	0.1 to 10 mm of streams and 0.1 to 1.0 mm^2 water bodies	20	15	25	15	33	20	78	50
3	0.1 to 10 mm of streams and 1.1 to 16 mm^2 water bodies	110	29	119	29	161	30	390	88
4	0.1 to 10 mm of streams and over 16 mm^2 water bodies	39	15	178	30	113	25	330	70
5	0.1 to 10 mm of streams and no water bodies	90	30	73	20	95	25	258	75
6	Over 10 mm of streams and less than 16 mm^2 water bodies	17	10	12	12	18	10	47	32
7	Over 10 mm of streams and over 16 mm^2 water bodies	5	5	2	2	6	6	13	13
	Total	544	134	531	138	616	146	1691	418

photographs. With a zoom transfer scope, the U-2 photo images were superimposed on 1:24,000 map sheets while stream length and surface water bodies were accurately measured within each subsample (fig. 4). Transparent wedge micrometers were used for stream length measurements to the nearest .01 inch (.004 mm). Areas were measured with a high density dot grid (144 dots per square inch). Stream length was converted to kilometers and water surface area to hectares. Individual streams and bodies of water were identified by number and their length and area recorded.

Each numbered body of water (stream or water body) was closely examined on the CIR photo and given four different classifications: (1) water resource class, (2) water size class, (3) water utility class, and (4) accessibility class (table 3). These classes should give the land manager some idea of the availability and potential utility of water resources in each county. Data for each county were punched for computer analysis.

Water utility was the most difficult class to assign. This classification was a subjective judgement made by the photo interpreter based upon visible evidence such as land use patterns, buildings, activities in the area, and associations between the evidence. To check utility, 50 samples were systematically selected to examine on the ground. In the time allotted it was possible to visit only 44. Each ground sample was described in writing and a color photograph taken for evaluation.

Results

The results of this inventory are experimental. We have attempted to verify our estimates of surface water by comparing them with Bureau of

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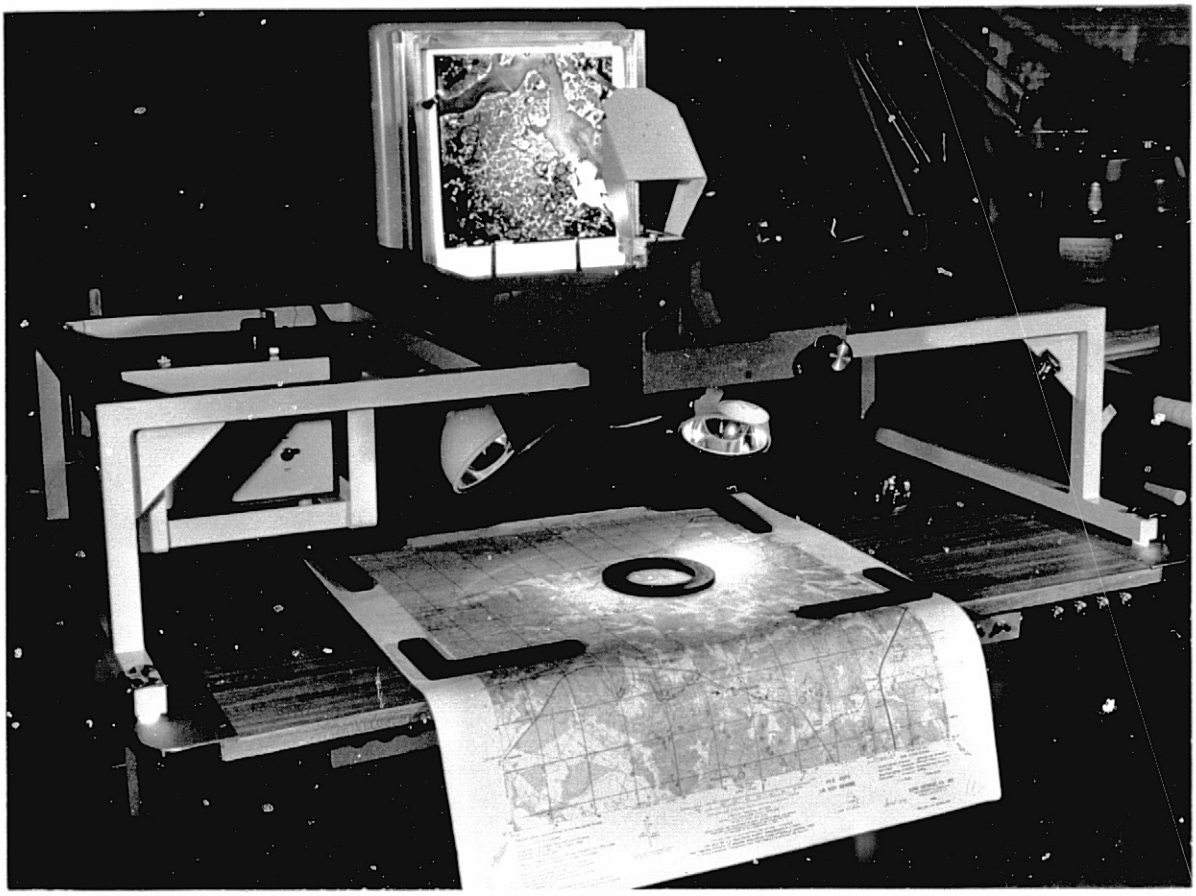

Figure 4. A zoom transfer scope was used to examine water bodies in 1 kilometer (.62 miles) square subsample cells on 1:120.000 scale U-2 CIR photographs and 1:24,000 USGS quadrangle map sheets.

Table 3.--Water resource classifications.

Classification	Class Code	Definition
Water Resource Class	53	streams and rivers
	54	sloughs, estuaries, and canals
	55	water impounded in reservoirs, lakes and ponds
Water Size Class		
Streams, sloughs, estuaries and canals	1	less than 10-meters wide
	2	10 to 100-meters wide
	3	100-meters to 1/8th mile wide
	4	Over 1/8th mile wide
Reservoirs, lakes, and ponds	5	less than 10-meters in diameter
	6	10 to 100-meters in diameter
	7	100-meters in diameter to 40 acres in size
	8	Over 40 acres in size
Water Utility Class	0	intermittent stream
	1	navigation
	2	recreation
	3	residential
	4	farm
	5	fisheries
	6	industrial
	7	unknown

Table 3.--Continued

Classification	Class Code	Definition
Accessibility Class	0	intermittent stream
	1	less than 100 meters to road
	2	101 to 300 meters to road
	3	301 to 1,000 meters to road
	4	More than 1,000 meters to road

the Census[2] statistics for inland water, however, variations in locating county boundaries and differences in defining inland water make the comparison suspect. These results are, however, compared rather favorably with estimates derived by other means in another section of the report and in Appendix A. Problems that arise when measuring water to meet a National standard are discussed as well.

Stratified Random Sampling

The county water resource inventory data indicate that, although two out of the three county estimates showed a slight gain in sampling efficiency using stratified random sampling, the gain in efficiency was too small to be significant (table 4). Standard errors of the sample cell means by county ranged from ±8.1 to ±9.4 percent for water-ways and from ±10.7 to ±59.4 percent for surface water at the 67 percent confidence level (1 standard deviation).

When length of water-way data for individual counties were combined, the standard errors of the sample cell means for stratified random sampling remained greater than for simple random sampling (table 4). However, the error was reduced to 7.6 percent by combining data. Stratified random sampling was 6 times more efficient than random sampling for combined surface water. We concluded from these results that under the conditions defined by this study, stratification of water populations on LANDSAT photographic data is beneficial for estimating surface water. However, because of problems in defining and delineating water-ways, stratification is not effective and does

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[2]The U. S. Bureau of the Census, Land and Water Area of the United States: 1970.

Table 4.--Mean length of water-ways and mean surface water area per square kilometer by county and standard errors of the means for both stratified and simple random sampling; according to Cochran (1953).

County	Length of Water-ways[1]			Surface water area[2]		
	Sample Cell Mean[4]	Standard error[3] Stratified	Standard error[3] Random	Sample Cell Mean	Standard error Stratified	Standard error Random
	Meters			Hectares		
King George	705.6	±66.7	±54.6	3.2	± 1.9	± 0.8
Northumberland	713.3	±57.7	±62.4	10.6	± 1.3	± 1.5
Lancaster	737.3	±60.4	±62.1	22.5	± 2.4	± 2.7
Combined Counties	695.7	±52.8	±51.7	11.1	±0.38	±2.43

[1] Rivers, streams, estuaries, canals, sloughs

[2] Reservoirs, lakes and ponds, and estuaries, sloughs, and rivers over 100 meters wide.

[3] 67 percent probability level

[4] A sample cell is 1-kilometer square.

not reduce population variation. As a result, stratified random sampling for both water-ways and surface water combined does not improve sampling efficiency. This does not mean, however, that better definition of water strata, better LANDSAT photo data, and better allocation of samples to the strata will not improve effectiveness of the sampling and increase sampling efficiency. Regardless, LANDSAT is a useful base for defining and enumerating the total population units for simple random sampling.

Water Comparisons

Total estimated length of water-ways and total surface water area were computed for the three sample counties (table 5). Surface water is compared with the Bureau of the Census statistics for counties (table 6). Discrepancies between the two sets of figures are caused by differences in locating county boundaries that follow water lines or the measurement and estimating procedures used in the two inventory systems.

Size Distribution

Of all the reported water-ways in each county, the greatest number are intermittent streams running only during the wet season (table 7). These stream beds are included in the less-than 10 meter (32.8 feet) wide class and were measured by the sample on aerial photographs and USGS map sheets. Intermittent streams represent about 47 percent of the reported total. Streams and rivers 11 meters (36 feet) up to 1/8th mile (201 meters) wide represent approximately 43 percent of the total; only 15 percent of these represent rivers over 100 meters (328 feet) but less than 1/8th mile (201 meters) wide. The remaining water-ways (10 percent) were over 1/8th mile wide and represent water defined by the Bureau of the Census as "Inland Water".

Table 5.--Total length of water-ways and area of surface water by county.

County	Water Resource			
	Water-ways[1]	SE	Surface Water Area[2]	SE
	- - Kilometers - -		- - - - - Hectares - - - - - -	
King George	384	±36	1,741	±1,034
Lancaster	392	±32	11,947	±1,274
Northumberland	439	±36	6,529	± 800
All Counties	1,215	±92	20,217	± 687

[1]includes rivers, streams, estuaries, canals, sloughs

[2]includes estuaries, rivers, sloughs, canals over 100 meters wide, and reservoirs, lakes, ponds.

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Table 6.--Area of water defined by Bureau of Census compared with surface water area defined by LANDSAT stratified sample; three counties.

County	Open Water[1] Bureau of Census	Surface Water[2] LANDSAT	Difference	
	- - - - - - - - - -	-Hectares-	- - - - - - - -	- -Percent- -
King George	1813	1741	-72	-4.0
Lancaster	4144	11,947	+7803	+188.3
Northumberland	8547	6529	-2018	- 23.6

[1]includes streams, rivers, sloughs and estuaries more than 1/8th of a statute mile wide (201 meters) and lakes, reservoirs, and ponds over 40 acres in size (16.19 hectares).

[2]includes all measurable surface water area.

Table 7.--Length of Rivers and Streams by size class, by County.

County	Length of Rivers & Streams[1]	Water Size Class			
		Less than 10m	11 to 100m	101m to 1/8 mile	Greater than 1/8th mile
	-Kilometers-				
King George	384	184	165	22	13
Lancaster	392	183	124	29	56
Northumberland	439	200	158	30	51
All Counties	1215	567	447	81	120

[1]includes estuaries, canals, sloughs, and intermittent streams.

Looking at the figures in Table 7 it is apparent that the counties are similar in distribution of water-ways under 1/8th mile wide. Only in the greater than 1/8th mile (201 meters) wide category do they differ to a great extent. For instance, Lancaster County with the Rappahanock River as one boundary has the largest total in this category. King George has the lowest total because the County boundary on its north follows the shore-line of the Potomac River rather than bisecting the River. Northumberland, like Lancaster, includes the mouths of several large tributaries opening into the Chesapeake Bay.

Surface water area in both Lancaster and Northumberland reflect the large rivers and bays within their boundaries (table 8). Of 11,947 hectares (29,521 acres) in Lancaster County, 35 percent are in bodies of water over 40 acres (16.2 hectares) in size. This area (4217 hectares or 10,420 acres) should agree with the Bureau of the Census figure for "Inland Water", however, it is 151 percent higher. As explained before, this is primarily due to the County line bisecting the Rappahanock River. By definition, the Bureau of Census recognizes this water as "water other-than-inland water" and considers it in the Chesapeake Bay.

Surface water in King George County is very limited when compared with the other counties.

Accessibility

Accessibility, or how available water is to man and animals, should be important in land management. Remote sensing can probably provide this information better than any other source. For instance, in this study accessibility was measured on the photo subsample by nearness to a road. Other references such as nearest developed area (urban), farm, or pasture, or whether a water body is within some fixed radius of a point, might have been used as well.

Table 8.--Surface water area in reservoirs, lakes, ponds, sloughs, estuaries and rivers by size class, and by county.[1]

County	Surface Area	Surface area classes			
		Less than 10m[2]	11 to 100m[2]	100m to 40 acres	Greater than 40 acres
	- Hectares -				
King George	1,741	0	926	574	241
Lancaster	11,947	0	4,518	3,212	4,217
Northumberland	6,529	0	2,350	2,089	2,090
Total	20,217	0	7,794	5,875	6,548

[1]includes sloughs, estuaries and rivers over 100 meters wide (class 3 and 4).

[2]diameter

Table 9 gives some indication of how accessible water is in each county. For instance, very few (6 percent) of the active rivers and streams are over 1,000 meters (3280 feet) from the nearest road. Thirty-two percent are within 100 meters (328 feet) which makes them extremely accessible for recreational pursuits of one form or another. Almost two-thirds of the sloughs, estuaries and canals are within 100 meters (328 feet) of a road and could be used for boating related recreation if owners of the land would allow access. This would also be true of almost 50 percent of the water impounded in lakes, ponds and reservoirs as well.

Since the distance to a road is measured on USGS map sheets up-dated using recent aerial photography, the accuracy of these measurements is better than could be obtained by almost any other method. The real problem to management would be to obtain access rights to the water for public use.

Utility

Photo interpreters need a strong background in water use as well as interpretation aids to interpret the utility of a particular body of water. Size, shape, general location, clarity of the water, landform, vegetation and other individual and associated factors contribute to the interpretation. It is a subjective classification but can lead to some useful information for the land manager.

Every body of water has one or more possible uses. In table 10, water has been classified into seven general classes according to what the photo interpreter considered the primary utility. Secondary and tertiary classifications are not given because they would add little to a meaningful analysis of the data.

There are 653 kilometers of water-ways in the three counties. Sixty-nine percent of these are between 11 meters (36 feet) and 100 meters

Table 9.--Percentage of water observed in each county by water resource accessibility class.

Resource Class	Accessibility Class[1]	King George	Lancaster	Northumberland	All Counties
		- - - - - - - - - - - - Percent	- - - - - - - - - - - - -		
Rivers and streams[2]	Less than 100 meters	35	30	30	32
	101-300 meters	27	21	25	25
	301-1000 meters	33	39	42	37
	Greater than 1000 meters	5	10	3	6
Sloughs, estuaries, and canals	Less than 100 meters	42	80	63	64
	101-300 meters	9	10	20	14
	301-1000 meters	42	7	16	19
	Greater than 1000 meters	7	3	1	3
Lakes, ponds and reservoirs	Less than 100 meters	45	51	52	49
	101-300 meters	26	33	29	29
	301-1000 meters	29	16	19	22
	Greater than 1000 meters	0	0	0	0

[1]Distance measured from stream to nearest road.

[2]Does not include intermittent streams.

(328 feet) wide. Recreational use was assigned to 63 percent of all water-ways---91 percent of these are in the 11 meters (36 feet) to 100 meters (328 feet) size class. Streams over 1/8th mile wide (201 meters) account for 69 percent of all streams classified for navigation. Navigation and recreation together account for 84 percent of the water-ways in the three county area. This large percentage is due primarily to a low non-urban population and few, if any, heavy industries. Residential, farm and fisheries uses make up only 13 percent of the total.

Surface water area is defined as all measurable water area including streams and rivers. Navigation was assigned to 33 percent of all the surface water in the three counties---70 percent of these were over 40 acres (16.2 hectares) in size. Ninety-one percent of water classified for recreation is between 11 meters (36 feet) wide and 40 acres (16.2 hectares) in area. Recreation accounts for 35 percent of all the surface water use. As with water-ways, navigation and recreation account for the largest percentage of the surface water. Residential and farm use account for an additional 18 percent.

Because of rural populations and little industrial activity there are few major sources of water pollution in the three counties. However, non-point sources of sediment from agriculture lands and poor land use practices up-stream from the study site can be detected by tonal variations in water.

Ground Assessment

Forty-four water classifications in the three sample counties were checked on the ground. Of these only six were considered misclassified. For instance, one estuary was called residential by the interpreter probably because of an unusually large number of residential dwellings

Table 10.--Water resources expressed as a percentage by size and utility class; three combined counties.

Utility Class			Water size class[1] Less than 10m	11 to 100m	101m to 1/8 mile	Greater than 1/8 mile
Length of rivers and streams[2]						
	Kilometers		Percent			
Navigation	139	21	0	4	27	69
Recreation	413	63	0	91	6	3
Residential	40	6	0	60	28	12
Farm	6	1	17	83	0	0
Fisheries	42	6	0	79	12	9
Industrial	4	1	0	75	25	0
Unknown	9	2	56	44	0	0
Total[3]	653	100	1	69	12	18

Table 10.--Continued

Utility Class			Water size by class[1] Less than 10m	11 to 100m	101m to 40 acres	Greater than 40 acres
Surface water area						
- - - - -Hectares - - - - -			- - - - - - - - - - - - - - Percent - - - - - - - - - - - - - -			
Navigation	6579	33	0	2	28	70
Recreation	6998	35	0	58	33	9
Residential	1914	9	0	38	47	15
Farm	1854	9	0	68	32	0
Fisheries	479	2	0	13	50	37
Industrial	359	2	0	83	17	0
Unknown	2034	10	0	91	9	0
Total[3]	20,217	100	0	41	31	28

[1]Column totals are not additive.

[2]Includes estuaries, sloughs, and canals.

[3]Totals do not agree with county summary totals due to the affect of weighting factors in the individual county subtotals.

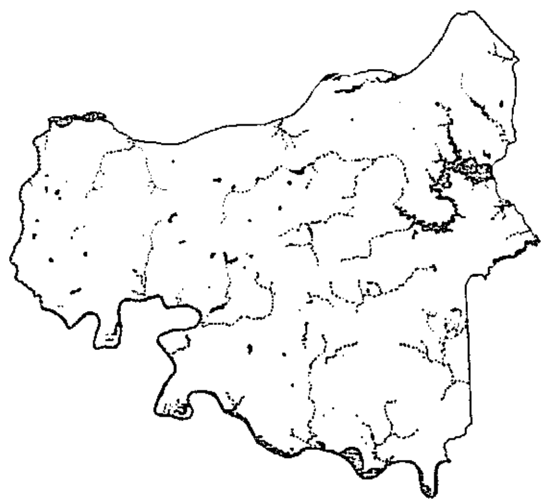
lining the shore. In this instance, however, the primary use of the water was recreation as evidenced by the number of boat docks and boats. Two ponds classified as farm were misclassified---one turned out to be a sewage disposal pond and the other was a dry field. Two ponds were misclassified as recreation. One was a farm pond and the other was in a new residential development where construction was about to begin. And finally, one misclassification was a recording error.

Interpreting water utility on remote sensing imagery with meaningful results requires well defined classes. Although the results in this study appear to be reasonable, the classes were extremely nebulus, i.e., they were not clearly defined by criteria that could be observed or measured on the imagery. Also, classes must be based upon what is physically present (observable) and what can be measured, not actual use. It is these observed and measured elements that must be fit into a potential utility pattern.

Cost

The total cost of the water resource inventory was $2,682 (table 11). Water resource maps created for the three counties by visual interpretation of LANDSAT and U-2 photo data (fig. 5) cost $790 and $931 respectively. Although computer mapping of water may be as accurate and require much less time than visual mapping, the cost will be higher.

(a)



(b)

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Figure 5.--LANDSAT photo data for (band 7) scene 2310-15062, November 28, 1975 was used to delineate water-ways and surface water shown in (a). U-2 1:120,000 CIR photos were used to map the ground truth in (b). The illustration is for King George County.

Table 11.--Cost analysis for a three county water resource inventory.

Material, method or task description	Cost: Manhours	Cost: Dollars
Photo products		
LANDSAT	25[1]	213
U-2	--	342
Maps and overlays	27	222
Interpretation and mapping		
LANDSAT	51	380
U-2	66	492
Data Summary and verification	9	67
Data Analysis		
Card Punch	9	36
Computer	15	125
Analysis	32	239
Summary	40	560
Total	274	2682

[1]To make 70mm negative for Bands 5 and 7 for two dates and make 1:125,000 scale enlargements.

Forest Area and Volume Estimates

Keeping stock of the Nation's renewable resources becomes increasingly important as the demand on these resources intensifies. Although population increases have moderated somewhat in recent years, demands for housing, food, water and recreational experiences have not---in fact, they continue to increase. This means that a slowly declining (there is some land exchange between the resource uses and others) renewable resource area base must meet these increasing demands. Periodic inventories of renewable resources are important to learn what is present now or what could be encouraged for the future by proper management treatments.

Remote sensing is a tool to aid the information gathering process for large populations of land units. In theory at least, the more heterogeneous the land use, the land forms and the land cover classes the more useful remote sensing should be in resource inventories. There is a point, however, where these differences become too complex even for stratification by remote sensing. Only by testing remote sensing in an operational environment will it be possible to fully understand what its role will be.

The forest inventory reported here paralleled an operational inventory in nine counties in the northern coastal plain of Virginia (fig. 1). Although the operational inventory has since been completed using conventional techniques, comparability of the two sets of data was maintained by using LANDSAT and aircraft imagery acquired in May 1975---at approximately the same time as the operational inventory was conducted. Ground data from the operational inventory was used in this quasi-operational test.

Background

Land-use classification has been the first stage in extensive nationwide forest resource inventories since the early 1940's. This classification is usually done by photo interpreters on available medium scale panchromatic aerial photographs. Many times these photographs are 5 to 8 years old at the time they are used. Since the primary purpose of land-use classification is to determine an accurate forest area base for expanding forest resource statistics, changes in land use since the photographs were taken can be a serious problem. If the forest area base is not accurate, data from ground subsamples expanded by a forest area expansion factor will be inaccurate. Unless, up-to-date photography or other remote sensing imagery is available on a wide area basis, it will be very difficult to adequately measure changes in the forest area base.

LANDSAT satellites with overlapping 18-day cycles can provide new coverage by seasons for almost any area in the United States. From LANDSAT-1 (ERTS-1) studies (Aldrich and others 1975), it was concluded that interpreters could correctly classify Level I information (forest, nonforest, water) 96 to 100 percent of the time on false color composites. It was also concluded that with improved spectral and spatial resolution the satellite imagery could be used in extensive forest inventory sampling strategies.

Classification System

This report describes how computer enhanced LANDSAT photographic data were used to classify Level I and Level II forest and land use classes (table 12). The classification system included the 12 individual classes in table 13. Not all of these classes, however, were found in the nine county site.

The operational Resources Evaluation Unit in the southeastern United States combines five agricultural nonforest classes and the marsh and swampland classes listed in table 13 as "other miscellaneous" in their first-level photo stratification. They do not stratify by forest types.

Our first-level stratification on LANDSAT data included forest, nonforest and water---forest land was further divided into conifer and deciduous based on the spectral values in the imagery. We could not classify marsh and swampland, or urban, because of limitations of the LANDSAT data. At the CIR photo phase in the sampling design, however, classes included all of those in table 13 with the exception of Grassland.

Techniques and Procedures

The techniques used to estimate forest area and volumes were geared very closely to those used by the Resources Evaluation Unit (formerly Forest Survey) in the southeastern United States.[3] The sampling technique is double sampling with regression for area adjustments. In the technique, a large number of 16-point photo clusters are classified for land-use and

[3]Forest Survey Manual for the Southeast, Parts I through V. U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, Asheville, North Carolina. 1968. Part I. p. 1-6.

Table 12.--A land-use classification hierarchy for remote sensing and ground information sources compatible with current nationwide forest resource evaluation objectives. Color definitions are based on high-altitude color infrared photography and simulated color infrared composites of LANDSAT data.

Classification	Color definitions (based on Munsell 1920-60, ISCC-NBS 1975)
I FOREST LAND	
II Conifer III Pine Pine-Hardwood IV Seedling and Sapling Poles Sawtimber	Density of conifer stands, number of hardwoods mixed in stand, and stand size influence color value and chroma. Dense stands are darker with less chroma. In the fall, before advanced hardwood coloration and leaf fall, conifer stands appear dark purplish red. Separation between Conifer and Hardwood classes is less distinct in fall than in winter or early spring. Where hardwoods and conifers are mixed in stands, hardwood color predominates, and stand is usually classified as Hardwood. In spring before hardwoods are foliated, conifers appear moderate to dark purplish red. Seedlings and saplings on prepared sites appear lighter than poles and mature sawtimber with closed canopies.
II Deciduous Hardwood III Upland Hardwood Bottomland Hardwood IV Seedling and Sapling Poles Sawtimber	Stands appear moderate grayish purplish red in fall and pale purple to moderate purplish red in spring. In fall, upland hardwoods cannot be distinguished from bottomland hardwoods. In spring, before foliation, upland hardwoods appear pale purple to light grayish purplish red. Bottomland hardwoods are generally a moderate purplish red. Stand size class (texture), density of crown canopy, and ground cover influence color value, density, and chroma but to a lesser extent than in conifer stands.

Table 12.--Continued

I NONFOREST	
II Grassland	Grassland appears deep pink in both fall and spring; sometimes mistaken for immature cropland in spring.
III Undisturbed Grass Disturbed Grass Dead Grass (Annual) New Improved Grass	
II Cropland	Mature crops in fall appear bluish gray to grayish blue. In spring, immature crops appear deep pink and may be mistaken for grassland.
III Immature Grain Immature Row Crop Mature Crop Harvested Crop Orchard Farmsteads	
II Bare Soil	In fall and spring bare soil appears cream colored on LANDSAT imagery. There is no distinction between plowed agricultural fields and sites prepared for new commercial developments. Generally in spring most areas of bare soil are newly plowed fields recently or soon-to-be planted.
III Plowed Fields Erosion Urban (site preparations) Rock Outcrop	
II Wild Vegetation	In fall, areas range from grayish purple of idle land to grayish purplish red of abandoned land to deep pink of Kudzu vine. Marsh and alder swamps are a moderate purple because of wet background. In spring, idle land becomes light grayish red to dark pink because of influx of new infrared-reflectant vegetation. Abandoned-transitional land (reverting to forest), on the other hand, is grayish purplish red and marsh and alder swamps are grayish violet. Deciduous Kudzu vine, purplish gray in the spring, easily separates itself from all other vegetation when fall and spring images are viewed together.
III Idle Land Abandoned Land Transitional Kudzu Marshland Alder Swamp	

Table 12.--Continued

II Urban	Areas are light blue in the fall and very pale blue in the spring. Unfortunately, because of low resolution of LANDSAT data, secondary roads, minor roads, and most utility lines are not resolved.
III Transportation & Utilities Home Developments Commercial Developments Recreation	
I WATER	
II Water	Water is dark greenish blue in fall and light greenish blue in spring. Farm ponds of less than .4 hectare (1 acre) can be seen on LANDSAT images if there is sufficient contrast with background.
III Clear Lakes & Ponds Turbid Lakes & Ponds Rivers & Streams	

Table 13.--A land-use and forest classification scheme adapted from the Forest Service Resource Data Standards Handbook[1] and Forest Survey Manual for the Southeast.[2]

Classification	Definition
Forest Land	Areas .4 hectare (1 acre) or larger in size and capable of supporting more than 10 percent cover by forest trees and not developed for nonforest use.
Conifer	Forests in which southern yellow pines singly or in combination comprise over 25 percent of the stocking.
Deciduous	Forests in which hardwoods singly or in combination comprise over 25 percent of the stocking.
Cropland	Land currently being utilized to produce agricultural crops that are harvested directly and not indirectly as pasture forage consumed by livestock.
Idle Farmland	Former cropland, orchards, improved pasture, and farm sites not tended within the past 2 years and presently less than 10 percent stocked with trees.
Improved Pasture	Land currently improved for grazing by cultivation, seeding, irrigation, or clearing of brush and trees.
Grassland	Land other than improved pasture on which the primary natural cover is grass and forbs.
Other Agriculture	All other farm land not used for crops, idle, or pasture. Includes farmstead, buildings, and service areas.

Table 13.--Continued

Marsh and Swampland	Land temporarily or partially covered by water and poorly drained land capable of supporting more than 10 percent cover of swamp vegetation (marsh grasses, cattails, etc.). Does not include spruce bogs, cypress land, or other hydric forest sites.
Urban and Other Areas	Areas within the legal boundaries of cities and towns; suburban areas developed for residential, industrial, or recreational purposes; schoolyards; cemeteries; roads, railroads; airports; beaches; powerlines and other right-of way; or other nonforest land not included in any other specific land class.
Census Water	Streams, sloughs, estuaries, and canals more than .2 kilometers (1/8 of a statute mile) in width; and lakes, reservoirs, and ponds more than 16.2 hectares (40 acres) in area.
Noncensus Water	Streams, sloughs, estuaries, and canals less than .2 kilometers (1/8 of a statute mile) in width; and lakes, reservoirs, and ponds less than 16.2 hectares (40 acres) in area. Minimum width of streams, etc., is 9.1 meters (30 feet) and minimum size of lakes, etc., is 9.1 meters (30 feet) in diameter.

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[1] Forest Service Handbook, Chapter 1309.13, U.S. Department of Agriculture, Forest Service.

[2] Forest Survey Manual for the Southeast, Parts 1 through 5, 1968, U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, Asheville, North Carolina. Definition of Terms, Pages D-1 through D-9.

a subsample is checked on the ground. Then a linear regression is fitted to develop a relationship between the photo and ground classifications of the subsample. Finally, the photo estimate is adjusted for change in land-use since date of photography and for misclassifications. The adjusted areas are used to expand per acre volume, growth, mortality and removal estimates derived from an independent permanent sample of 10-point clusters on the ground.

Area Estimates

For area estimates, 1:125,000 scale enlargements were made of the LANDSAT image for each county (fig. 6). A grid overlay of 16-point clusters (4X4) was constructed to sample the area at an intensity of approximately 90 hectares (222 acres) per cluster. This sampling intensity was designed to estimate forest area within a sampling error of ±3 percent per million acres (404,858 hectares) using conventional techniques. An overlay of each county was made from a 1:250,000 USGS map sheet and scaled to the photo enlargements. In addition, a scaled overlay of permanent plot locations was made using plot coordinates, a coordinatograph, and photographic techniques. During the interpretation phase, the permanent plot locations in the overlay were overlaid with a scaled cluster template and the points interpreted. The clusters were added to the large area sample.

Experienced photo interpreters examined each cluster with the aid of a 2X magnifier and classified the points into one of five classes---forest land, conifer, deciduous, nonforest, and water. Each cluster was recorded by its position within the overlay grid or by permanent subsample number.

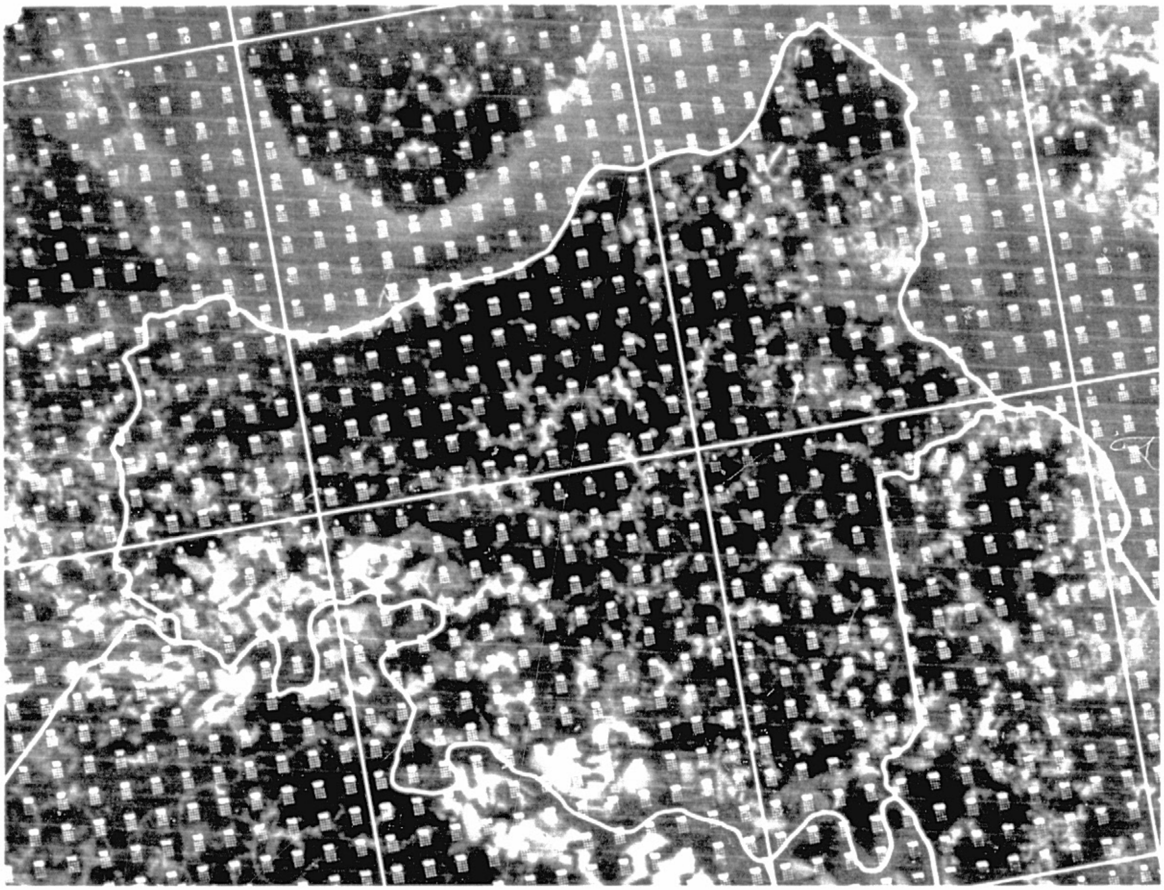

Figure 6.--A 16-point cluster overlay was used on 1:125,000 scale combined color enlargements of LANDSAT for each county to estimate forest area by conifer and deciduous types. This illustration of King George County was made using the overlay positive transparency and the negative of Band 5 (red), Scene 2122-15074, May 14, 1975.

Using computed proportions in each photo subsample cluster and corresponding ground cluster[4] as continuous variables, computations were made for each LANDSAT land-use class in the photo sample (see footnote 3).

Where:

x = proportion of land-use in a CIR photo subsample cluster.

y = proportion of land-use in a ground or LANDSAT subsample cluster.

p = proportion of land-use in the LANDSAT sample cluster.

P = adjusted land-use proportion in the county.

a = regression constant.

b = regression slope coefficient.

n = number of clusters in subsample.

m = total number of photo clusters.

N = total number of sampling units in the population.

L = adjusted area in land-use class.

A = total area being sampled.

and:

SS_y = corrected sums of squares of y.

$$= \Sigma y^2 - \frac{(\Sigma y^2)}{n}$$

SS_x = corrected sums of squares of x.

$$= \Sigma x^2 - \frac{(\Sigma x^2)}{n}$$

SP_{xy} = corrected sums of squares of the cross products.

$$= \Sigma xy - \frac{(\Sigma x)(\Sigma y)}{n}$$

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[4]Ground clusters were examined by the Resources Evaluation Unit, Asheville, North Carolina.

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$s_y{}^2$ = variance of y.

$$= \frac{SS_y}{n-1}$$

Computations were made for:

1. The mean proportions for individual land-use classes using ground, or CIR photo data.

$$\bar{y}_j = \frac{\Sigma_{i=1}^{n} (y_{ij})}{n}$$

where:

y_{ik} = proportion of the i^{th} cluster in land-use class j.

$\bar{y}_j$ = mean proportion in land-use class j.

2. The mean proportions for grouped land-use classes using CIR, LANDSAT, and ground data.

$$\bar{y}_k = \frac{\Sigma_{i=1}^{n} (y_{jk})}{n}$$

where:

y_{ik} = proportion of the i^{th} cluster in grouped land-use class k.

$\bar{y}_k$ = mean proportion in grouped land-use k.

3. Regression constant (a) and slope coefficient (b) were computed for (1) the relationship between land-use proportions on LANDSAT and the corresponding proportions on the ground and (2) the relationship between land-use proportions on the CIR photos and the corresponding proportions on LANDSAT imagery. The equation for adjusting land-use proportions took the form:

$$P = a + b\ (\bar{p})$$

4. The squared standard deviation from the regression for each method.

$$s_{y \cdot x}^2 = \frac{SS_y - \frac{(SP_{xy})^2}{SS_x}}{n-2}$$

5. The adjusted area for each combined land-use class for each method.

$$L = (P)(A)$$

6. The standard error of the adjusted forest area for each method expressed as a percent.

$$s_p = \sqrt{s_{y \cdot x}^2 \left[\frac{1}{n} + \frac{(\bar{p} - \bar{x})^2}{SS_x}\right]\left[1 - \frac{n}{m}\right] + \frac{s_y^2}{m}\left[1 - \frac{m}{N}\right]}$$

$$SE = \frac{(s_p)}{(P)}(100)$$ at the 67 percent level of confidence.

Bureau of the Census land areas, adjusted by the RRE Unit for water, were used in the study to keep forest area and other estimate comparable. A sampling error was computed for each county forest area estimates, the conifer and deciduous forest type estimates, and the combined county totals.

In another part of the study, CIR photo classifications for the subsample clusters were used as a second phase to estimate area proportions by individual land-use classes (table 13). These proportions were used to break down the grouped land-use estimates made on LANDSAT.

Volume Estimates

The resources evaluation sampling design is a random-systematic sample of permanent ground locations. Nonforest locations become forest locations when nonforest land is found reverted to forest land. At each forest location, a 10-point cluster is established and a basal area 37.5 variable plot is used at each point to select sample trees. Volumes of all sample trees over 5.0 inches in diameter at breast height (d.b.h.) are expanded to the per acre and the adjusted forest area (population) level. The accuracy objective is ±5 percent per billion cubic feet of growing stock volume.

Inventory volume (board foot and cubic foot) estimates at the population level (county adjusted forest area) were obtained by multiplying volume per tree times trees per acre times the adjusted acres of forest land obtained from the independent LANDSAT area sample. Volume by forest type was obtained by multiplying mean volume per acre in conifer and deciduous types by the adjusted conifer and deciduous forest areas estimated using LANDSAT data.

Board foot and cubic foot volumes were computed for individual counties and for all counties combined. Volume variances were computed for all estimates by the equation:

$$s^2 = (N\bar{p}\bar{v})^2 \left[\frac{s\bar{p}^2}{\bar{p}^2} + \frac{s\bar{v}^2}{\bar{v}^2} \right]$$

Where:

s^2 = variance of total volume

N = area sampled

$\bar{p}$ = proportion of area in forest

$\bar{v}$ = net cubic volume per acre of growing stock

$s_{\bar{p}}^2$ = variance of $\bar{p}$

$s_{\bar{v}}^2$ = variance of $\bar{v}$

Computations were made for:

1. variance of $\bar{v}$

$$s_{\bar{v}}^2 = \frac{\Sigma v^2 - \frac{(\Sigma v)^2}{n}}{(n-1)(n)}$$

2. Estimated total volume (V) in the area.

$$V = N\bar{p}\bar{v}$$

3. Sampling error in percent

$$SE = \frac{(\sqrt{s^2})(100)}{V}$$

4. Sampling error per billion cubic feet of growing stock in percent.

$$SEB = \frac{(SE)(\sqrt{V})}{\sqrt{1,000,000,000}}$$

Results

To evaluate these results, it should be recalled that per acre volumes were extrapolated from RRE Unit data summaries and multiplied times the areas derived from the LANDSAT large area sample. In the large area sample it was assumed that photo interpreters would call mixed conifer-deciduous areas conifer type because of previous experience on late fall and early spring imagery. This apparently was not true, however, and the affect of this will be brought out in the discussion.

Area Comparisons

County forest area estimated from LANDSAT color composites were within $\pm$ 10 percent of estimates made using ASCS photographs (table 14). Five county estimates were high and four estimates were low. Both techniques used identical ground cluster data to develop linear regression adjustments for land use change and misclassifications. The accummulated difference in area for all nine counties is only 0.8 percent.

Generally speaking, the greater the forest area in a county the lower the sampling error, table 14. This was to be expected since there are fewer photo and ground samples in the smaller counties and variance will be greater. It is also quite apparent from table 14 that sampling errors by county are roughly 2 to 3.5 times larger for LANDSAT estimates. These errors result because of discrepencies between ground and LANDSAT cluster point locations. Such discrepencies cause higher squared standard deviations for regression and result in higher standard errors for the adjusted areas. Errors of this type are caused by misregistration of the

Table 14.--Comparison of LANDSAT and Forest Survey adjusted forest areas and their sampling errors in terms of one standard error.

County	LANDSAT		Forest Survey[1]	
	Forest Area	Sampling Error	Forest Area	Sampling Error[2]
	-Hectares-	- -Percent- -	-Hectares-	- -percent- -
Caroline	108,253	3.90	106,555	2.07
Essex	40,107	7.24	43,369	2.02
King and Queen	58,289	3.85	65,141	2.34
King George	29,613	5.92	29,216	3.77
Lancaster	19,032	12.31	20,917	3.90
Middlesex	21,077	11.05	21,785	3.61
Northumberland	30,768	8.31	28,000	2.91
Richmond	35,302	6.97	31,982	2.57
Westmoreland	37,248	8.44	35,814	2.87
All Counties	379,689	2.31	382,779	0.98

[1]Cost, Noel D. 1976. Forest Statistics for the Coastal Plain of Virginia. USDA Forest Service Resource Bulletin SE-34. Acres converted to hectares by the factor 2.471 acres per hectare.

[2]Sampling error computed for commercial forest area only. King George and Westmoreland County forest areas include 983 and 633 hectares respectively of productive reserved forest land.

cluster template over the ground plot location. Since the photo scale (1:125,000) is so small and LANDSAT data resolution so coarse, these errors will always occur when these comparisons are made. What is most important is the fact that the areas themselves are very close to the RRE Unit estimates. Also, the estimate of total forest area is well within the national accuracy standard of ± 3 percent per million acres.

Areas of conifer and deciduous types, adjusted by regression techniques, are listed in table 15. The RRE Unit areas of forest type are based on the ground sample. As a result,some differences by counties were very large. When the nine county RRE totals for pine and oak-pine were combined they made up 48 percent of the forest area. However, if the mixed oak-pine type is added to deciduous rather than conifer there is better agreement. The conifer type alone, according to RRE Unit summaries, is 31 percent. The adjusted large area sample on LANDSAT data showed that 33 percent of the forest area was conifer.

Sampling errors in table 15 indicate that most county area estimates were within ± 25 percent. Only in conifer type for Lancaster, Middlesex, and Northumberland Counties was this error exceeded. Deciduous types, with greater areas, had sampling errors ranging from about 7 to 18 percent. It is noteworthy that for nearly one million acres of forest land in the combined counties, the sampling error for conifer was only ± 6.7 percent and for deciduous the error was only ± 3.7 percent.

Volume Estimates

Mean volumes by conifer and deciduous types were derived by summarizing per acre volumes for individual ground locations within pine, oak-pine and hardwood types. The volumes for plots in mixed

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TABLE 15.--LANDSAT forest area by county and major forest types with sampling errors in terms of one standard error.

County	Total[1]	Forest Area			
		Conifer[2]		Deciduous[2]	
		Area	Sampling Error	Area	Sampling Error
	-Hectares-	-Hectares-	- - -Percent- - -	-Hectares-	- - Percent- -
Caroline	108,253	32,618	13.79	75,635	6.81
Essex	40,107	18,500	14.29	21,607	11.14
King and Queen	58,289	18,101	18.35	40,188	7.70
King George	29,613	12,605	16.94	17,008	13.43
Lancaster	19,032	8,696	26.59	10,336	18.07
Middlesex	21,007	5,310	48.39	15,767	13.10
Northumberland	30,768	6,748	38.44	24,020	12.35
Richmond	35,302	11,157	23.98	24,145	13.49
Westmoreland	37,248	12,113	21.89	25,135	11.42
All Counties	379,689	125,848	6.69	253,841	3.74

[1]Measured by large area sample on LANDSAT and adjusted by regression developed from a subsample on the ground.

[2]Measured by large area sample on LANDSAT and adjusted by regression developed from a subsample on 1:120,000 CIR photographs.

oak-pine in this instance were added to the volume in pine type. This is contrary to the RRE county and unit summaries (see footnote 1, table 14) where oak-pine type area is summarized with hardwood types.

Table 16 reports the net cubic-foot and board-foot volume by conifer and deciduous types measured on LANDSAT inventory area sample. The reliability of volume estimates and independent area estimates are given in table 17.

As might be expected, sampling errors for county estimates are relatively high. For the entire nine county area, however, cubic foot volume estimates will be within ± 10.2 and ± 8.7 percent of the true volumes for conifer and deciduous types respectively, 2 out of 3 times. Although these estimates are used here and in the discussions that follow, they are experimental and should not be used in operational planning.

There are no RRE county summaries of volume by forest type. Thus, there is no way to compare volumes in this experiment with those derived from the operational inventory.

Cost

Cost comparisons used in table 18 are restricted to direct costs for photos, photo handling, and photo interpretation. In addition, two additional costs inherent with the LANDSAT technique are listed separately for emphasis. These costs are those necessary to produce precise overlays of permanent RRE ground locations. More efficient point digitizers and automatic plotters would reduce these costs significantly. It should be added that coordinates of permanent ground sample locations may be required in the operational procedure someday to implement combining information from different sources. If this is the case, the expense will be added to the

Table 16.--Net cubic-foot and board-foot volume by broad forest type and by county.[1]

County	Cubic foot volume			Board foot volume		
	Total	Conifer	Deciduous	Total	Conifer	Deciduous
	- - Thousand Cubic Feet - - -			- - Thousand Board Feet - -		
Caroline	450,790	111,951	338,839	1,184,021	257,027	926,994
Essex	163,444	77,164	86,280	447,970	244,016	203,954
King and Queen	206,298	61,412	144,886	551,338	159,679	391,659
King George	121,223	56,378	64,845	301,811	144,932	156,879
Lancaster	48,489	25,248	23,241	103,528	60,059	43,469
Middlesex	66,246	21,597	44,649	161,100	68,217	92,883
Northumberland	115,129	33,817	81,312	282,486	116,241	166,245
Richmond	142,394	30,767	111,627	378,301	68,894	309,407
Westmoreland	125,779	38,699	87,080	264,034	65,217	198,817
All Counties	1,439,792	457,033	982,759	3,674,589	1,184,282	2,490,307

[1]Mean net cubic-foot and board-foot volume per acre was determined from Forest Survey sample data and expanded by LANDSAT forest type areas.

Table 17.--Sampling Errors for County and nine county totals in terms of one standard error.

County	Forest Area		Volume			
			Conifer		Deciduous	
	Conifer	Deciduous	Cu. Ft.	Bd. Ft.	Cu. Ft.	Bd. Ft.
	Sampling Error (percent)					
Caroline	13.79	6.81	9.54	16.90	9.10	16.41
Essex	14.29	11.14	24.60	33.09	14.13	23.84
King and Queen	18.35	7.70	16.25	22.58	15.88	23.58
King George	16.94	13.43	22.67	39.95	13.32	17.90
Lancaster	26.59	18.07	34.68	51.38	30.70	43.48
Middlesex	48.39	13.10	35.34	50.46	25.40	29.38
Northumberland	38.44	12.35	47.44	52.45	12.99	22.79
Richmond	23.98	13.49	39.16	50.21	15.34	28.42
Westmoreland	21.89	11.42	32.34	45.14	14.12	29.95
All Counties	6.69	3.74	10.24	17.53	8.69	11.15

Table 18.--Comparative cost of land use and forest type stratification on LANDSAT photographs and on 1:20,000 ASCS photographs.

Item and Basis		Cost ASCS Person/hours	Cost ASCS Dollars	Cost LANDSAT Person/hours	Cost LANDSAT Dollars
Photo Handling	Ordering, organizing, labeling photographs and date products, enhancing images, transferring plots, (GS-7, GS-9 pay scale)	80	444	45	345
Photographic costs	ASCS photos with cluster grid (est. $1.00 per photo), LANDSAT data tapes, color composite, color prints. (Gov't. rates)	--	373	--	194[1]
Photo Interpretation	Land use: ASCS at 3 clusters per minute, LANDSAT at 2 clusters per minute; forest type classification: ASCS and U-2 photo at 12 clusters per hour. (GS-7 pay scale)	66	370	114	631[2]
Special Mapping	Measure plot coordinates	--	---[3]	24	163
	Prepare template overlays (GS-9 pay scale)	--	---[3]	72	400
Total Cost		146	1187	255	1733

[1]Includes only 22 percent of the total cost of one set of LANDSAT data tapes.
[2]The LANDSAT area sample had 27 percent more clusters than the ASCS area sample.
[3]These costs are not presently part of the operational inventory system.

ASCS photo method. The total cost of the LANDSAT method exceeds the present system by 46 percent, however, it should be noted that if the special mapping costs are excluded, the comparative costs are $1187 and $1170 for the operational and LANDSAT systems respectively.

Time is sometimes more important than total cost. In this quasi-operational inventory study the time to complete the interpretation phases on LANDSAT imagery exceeded the operational inventory by 9 percent. In total person/hours, the LANDSAT technique exceeded the operational system by 75 percent.

In summary, it appears that to use up-to-date LANDSAT photographic data in resource inventories, one must be prepared to spend both more money and more time than would be expected using available 1:20,000 scale ASCS aerial photographs. There may be some cost advantages in the LANDSAT data to measure forest types, water and changes that could not be evaluated in this study. The added cost of the LANDSAT technique would then be justified.

COMPUTER AIDED INVENTORY OF FORESTLAND

by

Edwin H. Roberts and Norman E. Merritt

Introduction

This inventory was to parallel a regional timber inventory conducted using conventional interpretation of LANDSAT photographic products and the operational Forest Survey being conducted at the same time. Comparative results and costs of the three inventory procedures would have established guidelines for both future use and continuing research in resources inventory techniques.

Unforturately, all objectives could not be met in the time span of this investigation due to problems resulting from a move of the research unit from Berkeley, California to Fort Collins, Colorado. In the time available for this study, computer assisted techniques have been used to inventory the forest area in nine Virginia counties. All counties were inventoried using a systematic sample of LANDSAT pixels and in three counties the areas in conifer, deciduous hardwood, nonforest, and water were estimated using all pixel data. Maps were produced from these classifications to show the distribution of ground cover classes in each of the three counties. For each of the nine counties a tabulation of forest area is produced and compared with the estimate from Forest Survey.

Background

Previous research performed by this unit and by other indicates that computer assisted classification using supervised procedures only is probably not the most effective method for classifying ground cover types. If the spectral data for two classes of interest does not differ, then it will be impossible to separate them. Using only supervised classification it is not known whether two classes are separable until training statistics are generated for each of them; even then, separability is known only between those specific classes.

By using unsupervised classification it is possible to partition the spectral data into separable clusters. These clusters can then be identified by the ground cover types they represent and the spectral data from these clusters can be used as input to the supervised classification procedures. After classification, the clusters can be combined into information classes of interest.

One original objective of this study was to determine, for the Virginia test site, what ground cover types and conditions corresponded to the spectral clustering of the data. Because of the physical move of the research unit and the problem this caused with the use of computer facilities, only a minimum of this objective could be met. However, unsupervised and supervised procedures were used for all the computer assisted classification and the spectral clusters generated during unsupervised classification were identified into aggregated ground cover classes.

Study Area: some special considerations

The nine county study area has been described earlier, but for computer assisted classification some of its features present special problems. The area is a mosaic of small, irregularly shaped agricultural fields, deciduous forest on both upland and bottomland, small natural stands and conifer plantations along with cutovers, abandoned agricultural fields and small towns. Because of the small average size of individual cover type areas there is a large amount of cover type border. Any pixel straddling a border has a spectral signature usually unlike that of the types on either side of the border and often more like some unrelated type.

Water borders seven of the nine counties and because official county boundaries encompass a different area of the surrounding water than is ascribed to them by the Bureau of Census, county area figures derived from LANDSAT do not agree with those published by Bureau of Census and used by Forest Survey.

In order to have area figures that can be compared with those of Forest Survey it was necessary to modify our water area figures from LANDSAT as described under Procedures.

Classification System

Final classification of the LANDSAT data for the nine county test site used three Level I classes: forest, nonforest, and water. The class forest was further subdivided into the Level II classes conifer and deciduous hardwood (Table 12). The data were actually classified into many more than the final four land cover classes. Nonforest for example contains a diversity of cover types from urban areas to bare and completely covered agricultural fields. These diverse cover types can not be characterized by a single spectral pattern, but must be recognized on an individual basis.

Unsupervised clustering of the data from test areas produced as many as twenty-five spectral clusters. These spectral values were used as input to the supervised classification program. After final pixel classification was completed, the clusters were combined into four classes; conifer, deciduous hardwood, nonforest and water.

A line printer map of Northumberland county in which eighteen spectral clusters are each printed as a different character is shown in Figure 7. The eighteen spectral clusters have been aggregated into four color coded land cover classes in Figures 8, 9, and 10 (Page 80, 81, and 82).

Procedures

Computer compatible tapes (CCT's) for LANDSAT II scenes 2112-15074 and 2112-15081, May 14, 1975, were used in computer assisted analysis of the nine county test site. The CCT's for the two scenes were reformatted and the data merged to form a new composite scene which covered the entire test site. Although the date was not optimum for differentiating between cover types of interest, a decision was made to proceed using these scenes rather than wait several months for something better.

Boundaries for the nine counties were drawn as shown on USGS topographic maps of the area. Where no boundaries were defined, as on the Chesapeake Bay, a generalized smooth boundary was drawn along the shoreline including some water. The county boundaries and 30 control points distributed throughout the area were digitized and fitted to the LANDSAT image using a least squares technique. A computer mask was then produced from the digitized county boundary data such that each pixel of the LANDSAT scene could be assigned to a county. Boundary and point digitizing, geometric fitting to LANDSAT data, and making the computer mask were contracted to the Remote Sensing Research Program at the University of California, Berkeley.

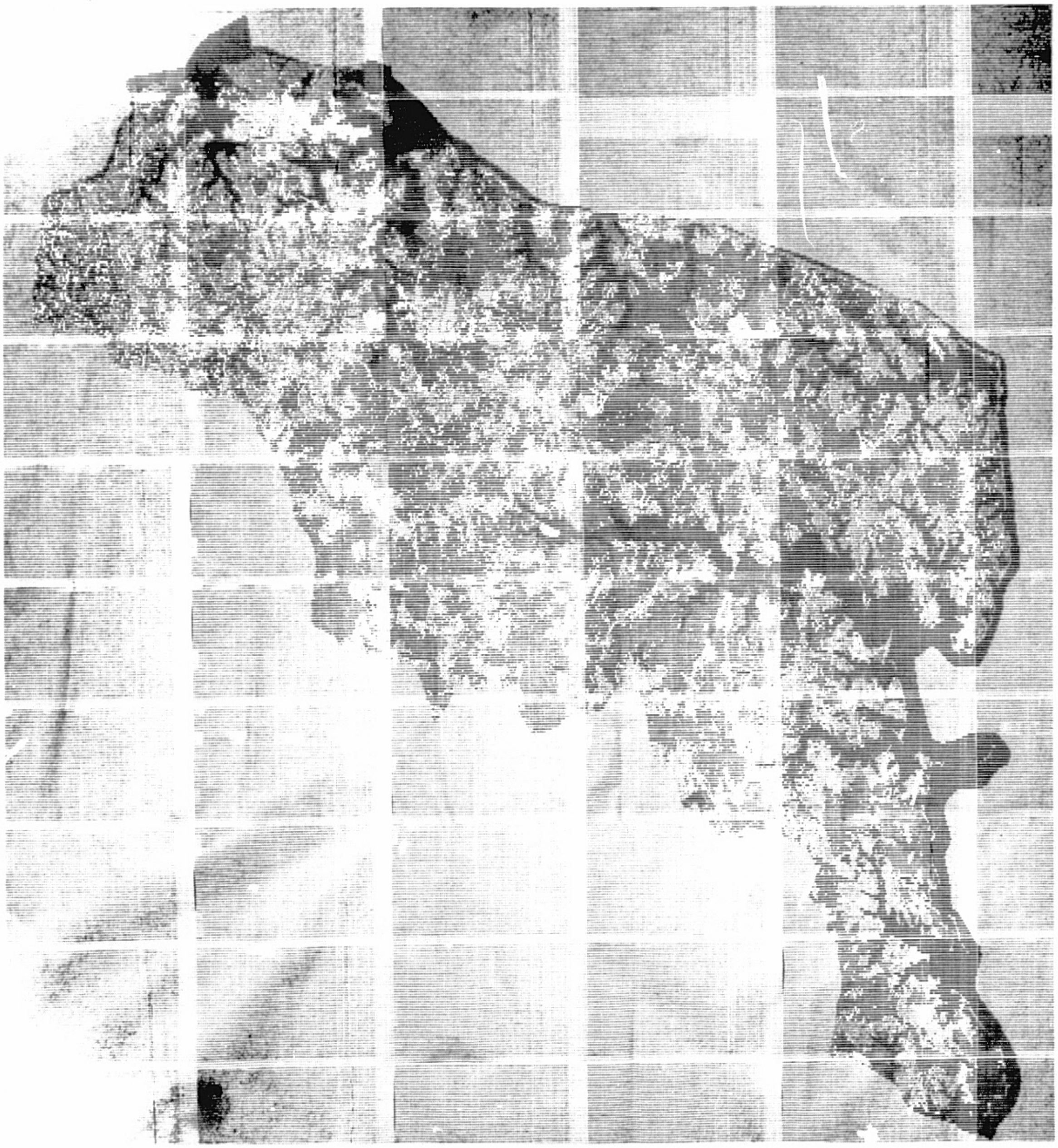

Figure 7.--Sixty sheets of computer printout were taped together to form this six foot by seven foot mosiac from the land cover classification of Northumberland County, Virginia. On this map eighteen spectral clusters are shown as different symbols. Although cumbersome to use for large areas such as this, these line printer maps are very useful for preliminary examination of test area classification. This map can be compared with Figure 10 where the clusters have been aggregated to four cover classes and displayed photographically in color.

With the move of our research group from Berkeley, California to Fort Collins, Colorado and the disruption in personnel and facilities use this caused, we felt working with additional LANDSAT scenes for computer assisted classification would be beyond our capabilities.

Cover type classification work began utilizing a previously developed set of computer programs known as HIST and EDMAP. HIST simply provides the user with a frequency distribution for the radiance count values by channel for a designated portion of a LANDSAT scene. This information is used to choose radiance count intervals for input to the EDMAP program. A vector is formed for each combination of channel and interval. By assigning a character to each vector and outputting on a line printer, a map is formed. The result is a quasi-unsupervised classification. Clusters are formed based on their spectral similarities rather than their cover type similarities, but the radiance count intervals are arbitrarily chosen. The clusters thus formed do not necessarily have less spectral variability within than among clusters.

The line printer maps and aerial photos of the area are viewed simultaneously under a Zoom Transfer Scope (ZTS) to determine the ground cover type or condition represented by each vector.

Statistics are derived for each vector type and then these are used as input to a supervised classification program. Cover types from the resulting classification can be aggregated into inventory or information classes of interest.

A preliminary classification was performed for a part of Northumberland County. Although the results compared reasonably well with aerial photos, little was learned of the natural spectral clustering of the data. At this time a version of the ISOCLAS spectral clustering program which we had been trying to procure became available to us from the Remote Sensing Research Program at the University of California, Berkeley. With the acquisition of this computer program we began unsupervised classification of the data.

As contrasted with the EDMAP program, ISOCLAS partitions the data into clusters by the use of a mathematical algorithm such that there is greater spectral similarity within clusters than among clusters as measured by the distance between the values for a data point and the cluster mean.

The clustering process is iterative and the number of iterations is selectable. After all data has been assigned to clusters, new means are calculated and clusters may then be split into new clusters if the standard deviation of the cluster exceeds a selected value. Two clusters are combined if the distance between their means is less than a specified value.

At least two areas of 1600 or more pixels were submitted for clustering from each county in order to include the diverse conditions encountered. Clustering results were output as lineprinter character maps. After the data were clustered, the clusters were given identities in terms of their ground cover characteristics, e.g., water, bottomland hardwood, upland hardwood, bare soil, etc.

The cluster maps were viewed simultaneously with high altitude CIR aerial transparencies using a ZTS. The cover type represented by each cluster was identified from the photographs. It was often found that a cover type was represented by several clusters. For example, the non-forest cover type included many clusters such as bare soil, roads, urban and various agriculture which could usually be identified, but which were not of individual interest. Within the forest cover type, only mixed forest could be consistently identified in addition to the conifer and deciduous hardwood types. Ground checking of the cluster maps did not reveal any consistent basis for further subdividing the forest classes.

After identifying the clusters their means were input as prototypes to the supervised classifier TYPIX. This classifier computes the distance between spectral values for a pixel and each prototype and assigns the pixel to the class of the nearest prototype. Small test areas within each county were classified to determine that the prototypes were sufficient. If not, further clustering was done and additional prototypes were generated. Five sets of prototypes were used to classify the nine county area.

The three counties of King George, Lancaster, and Northumberland were inventoried by classifying all data points. From this classification color coded photographic maps were made by a computer controlled film recorder. In addition to providing a visual display, the complete classification of these three counties provided a base for comparison with the inventory performed by systematic sampling of the LANDSAT data. For all nine counties a systematic sample of pixels was classified in order to save computer processing time and costs.

Forest Survey must meet accuracy standards within the sixty-seven percent confidence limit of ± three percent sampling error for area of commercial forestland. For individual counties the allowable sampling error is ± ten percent. The LANDSAT data were sampled at an intensity of seventeen percent by classifying every third pixel on every other line. Assuming an overall classification accuracy of only seventy percent (the performance in test areas was better than eighty percent) the sampling error is less than one percent even on a per county basis.

Total area within each county had to agree with that used by Forest Survey if results from the two inventories were to be compared. Since the area to be inventoried was defined differently for the two inventories, a procedure was devised to force the area from the LANDSAT data to be the same as that used by Forest Survey. Two assumptions were made: (1) a high degree of accuracy was attained in differentiating land and water in the LANDSAT classification, and (2) the difference in area ascribed to each county by the inventories was due entirely to a difference in defining the water that was to be included. The total pixels in each county classified into land catagories was divided into the land area estimated by Forest Survey. This gave an area/pixel for each county as shown in the tabulation below.

Caroline	.473
Essex	.468
King & Queen	.470
King George	.457
Lancaster	.486
Middlesex	.476
Northumberland	.470
Richmond	.469
Westmoreland	.461

This expansion factor was used as a multiplier to expand the pixel count for each county to area in hectares. The county land area plus the area of non census water as determined by Forest Survey was subtracted from the county area as determined from LANDSAT data. The difference, water included within the boundaries drawn for LANDSAT but not considered for inventory by Forest Survey, was then subtracted from the LANDSAT water area. The remainder of the water was deemed to be non census water.

Results

For the entire nine county test site, estimates of forestland area differed by less than one percent between the Forest Survey inventory and computer assisted classification of LANDSAT data (Table 19). For individual counties a difference of up to twenty-one percent occurs. These differences could be due to inaccuracies in classification or could be accounted for by the simple statistical probability of difference due to sampling.

Forestland for the LANDSAT effort was defined differently than for the Forest Survey. For LANDSAT, forestland was defined as land with an actual cover of trees or wildland vegetation; for the Forest Survey, land can be as little as ten percent stocked and be classed as forest. Some of the latter was probably called nonforest from LANDSAT data and was certainly not called conifer.

The accuracy of classification for the sampled pixels from the entire nine county area was not checked because single pixels could not be accurately located. However, pixel classifications were checked against aerial photos for the three counties that had all pixels classified, and for test areas in the other six counties. The following general conclusions were reached: The accuracy of water classification was greater than ninety-eight percent; water was confused only with wet marsh and swampy forest. In keeping with the great variety of

Table 19.--Comparison of forest area estimated by computer assisted classification of a 17 percent systematic sample of LANDSAT data and forest area estimated by the 1976 Forest Survey.[1]

County	Forest Area			
	LANDSAT	Forest Survey	Difference	
	- - - - hectares - - - -		- hectares -	percent
Caroline	109,799	106,555	3,244	3
Essex	45,380	43,369	2,011	5
King and Queen	56,600	65,141	8,541	13
King George	31,492	29,216	2,276	8
Lancaster	23,789	20,917	2,872	14
Middlesex	21,803	21,785	18	0
Northumberland	22,078	28,000	5,922	21
Richmond	29,260	31,982	2,722	9
Westmoreland	40,212	35,814	4,398	12
All Counties	380,413	382,779	17,778	1

[1]Cost, Noel D. 1976. Forest Statistics for the Coastal Plain of Virginia. USDA Forest Service Resource Bulletin SE-34.

conditions represented, nonforest contained the greatest number of spectral clusters. Many of these clusters could easily and reliably be identified into cover types; however, some agricultural fields in early stages of growth, but having nearly full ground cover have identical spectral patterns as some stands of upland hardwood. The resulting misclassification of some hardwood forest and agriculture was probably the only case where a homogeneous type of over five hectares in area might be misclassified. Hardwood was seldom confused with anything other than agriculture. Pure pine stands were sometimes confused with hardwood swamp, but little area was involved. Mixed conifer-hardwood forest was aggregated either with conifer or with hardwood depending on the proportion of each. Areas of mixed forest with approximately twenty-five percent or more of the crown cover in conifer were usually classified as conifer.

Sixty-eight percent of the land area of the nine county test site was classified as forestland; forty-one percent of this is conifer and fifty-one percent hardwood. Percentages by county are shown in Table 20.

Water is a large percentage of the total area of some counties as can be seen in Table 21. Much of this water area is removed from the area to be inventoried by Forest Survey before sampling for forest area is performed. The LANDSAT inventory area was adjusted to correspond as nearly as possible. The resulting changes in proportion can be seen for three counties in the table.

The greatest source of classification error was the small average size of individual cover types areas. This distribution results in a large number of border pixels. Border pixels often have a spectral

Table 20.--Percent of county area in each land cover class as derived from computer assisted classification of a 17 percent systematic sample of the LANDSAT data.[1] Figures in parentheses are from the 1976 Forest Survey.

County	Forest Land			Nonforest		
	Total	Conifer	Hard-wood	Total	Water	Other
	- - - - - - - - - - - -percent- - - - - - - - - - -					
Caroline	79(76)	35	44	22(24)	1	21
Essex	70(67)	25	45	30(33)	1	29
King and Queen	69(79)	47	22	31(21)	1	30
King George	69(64)	16	53	31(36)	1	30
Lancaster	67(59)	30	37	33(41)	2	31
Middlesex	65(64)	20	45	35(36)	2	33
Northumberland	45(57)	11	34	55(43)	3	52
Richmond	61(65)	16	44	40(35)	1	39
Westmoreland	68(60)	26	42	32(40)	1	31

[1]Figures are not additive because of rounding to the nearest whole percent.

Table 21.--Estimated area by cover class from computer assisted classification of all LANDSAT data within each of three counties. Adjusted percentages and area of water are obtained by removing from each county a number of pixels classified as water sufficient to make the county area inventoried by LANDSAT and by Forest Survey equal. The adjusted percentages can be compared with those in table 20 for the systematic sample.

County	Conifer	Hardwood	Nonforest	Water	Total
King George					
Unadjusted					
Hectares	7,456	23,840	13,558	2,732	47,586
Percent	16	50	28	6	
Adjusted					
Hectares	7,456	23,840	13,558	731	45,585
Percent	16	52	30	2	
Lancaster					
Unadjusted					
Hectares	9,906	13,736	10,886	16,732	51,260
Percent	19	27	21	33	
Adjusted					
Hectares	9,906	13,736	10,886	956	35,484
Percent	28	39	31	3	
Northumberland					
Unadjusted					
Hectares	9,895	11,917	25,903	11,115	58,830
Percent	17	20	44	19	
Adjusted					
Hectares	9,895	11,917	25,903	1,497	49,212
Percent	20	24	53	3	

pattern unlike any of their component cover types. Because of the relatively larger number of spectral clusters comprising the nonforest type and the spectral diversity of these clusters, border pixels probably most often fit one of these clusters.

We have estimated the cost of classifying an average sized county (50,000 hectares) in the nine county test site. The tape purchase cost is prorated from the nine county area; had it been prorated from the entire LANDSAT scene the cost would be much lower. The estimate is for that unique, but certainly not optimum, combination of facilities available to the project during the course of the study. These costs reflect an estimate for the research mode in which they were incurred.

	Dollars	Manhours
Purchase CCT's	40	---
Computer costs and analysis or interpretation time		
Tape reformatting	30	2
HIST	10	4
BGREYS	40	10
ISOCLAS	120	20
TYPIX	160	4
Produce land cover map photo	40	3
	400	53

C-2

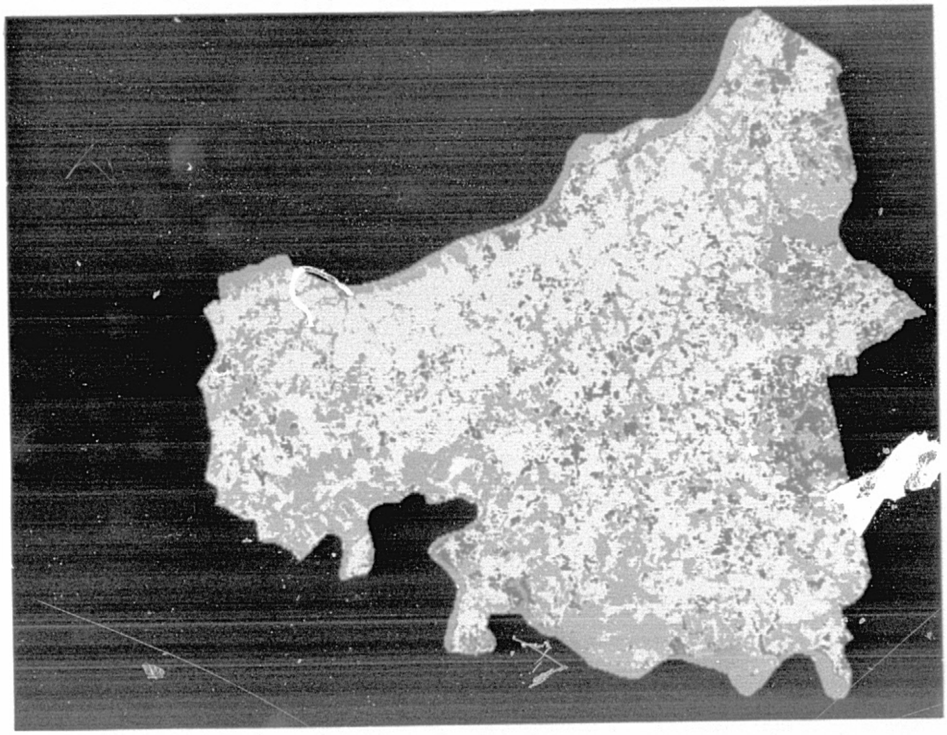

Figure 8.--Computer assisted land cover classification of King George County, Virginia. Color code: Green, conifer forest; Yellow, deciduous hardwood forest; Rust, nonforest; Blue, water.

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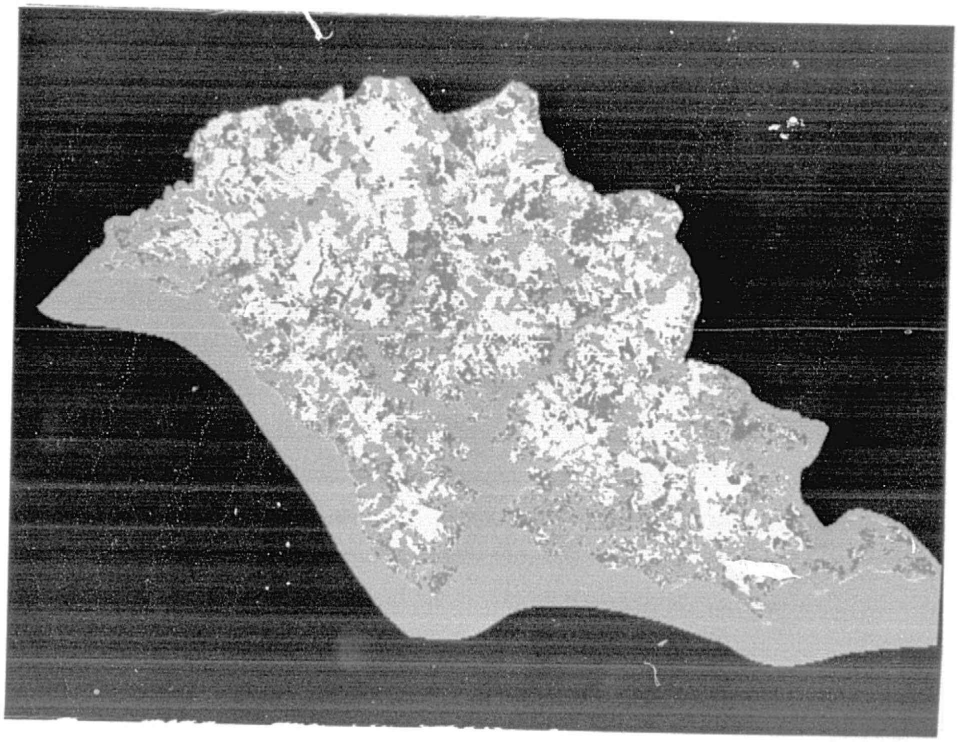

Figure 9.--Computer assisted land cover classification of Lancaster County, Virginia. The water in the lower part of the figure is the north side of the Rappahannock River; this water area is not counted as part of the county in the Forest Survey inventory. Color code: Green, conifer forest; Yellow, deciduous hardwood forest; Rust, nonforest; Blue, water.

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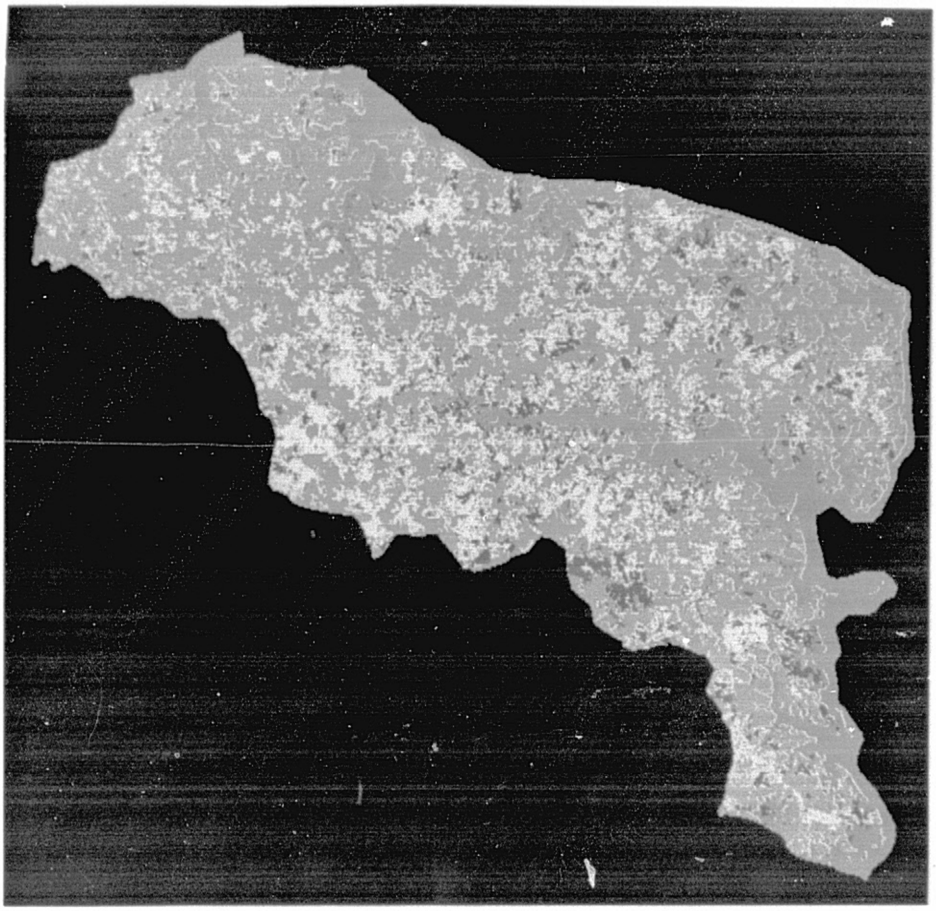

Figure 10.--Computer assisted land cover classification of Northumberland County, Virginia. Color code: Green, conifer forest; Yellow, deciduous hardwood forest; Rust, nonforest, Blue, water.

STANDARDIZATION AND QUANTIFICATIONS OF LANDSAT DATA

Solar and Atmospheric Effects on LANDSAT Imagery

by

Robert W. Dana

Introduction

The application of spectral signature extension from one satellite image to another requires a technique for calibrating and changing solar and atmospheric effects. The effects of changes in solar zenith angle, aerosol content and humidity are primary physical factors that might be accounted for in adjusting signatures for computer-aided classification. Research by Fraser (1974), Turner and others (1974), Potter and Mendlowitz (1975) and Rogers and others (1973) exhibited significant variations in either path radiance or beam transmittance, which could significantly effect the radiance of terrain elements measured by LANDSAT.

This report deals with development of an empirical method to determine solar and atmospheric affects by comparing LANDSAT MSS data with terrain reflectance data. The physical model is expressed as:

$$L = L_p + L_t r, \qquad (1)$$

in which L is the satellite radiance, L_p is the path radiance, representing scattered sunlight into the field of view of the sensor and r is the Lambertian reflectance of the terrain element. The coefficient L_t represents the product HT/π for the solar irradiance H on the ground and the vertical transmittance T of the atmosphere.

Turner (1975) has shown that in cases in which a pixel is surrounded by many pixels of greatly differing reflectance, it may be necessary to add a term (or terms) to the equation relative to background reflectance. This would account for light reflected off the ground into the satellite viewing path and then scattered toward the sensor.

The method used in this study was to measure the reflectance, from a low-flying aircraft, of many terrain elements which could be registered to LANDSAT digital data. The LANDSAT radiance is then fitted to reflectance by regression to find the coefficients L_p, L_t and any additional background related coefficients. Due to the linearity of the MSS calibration, the coefficients L_p and L_t could also account for changes in sensor conversion between digital counts and radiance expressed as $mw/cm^{-2}sr$.

Background

The reflectance measurement technique described in this report was employed in an earlier study in California and South Dakota (Dana 1975). Wide band reflectance values acquired from a low-flying aircraft in Northern California correlated well with Skylab (EREP) S190A sensors, and reflectance values from the Black Hills of South Dakota also correlated with LANDSAT 1 data. The coefficients of the regression lines in these two examples gave reasonable values for the path radiance and beam transmittance. However, this earlier aircraft system was able to measure only one spectral band of reflectance at a time, and repeated flight lines were required to complete the other bands. An improved system was developed for this study to measure four registered bands simultaneously; therefore, four times as much data can be gathered (and more precisely) during the approximately one hour time span relevant to a LANDSAT overpass.

Study Area

Test subsites for the determination of solar and atmospheric effects are in the nine county Virginia test site (fig. 1). Of the total of five subsites, three are along the coast to test the full effects of maritime air. One subsite is in the SE corner of Lancaster County near Windmill point, and two are in Northumberland County: (1) at Dameron Marsh south of Ingram bay, and (2) at the northern end of the county between Monday Point and Lewisetta.

Two subsites are located inland in Essex and Caroline Counties. The former is at Millers Tavern west of Brays near the center of Essex County. The latter is near the western extremity of the nine county area around Lake Caroline.

All subsites include bare plowed fields, agricultural crops, pine, hardwood and mixed pine-hardwood stands. In all but the Windmill Point area there were examples of forest areas clear cut within the past 10 years. Most subsites included a few grazed pastures. All but the Millers Tavern area included census water.

Instrumentation

The measurement of terrain reflectance required an assembly of instruments in a twin engine aircraft. It consisted of an inverter to power several A/C driven devices, a digital data logger, a four-channel radiometer, an irradiance meter and a video camera with recorder for support photography.

The most critical component of the system was a four-channel radiometer capable of measuring radiance in the LANDSAT-MSS-matched wavelength bands. Through boresighted optics, the four measurements were made of virtually the same spot on the ground with a field of view of 9.4 degrees. Details of this instrument which was designed and constructed in our laboratory are given in Appendix B.

The digital data system sampled the analog signals from the radiometer and an irradiance meter once per second. This data, along with a time code from a digital clock, was recorded on computer compatible tape. The sampling interval on the ground was approximately 50m, slightly less than the dimensions of a LANDSAT picture element. The irradiance meter consisted of a diffusing receptor mounted on the top surface of the aircraft, a fiber optic light guide and a small filter-wheel radiometer for wavelength separation and detection. The filters are matched to those in the four-channel radiometer.

The video system with a silicon diode array camera boresighted to the downlooking radiometer is described by Dana (1975) and by Aldrich and others (1976). We added, for this experiment, a video clock module which displays elasped time in minutes, seconds and hundreths in the corner of the picture frame. The camera was filtered for MSS band 5 throughout the flights. Fig. 1 and 12 show most of the aircraft systems as it was mounted in the Aero Commander 500 B.

Concurrent to the aircraft flights we performed irradiance measurements on the ground at two subsites. We used a spectrometer equipped with a circular variable filter (CVF). At intervals of 20 nanometers (nm) the incident sunlight was scanned between the wavelengths of 440 and 1180 nm.

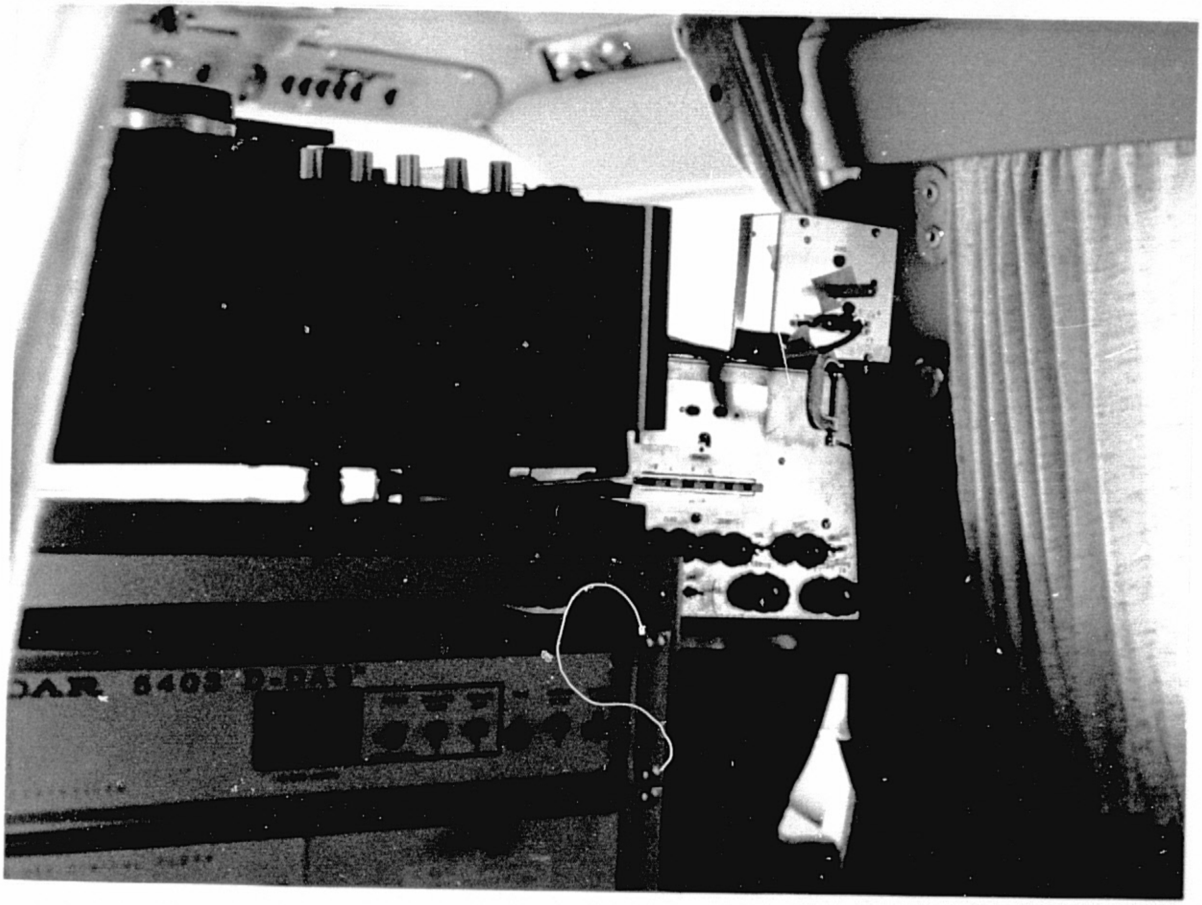

Figure 11.--Aircraft radiometric instrumentation. Clockwise from lower left--data system, video tape recorder, irradiance meter and four channel radiometer electronics module.

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Figure 12.--Aircraft radiometric instrumentation. Left to right--the data system, video monitor, four channel radiometer optical sensing head, silicon vidicon camera.

Data Acquisition

The bulk of the data acquisition for this study was done on the third and fourth days after the primary LANDSAT pass of April 20, 1976. Once a field crew determined that the satellite had encountered a clear atmosphere and that the image would be useable, the plane and flight crew were sent from California to the Virginia site. On April 23, before any significant phenological changes could have occured since the LANDSAT date, the coastal subsites were flown. On the next day the two inland subsites were flown. At each subsite three or four flight lines were flown generally in a west to east direction. For the pilot's convenience, and the convenience of locating flight lines on maps and LANDSAT printouts, we tried to align the flight line with easily recognized terrain features along the direction of LANDSAT scan lines. For the duration (3 to 5 minutes) of the 5 to 9 mile flight lines, the data logger and radiometers were running. The irradiance measurements were primarily of the red band, band 5. We did sample all four bands of irradiance at least once at each subsite to test for changes in spectral sunlight distribution.

Analysis Techniques

The first step in the data analysis was to prepare maps of the experimental subsites on which identification numbers and land class codes could be written for areas along the aircraft flight lines. These maps were sketched, using the zoom transfer scope, from available 1:120,000 scale CIR photography, taken in May 1975. The scale chosen for the subsite sketch maps was approximately 1:24,000 matching the scale of grey-scale printouts of LANDSAT tapes.

For the purpose of this report the term "data field" or simply "field" will be used for those recognizable terrain features and areas over which sampled radiance data were integrated to obtain registered data pairs for the correlation. A field could represent an agricultural field, forested area or stretch of water which appears relatively homogeneous on video imagery and aerial photography. At each subsite each individual field is given a number.

The next activity in the analysis was to review the video tapes recorded during the radiance flights. We used the same standard ½ inch video tape recorder and closed circuit monitor that were used for data acquisition. Candidate data fields under the center of the video image strip, which looked to be at least 2 LANDSAT picture elements in width, were chosen and given a number. Video clock times for aircraft passage were also recorded. As near as could be determined from the black and white imagery, classifications such as, bare field, agricultural crop, pine, hardwood, shallow water and deep water were also recorded.

Lists of passage times of the candidate fields were then compared with the printouts of time, radiance and irradiance from the aircraft tapes. Field boundaries were located on the printout, usually within 1 second of the times derived from the video base. Care was taken to eliminate sample points which appeared to straddle, if only partially, the field boundaries. With each subsite a few fields were eliminated due to data dropouts from the aircraft data stream.

Mean radiance (voltage) values were computed for each field and calibration coefficients applied to derive radiance L in mV $cm^{-2}sr^{-1}$. Irradiance H was plotted for each flight line, and the four bands adjusted according to variations in the band 5 signal. Calibration was performed on this data and the mean reflectance of each field was computed from the equation $\pi L/H$.

LANDSAT radiance values, in digital counts, were printed out for each subsite and for each available coverage date after LANDSAT line and pixel locations were found from grey-scale maps. In addition, an ISOCLAS unsupervised classification (see Page 71) was made for each area. These maps displaying 10 clusters from 5 processing iterations proved more useful in locating flight lines (and therefore data fields) than grey-scale maps of either band 5 or 7. The extra information from four bands rather than one band made them worth the extra processing cost.

About 90 percent of the fields located on LANDSAT were felt to be well registered with the aircraft data. Due to the shape, small size and orientation of some fields the remainder were of doubtful registration. They were kept in the data base but coded so they could be eliminated later.

Mean values of the fields were computed and converted, using NASA calibration data (LANDSAT Newsletter 1977), to radiance units of mw $cm^{-2}sr^{-1}$. The conversion equations were:

$$L_4 = 0.08 + 0.0201\ C_4, \qquad (2)$$

$$L_5 = 0.06 + 0.0134\ C_5, \qquad (3)$$

$$L_6 = 0.06 + 0.0115\ C_6, \qquad (4)$$

$$L_7 = 0.11 + 0.0603\ C_7, \qquad (5)$$

for bands 4, 5, 6, and 7 respectively, in which C was the radiance in digital counts.

In the final stage of analysis, a linear least-squares fit was applied to the bivariate population of LANDSAT radiance L and aircraft reflectance r. The independent variable was taken as r and the dependent variable was L. The coefficients of the regression line and the coefficient of determination were then computed for all data sets.

The results of regression analysis of eight subsite/date combinations (Table 22) show a general agreement with the linear, two-term model. Except for two cases (Dameron 4/19 bands 6 and 7), the coefficients of determination r^2 are greater than .83.

The most intensively studied site, Monday Pt., displays a very linear relationship (fig. 13 and 14) between aircraft-measured reflectance and MSS radiance. Here, the problem of obtaining a continuous range of target reflectances to measure atmospheric parameters in the infrared bands 6 and 7 are exemplified. There is a tendency toward three data clusters---high reflectance targets such as bare fields, green crops and green pastures, medium-high reflectance forest stands and drier pastures, and the very low reflectance water bodies. However, a pair of marshland fields in the Windmill site (fig.15) with reflectance values in the .09 to .13 range fall on the regression line and partially justify the regression solution for the whole range of infrared reflectances. The Millers' Tavern site, with no water bodies produced a linear fit with low scatter despite the limited reflectance spread (fig. 16 and 17). The poorest linear fit occurred with the Dameron site on April 19, 1976 (fig. 18). Few water bodies or marshes were usable on this date because a fog cloud extended in from Chesapeake Bay covering most of them. Our observer on the ground the day of the aircraft overflight found evidence that the Dameron area had received a moderate rainfall, probably within the previous 24 hours. This undoubtedly darkened the soil in the infrared wavelengths, reducing the reflectance in bands 6 and 7 below the levels of the LANDSAT passes, a few days earlier.

A close look at the classification of the data fields of the coastal sites revealed that the mean reflectance of bare soil and sparse or immature agricultural crops was 25 percent lower for the Dameron area than for the other two sites. If these data points on fig. 18 were shifted toward 25 percent

Table 22.--Results of regression analysis for eight subsite/date combinations. The symbols r^2, L_p and L_t are coefficient of determination, path radiance and coefficient of transmitted component respectively. The units of L_p and L_t are $mWcm^{-2}sr^{-1}$.

Date	Site	Band 4			Band 5			Band 6			Band 7		
		r^2	L_p	L_t	r^2	L_p	L_t	r^2	L_p	L_t	r^2	L_p	L_t
April 20, 1976	Monday Pt.	.91	.42	2.77	.94	.25	2.49	.97	.16	2.21	.97	.21	4.20
	Dameron Marsh.	.84	.37	4.11	.91	.23	3.43	.84	.19	2.31	.84	.29	4.26
	Windmill Pt.	.90	.40	2.65	.93	.23	2.50	.95	.18	2.00	.97	.23	3.89
	Millers Tavern	.96	.42	2.44	.97	.27	2.30	.94	.18	2.07	.88	.20	4.09
	Lk. Caroline	.93	.42	2.45	.91	.28	2.02	.94	.18	2.18	.97	.23	4.42
April 19, 1976	Monday Pt.	.94	.42	2.87	.96	.23	2.68	.98	.14	2.40	.98	.16	4.58
	Dameron Marsh.	.84	.32	5.23	.90	.21	4.05	.50	.25	2.22	.55	.52	3.76
	Windmill Pt.	.95	.38	3.45	.97	.21	2.99	.98	.16	2.32	.98	.19	4.29

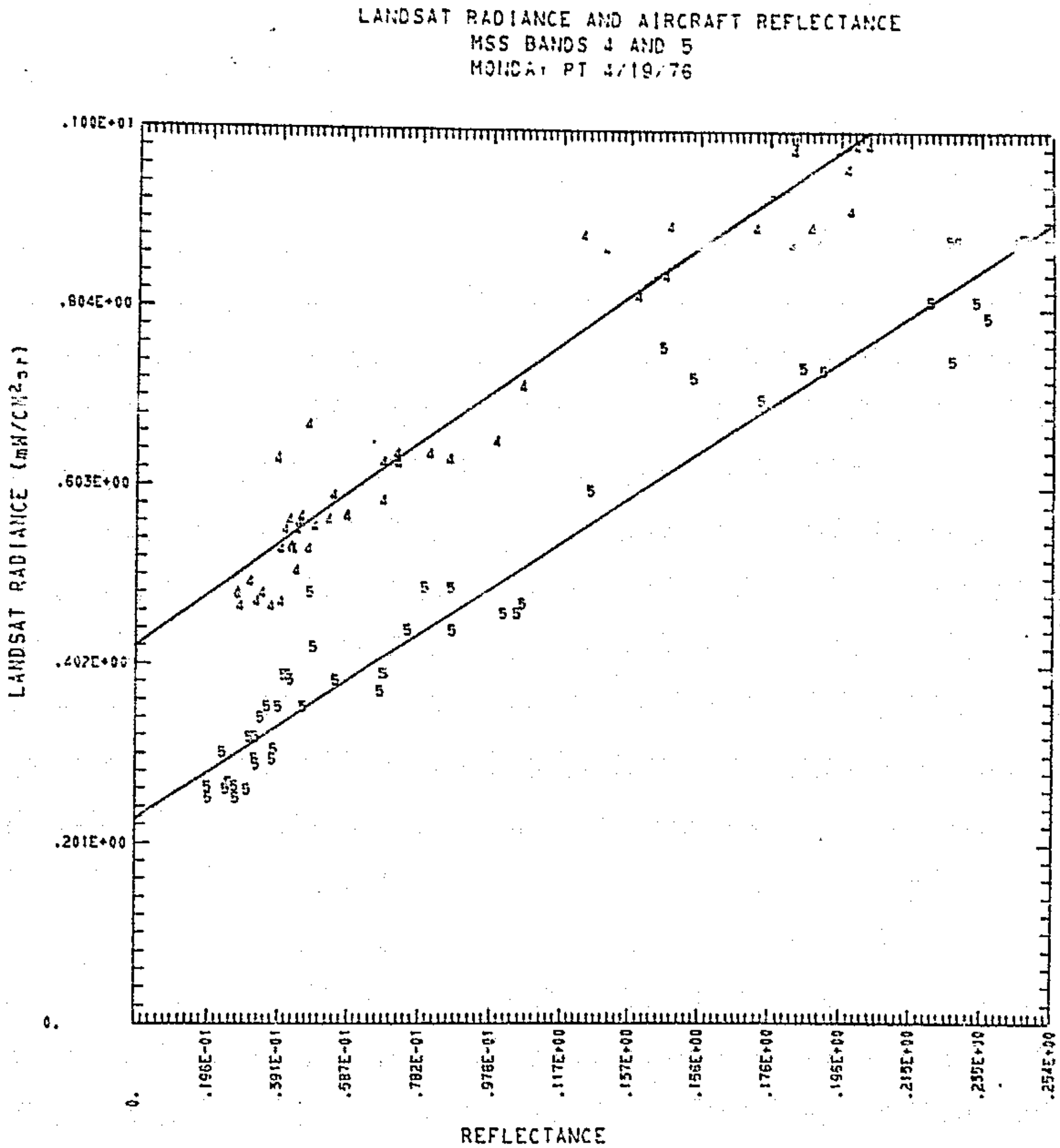

Figure 13.--Scatter diagram for the Monday Pt. subsite on April 19, 1976 for MSS band 4 and 5. Coefficients of the regression lines are given in Table 22.

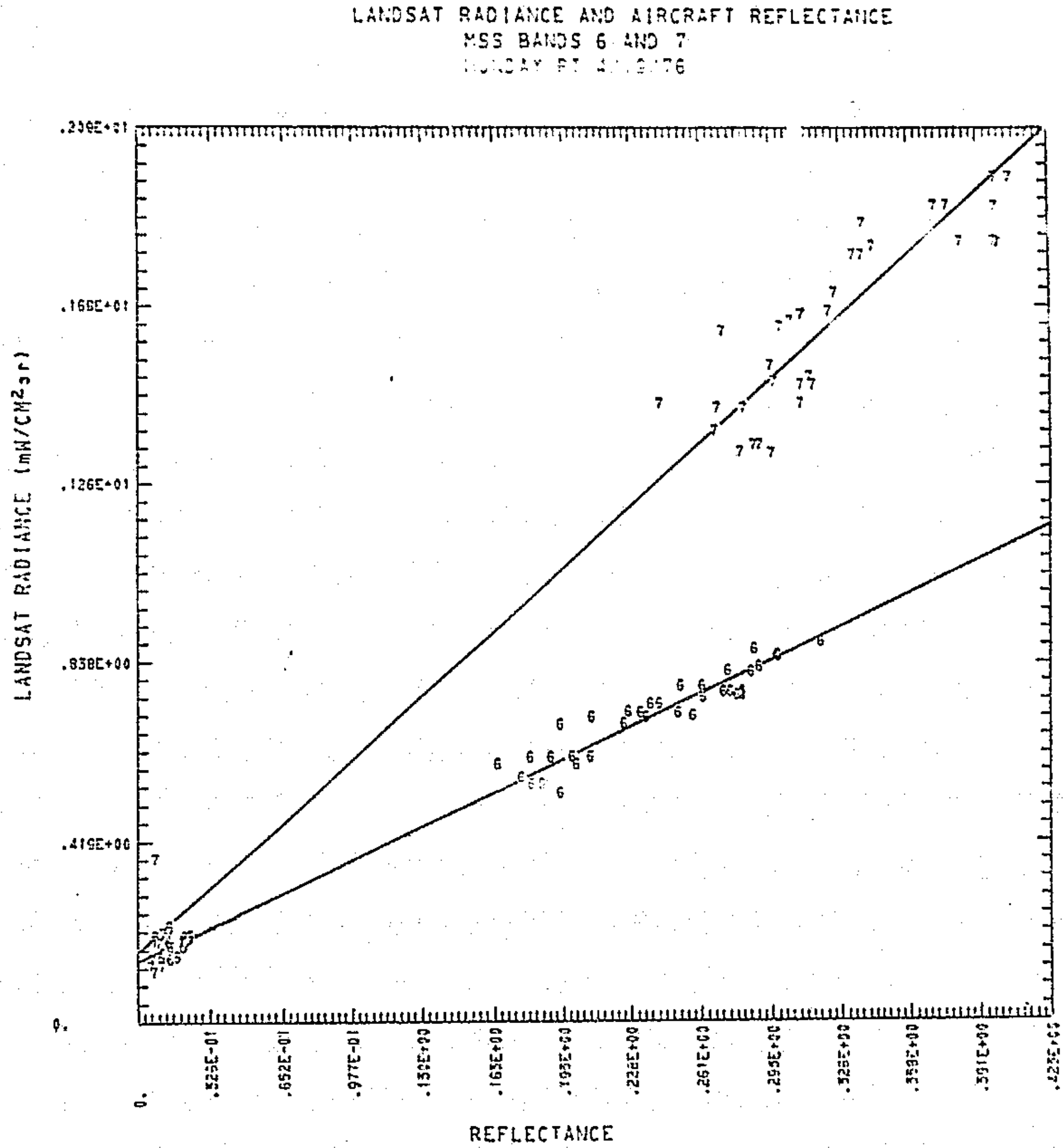

Figure 14.--Scatter diagram for the Monday Pt. subsite on April 19, 1976 for MSS band 6 and 7. Coefficients of the regression lines are given in Table 22.

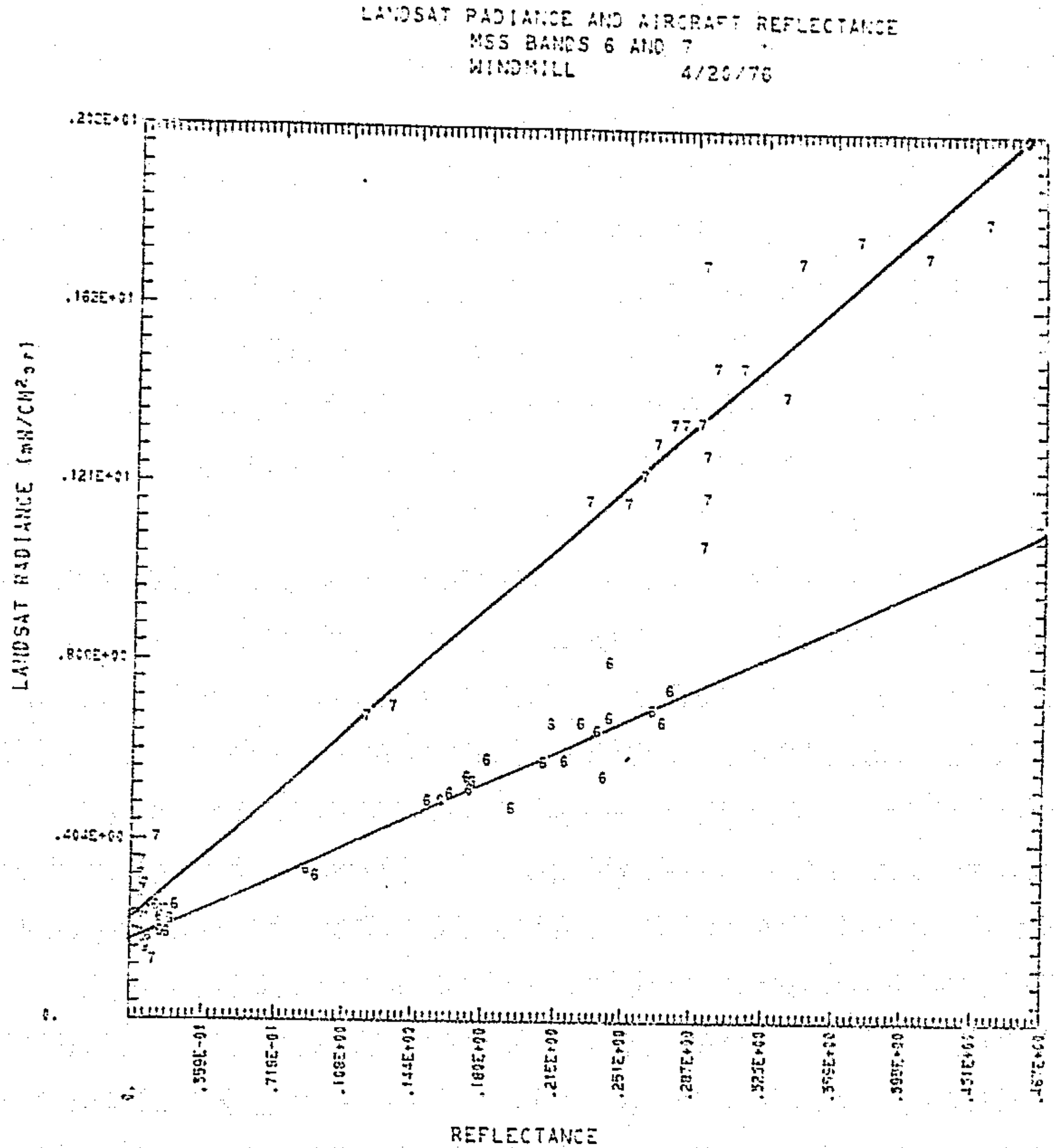

Figure 15.--Scatter diagram for the Windmill subsite on April 20, 1976 for MSS band 6 and 7. Coefficients of the regression lines are given in Table 22.

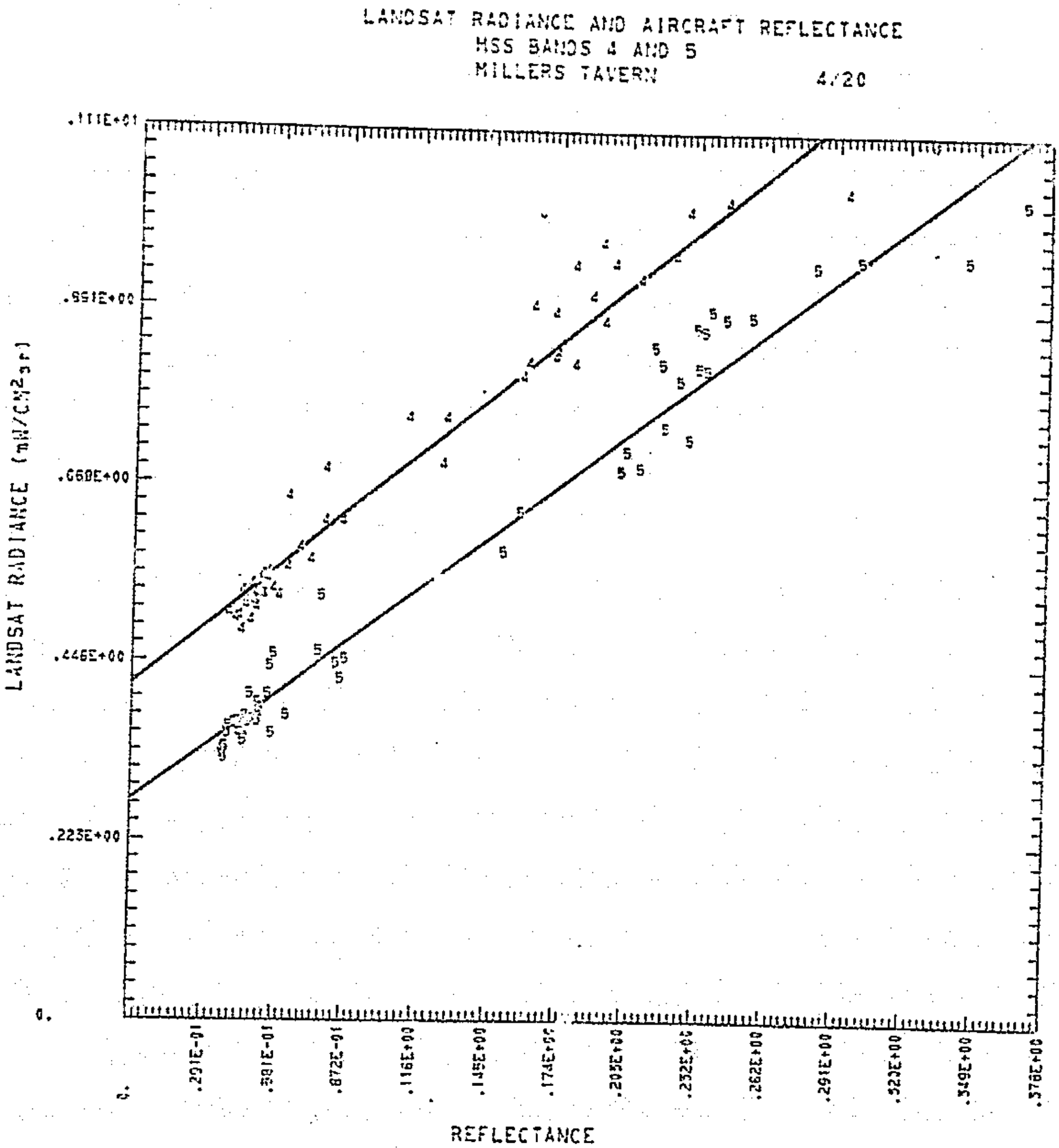

Figure 16.--Scatter diagram for the Millers Tavern subsite on April 20, 1976 for MSS band 4 and 5. Coefficients of the regression lines are given in Table 22.

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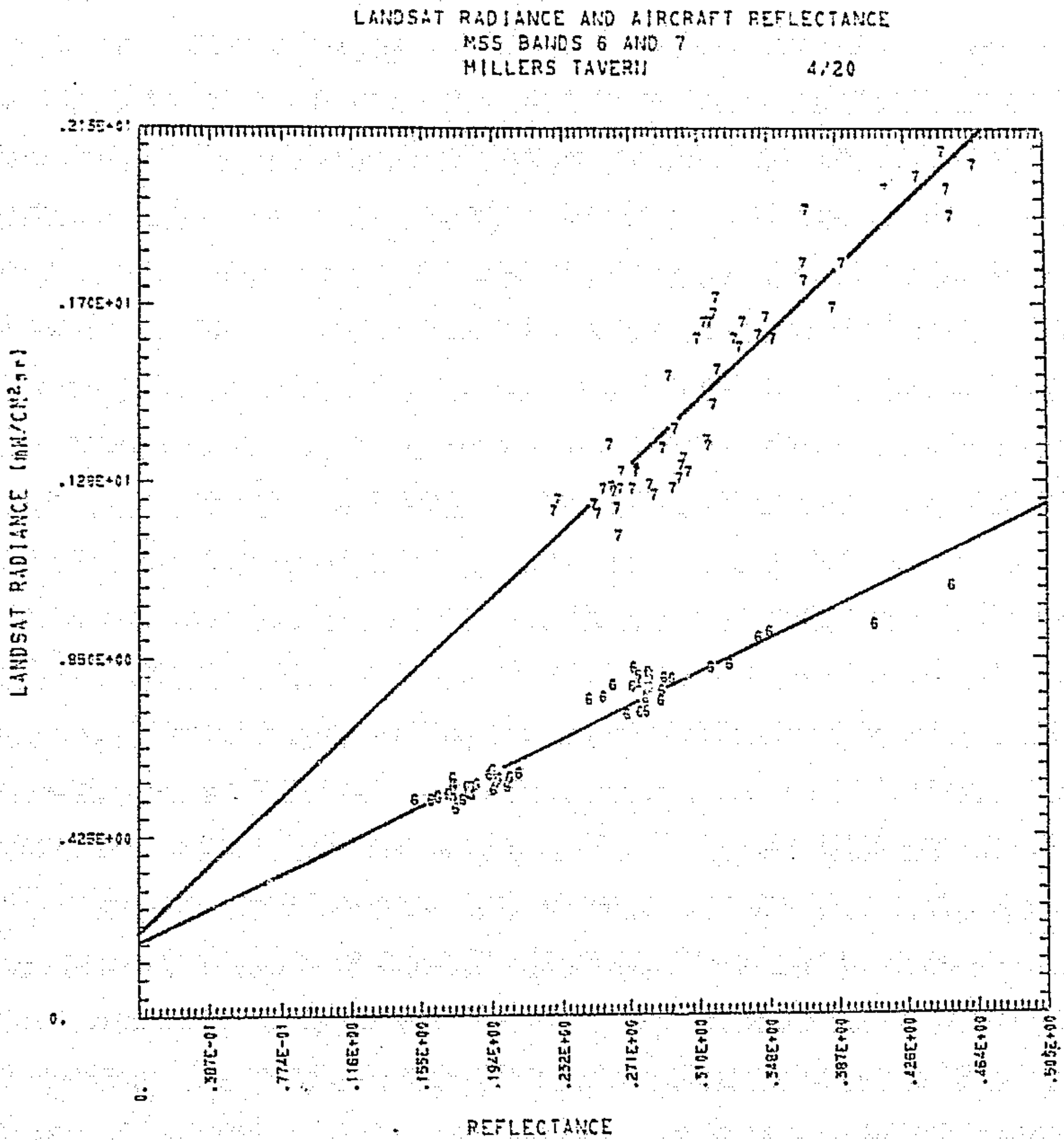

Figure 17.--Scatter diagram for the Millers Tavern subsite for April 20, 1976 for MSS bands 6 and 7. Coefficients of the regression lines are given in Table 22.

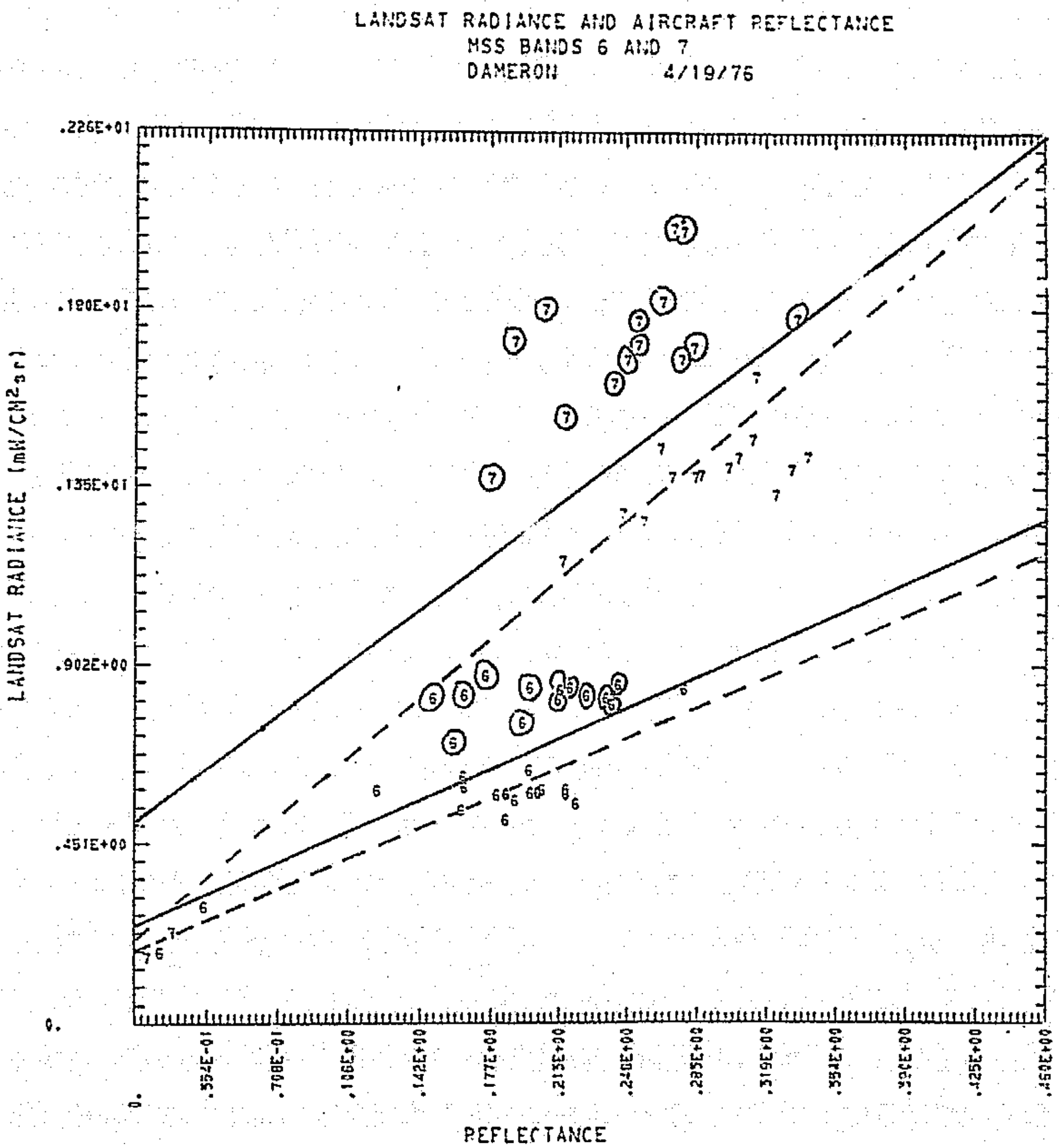

Figure 18.--Scatter diagram for the Dameron subsite on April 19, 1976 for MSS bands 6 and 7. Solid lines are regression lines with coefficients given in Table 22. Dashed lines are mean regression lines of the other seven sites. Circled data points are bare fields or sparse crops.

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higher reflectance, the regression line would approach the typical line of the other seven sites. The complication of the rainfall probably increased the scatter in the models for bands 4 and 5 of April 19 and for all bands of April 20 at the Dameron site (Table 22).

With this data set, as with others, indications of background reflectance effects were sought to explain scatter in the data. Few of the points which lie far off the regression lines appear to be surrounded by areas significantly higher or lower reflectance. The difficulty in finding field-averaged background reflectance for varying size areas around the data fields made this activity beyond the scope of this study.

To determine the applicability of the atmospheric parameters we compared the mean radiance values for recognizable clusters in ISOCLAS runs of the various subsites. We standardized to a run of 5 iterations to derive 10 clusters on the LANDSAT tapes. As an example, Table 23 shows the percent difference in cluster mean values between the same precisely defined Windmill Pt. site on April 19 and April 20. Using the regression derived parameter L_p and L_t for both dates, the April 20th signatures were corrected to the conditions of April 19th. Comparison of Table 23 with Table 24 shows that the first cluster was over-corrected, and the last cluster was changed very little, but the remaining three clusters were brought closer together by the atmospheric correction.

The Monday Pt. scenes differ very little in radiance between the two dates and the similarity of atmospheric parameters (Table 22) bears this out. To summarize this comparison, the values of L_p and L_t, when used to convert radiance to reflectance, show agreement between dates to within 0.010 reflectance.

An adequate test of the applicability of this technique for signature

Table 23.--Percent difference in LANDSAT radiance between the April 19, 1976 and April 20, 1976 scenes of the Windmill Pt. Site. Mean values of five ISOCLAS clusters are shown.

Cluster	MSS Band 4	MSS Band 5	MSS Band 6	MSS Band 7
	- - - - - - - -	- - -Percent-	- - - - - -	- -
1 (Bare Soil)	-5.1	-5.3	-3.0	-2.4
3 (green crops)	-3.2	-3.7	-6.3	-6.8
4 (Deep water)	3.6	7.2	11.1	28.2
6 (Shallow water)	-1.1	3.4	12.8	33.5
7 (Forest)	-0.8	0.0	-3.0	-4.1

Table 24.--Percent difference between LANDSAT radiance on April 19, 1976 and LANDSAT radiance on April 20, 1976 corrected by the atmospheric coefficients of both scenes. (Monday Pt. site). Mean values of five ISOCLAS clusters are shown.

Cluster	MSS Band 4	5	6	7
	- - - - - - -Percent- - - - -			
1 (Bare soil)	8.3	8.1	6.1	3.8
3 (Green crops)	0.5	0.0	1.6	-0.5
4 (Deep water)	2.5	1.7	-2.1	-3.7
6 (Shallow water)	2.5	6.1	6.9	14.1
7 (Forest)	1.2	2.1	3.2	0.9

extension requires data sets sampling a wider range of atmospheric effects. It would seem that haze conditions which alter satellite radiance by 10-15 percent or more might be reasonably corrected. This is in light of the fact that the radiance and irradiance measurements used in the terrain reflectance determinations are uncertain to about 5-7 percent.

Comparisons of different subsites with ISOCLAS results requires much more work than originally was anticipated. For instance, ISOCLAS tends to split clusters differently for different areas, resulting in uncertainty about common identity of cover classes. Out of a possible 10 clusters one subsite might produce three bare soil clusters, two water clusters, two vegetation clusters and three mixed pixel clusters. Another subsite might produce two soil, three water, three vegetation and two mixed pixel clusters out of the ten. For this reason, and the fact that few significant differences in L_p and L_t values occurred, no thorough comparisons of subsites was performed.

In conclusion, this study produced substantial evidence for the validity of a linear atmospheric model with an additive (path radiance) term and a multiplicative (transmittance) term. The display of the usefulness of signature extension with this technique requires data sets with greater haze variations than were encountered on the two dates examined.

RESOURCE INFORMATION FOR AREA DECISION MANAGEMENT PLANS

by

Robert C. Aldrich

Introduction

There are many sources of information to aid land managers and county planners in making short and long range plans. Information is available from several federal departments and bureaus including the Bureau of the Census, Department of Agriculture, Department of Interior, and National Oceanic and Atmospheric Administration. Information can be obtained in the form of tabulations and maps to show population growth and distribution, land areas, soils and soil uses, land uses, forest areas and volumes, water, topography, climate and other information.

This section will show how results of inventory studies in this report might be used in combination with other information sources to make an area decision management plan.

Area Description

King George County was picked for this demonstration because it has more information available than other counties and is small enough to be manageable yet is large enough to have reliable sample statistics (fig. 19). The total area of King George County is 47,398 hectares (117,120 acres) of which 45,585 hectares (112,640 acres) is land area.[5]

[5]Bureau of the Census, Land and Water Area of the United States, 1970.

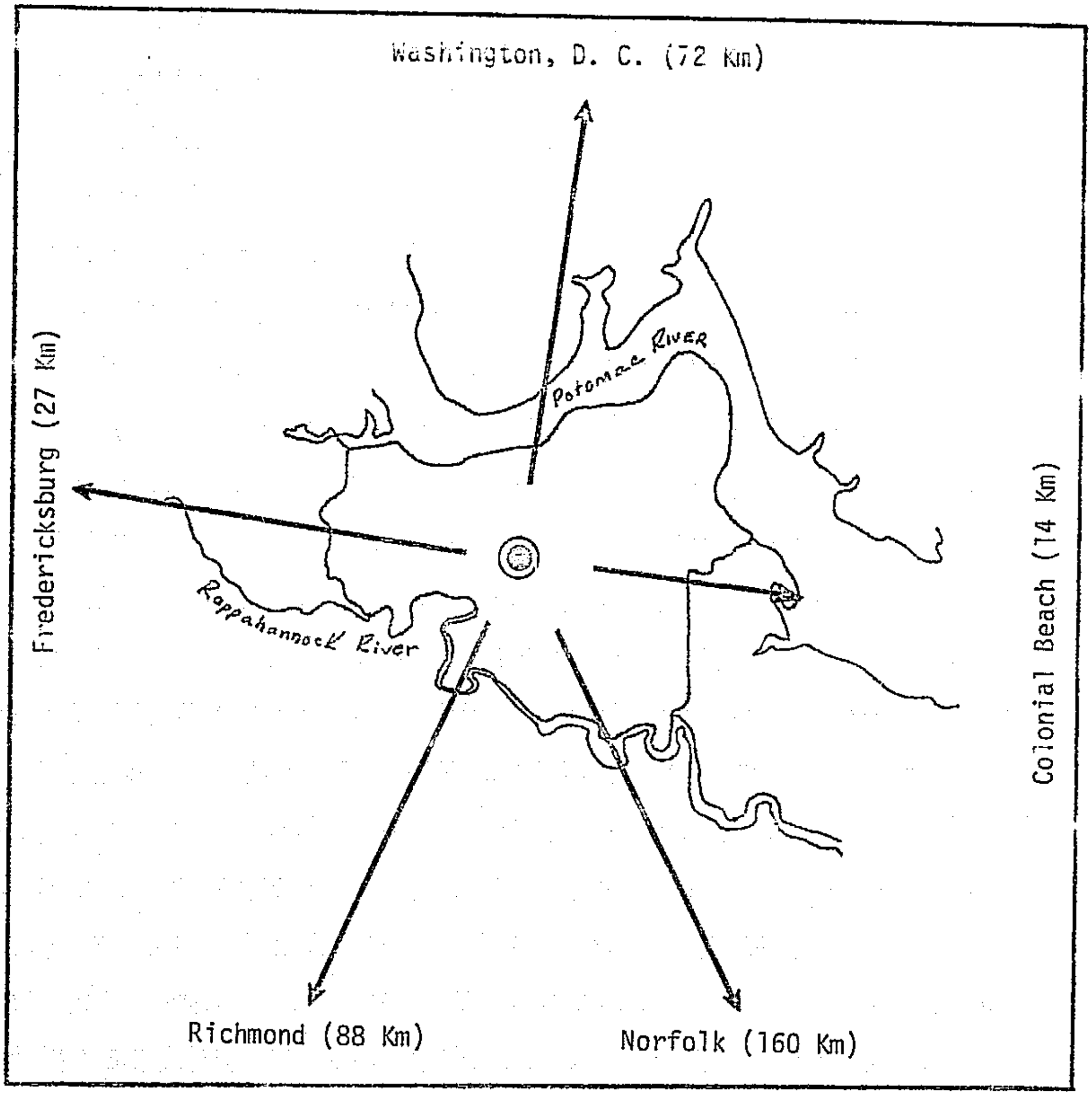

Figure 19.--King George County, Virginia lies between the Potomac River on the north and the Rappahannock River on the south. Washington, D.C., Richmond and Norfolk are all within 100 miles (160 kilometers).

The county lies in the Northern Atlantic Slope Truck, Fruit and Poultry Land Resource Region of the Northern Coastal Plain Land Resource Area.[6]

King George County has a history of agriculture use that resulted in most of the lands being cleared and cultivated for crops such as corn, tobacco, small grains, and hay (USDA SCS 1974). Over the years soil erosion, a reduction in soil fertility, and changing market conditions, have made most farming operations in the county unprofitable. As a result, much of the farmland reverted back to forest land either naturally or by planting. This means that most of the forest area at one time was used for agriculture. Forest land now represents 62 percent of the total land area.

Dahlgren Naval Weapons Laboratory and Proving Grounds is located in the northeast corner of the county on the Potomac River. This facility is the only federal land and is the largest public property in King George County. However, because the land is used for testing weapons, it is not useable for other purposes and all forest land has been removed from the commercial forest area base.

Physical Characteristics

Elevations in King George County range from sea level to 200 feet (61 meters)--the mean elevation is 82 feet (25 meters) above sea level. Within this undulating to rolling, frequently dissected coastal plain county are 8 soil associations that include landscapes with distinctive patterns of soil (fig. 20). These soils are underlain by unconsolidated sands, silts, and clays (USDA SCS 1974). The eight associations are described by the SCS as follows.

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[6] United States Department of Agriculture, Soil Conservation Service, USDA. Agriculture Handbook 296, "Land Resource Regions and Major Land Resource Areas of the United States", 1963.

LEGEND

Land-use

	Color
conifer forest	green
deciduous forest	yellow
nonforest	orange
water	blue

Soils Association (red)

	Code number
Tetotum-Bladen-Bertie	1
Marr-Westphalia	2
Sassafras-Aura-Caroline	3
Turboville-Kempsville	4
Wickham-Altavista-Dogue	5
Sassafras-Galestown-Kempsville	6
Bourne-Caroline	7
Craven-Caroline	8

Transportation (Black)

	Symbol
All weather surface (County)	----------
Hard surface (State)	
Secondary	———
Primary	———
U.S. highway	———
Abandoned RR	+ + + +

Disturbed Forest (Brown)

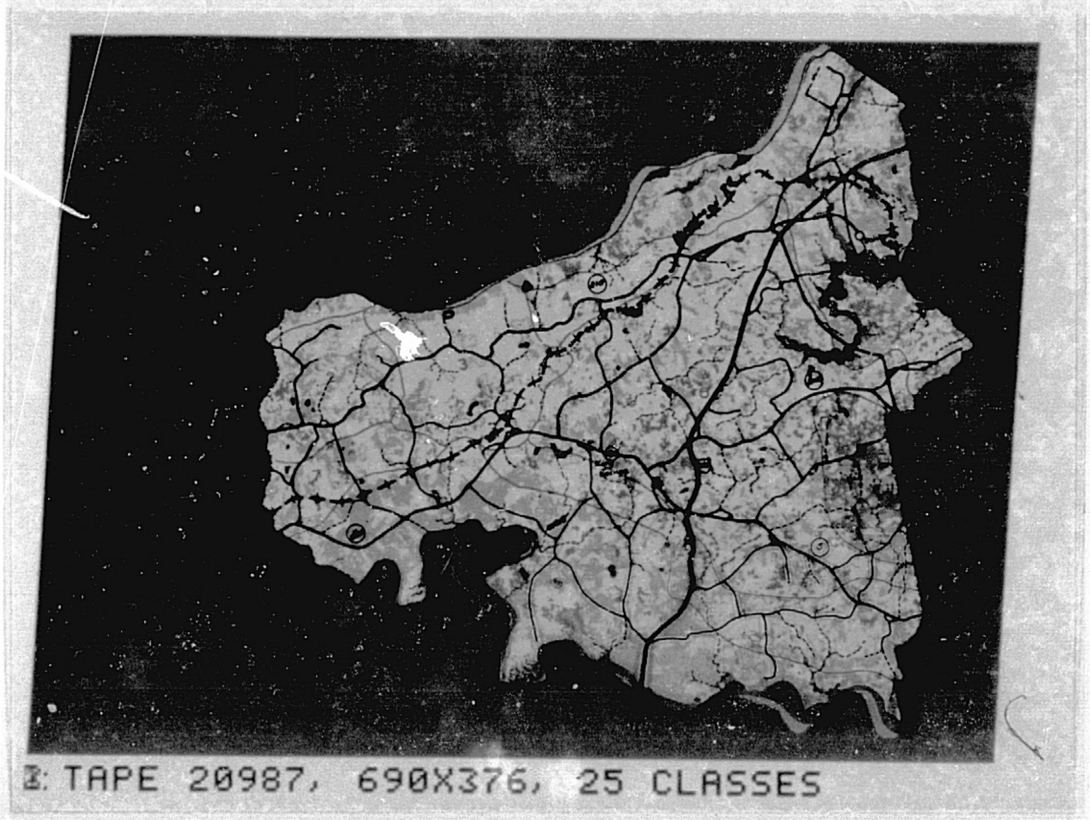

Figure 20.--Layered information from many sources can be an aid to land management and county planners. This base map shows land-use in broad categories that were classified with LANDSAT data using computer techniques. The water overlay was drawn using high altitude color infrared photographs (1:125,000 scale). The soil association map overlay was taken from the "Soil Survey, Stafford and King George Counties", 1974, United States Department of Agriculture, Soil Conservation Service. The transportation overlay was drawn from the official county map. Cut-over areas in the disturbed forest overlay were interpreted from high altitude CIR films. A legend on the opposite page identifies the color, code numbers and symbols used in the five information layers.

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Sassafras-Galestown-Kempsville Association

These are deep, well-drained to somewhat excessively drained soils having a sandy clay loam or loamy fine sand subsoil. This association occupies an area of broad, nearly level to gently sloping tops of ridges and steep sides of ridges. Slopes are predominantly 0 to 6 percent on the top and 15 to 45 percent on the sides. Alluvial areas along the small streams are wet and swampy. This association covers 30 percent of King George County.

Most of the nearly level to gently sloping ridges are in crops and pasture. Steeper slopes and some ridge tops are wooded. Oak, hickory, and yellow poplar are predominant. Small homesites are appearing along roads in this association. There are only slight limitations for septic tank systems.

Sassafras-Aura-Caroline Association

These soils are deep, well-drained soils having sandy clay loam, heavy clay loam, or clay subsoil. This association is found in one small area in King George County and amounts to 8 percent of the total area. It is undulating to hilly, but includes narrow ridges where slopes are 2 to 10 percent on the top and 10 to 35 percent on the sides. Most of this association is wooded with oak, hickory, and yellow poplar predominant. Virginia pine and loblolly pine are found on farmland that has reverted to forest. This land has moderate to severe limitations for septic tank systems but the number of homesites along roads is increasing.

Marr-Westphalia Association

This association occupies a small area in western King George County and makes up 2 percent of the county area. The soils are deep, well-drained and have sandy clay loam or very fine sandy loam subsoils. The land is rolling to hilly but includes narrow ridges with slopes of 2 to 10 percent on top and 10 to 30 percent on the sides. These soils are underlain by thick deposits of very fine sands and a few small areas of silt. Most of these soils are wooded and the rest are in crops, pasture, and small homesites. Hickory, oak, yellow poplar and gum are the predominant tree species. Land reverting to forest is in Virginia pine. There are moderate to severe limitations on septic tank systems in these areas.

Bourne-Caroline Association

These soils found in western King George County are deep, moderately well-drained to well-drained having a fragipan or having heavy clay loam and clay subsoil. The land is undulating to rolling but includes broad ridge tops with slopes 0 to 6 percent on top and 6 to 18 percent on the sides. Most of this association is in crops and pasture. It has severe limitations for septic tank systems although homesites are increasing in this association at a rapid rate.

Craven-Caroline Association

The soils of this association are deep, well-drained to moderately well-drained soils having heavy clay loam and clay subsoil. Making up about 5 percent of the county total area, this association is located in the eastern part of King George County. It is nearly level to gently sloping but includes short, sharp slopes along the larger drainage-ways and small streams. Slopes range from 0 to 6 percent on the broad areas and from 6 to 18 percent on the short, sharp slopes. Most of this association is wooded. Oak and hickory predominate with Virginia pine and loblolly pines coming in on cut and burned areas and on farmland reverting to forest. Most of the association has severe limitations for septic tank systems.

Tetotum-Bladen-Bertie Association

These deep, moderately well-drained to poorly drained soils have clay loam, sandy clay loam, or clay subsoils and are located in northern King George County. Slopes are dominantly 0 to 10 percent. Steep banks along the Potomac River have active shoreline erosion. These soils make up 13 percent of the county area. This association is mostly wooded with mixtures of oak, hickory, gum, sycamore, maple, birch, and willow predominating. Virginia pine and loblolly pine occur in farmland reverting to forest. The soils have moderate to severe limitations for septic tank systems. Homesites and some boating and recreation facilities are developing along larger streams and the Potomac River.

Wickham-Altavista-Dogue Association

The soils in this association make up 25 percent of King George County. The soils are deep, well-drained to moderately well-drained and have sandy clay loam, clay loam, or clay subsoils. Slopes are mostly 0 to 6 percent but range from 0 to 12 percent. Sand and gravel pits and Tidal marsh along the Rappahannock River also make up significant areas of this association. Most of the association is in crops with few acres of pasture and woodland. This association has possibilities for septic tank systems with very slight to moderate limitations.

Turbeville-Kempsville Association

This association occupies a small area in the west-central part, and a narrow belt in the eastern part of King George County. The association includes 15 percent of the county area. The soils are deep, well-drained and have sandy clay loam, heavy clay loam, or clay subsoils. Most of this association is wooded with oak, hickory, and yellow poplar the predominant species. Virginia pine and loblolly pine are found on farmland that is reverting to forest. There are some crops and pastures in this association. Limitations of the soil for septic tank systems are moderate to slight.

Soil association descriptions plus soil association maps, topography and other resource information should be useful to planners who want a general idea of conditions in the county, who want to compare different sections of the county, or who are looking for areas suitable for a particular land use.

Climate

King George County enjoys a relatively moderate climate with temperatures ranging from the mid-teens up to the high nineties. The last frost in the spring occurs in mid-April and the first frost of the fall occurs in late October. Between these two dates the average daily temperatures range from 53°F (11.7°C) to 77°F (25.0°C). A maximum of 98°F (37°C) was recorded on August 3, 1975. The lowest temperature in 1975 was 16°F (-9°C) and occurred on February 10.

Normal annual precipitation for King George County and vicinity is 42.9 inches (109 cm). In 1975 the total annual precipitation was 55.1 inches (140 cm) or 12.2 inches (31 cm) above normal. A large part of this increase occurred during a late September torrential downpour (fig. 21).

Some comparative statistics related to precipitation that should be of concern in land management and planning are tabulated below:

	1975[7]	Normal[8]
Total annual precipitation	55.1	42.9
Growing season precipitation:		
March-April-May	13.8	10.0
June-July-August	14.9	14.0
Sept.-Oct.-Nov.	16.2	8.0

[7]United States Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service; Virginia, Volume 84, No. 1-13, 1974; Volume 85, No. 1-13, 1975; and Volume 86, No. 1-9, 1976.

[8]From "Climatic Atlas of the United States", Environmental Data Service, Environmental Science Service Administration, U.S. Department of Commerce, 1968.

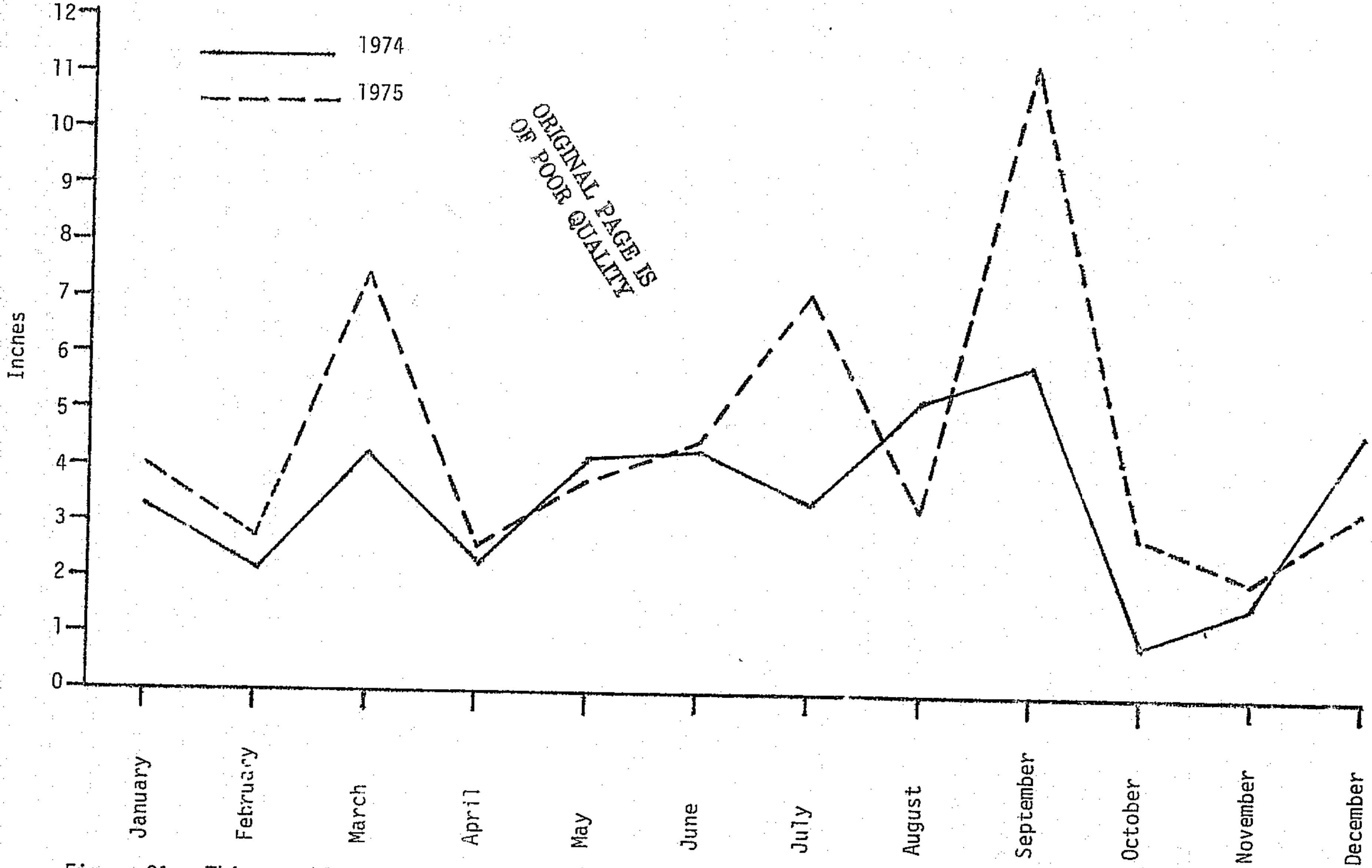

Figure 21.--This monthly precipitation profile for 1974, 1975 and part of 1976 shows the extreme variations during 1975. A torrential down-pour occurred in late September 1975 causing flooding along the Potomac River and northern Virginia.

Other climate related information of interest includes the following:

	Severity or frequency
Forest fire occurrence[9] (frequency of 0-132 fires per million acres protected by state fire-control organizations during 1956-1965)	very low
Major forest insects (William H. Bennett, Southern Forest Exp. Station, New Orleans, La.)	low
Glaze storms (frequency 1925-1953)[10]	7-13
Damaging tropical storms (1901-1955)[11]	6-10

Population

The Bureau of the Census in 1970[12] reported a population of 8,039 people in King George County with a density of 45.7 per square mile (17.9 per square kilometer). The total population was listed as rural. The gain in population since 1960 was 796 or 11 percent. According to the 1970 Census there are no incorporated or unincorporated places over 1,000 in population. This means that a large part of the population of

9 From M.L. Doolittle, "Forest Fire Occurrence in the South", 1956-1965, USDA Forest Service Research Note SO-97, 1969.

10 From Technical Report EP-105, "Glaze, Its Meteorology and Climatology, Geographical Distribution, and Economic Effects," Environmental Protection Research Division, Quartermaster Research and Engineering Command, U.S. Army, 1959.

11 From "Climates of the States--Florida", Environmental Data Service Environmental Sciences Services Administration, U.S. Department of Commerce, 1967.

12 From Table 9. Population and Land Area of Counties: 1970 and 1960 Department of Commerce, Bureau of the Census, Virginia 48-51.

King George County is probably made up of rural families in agricultural related work and non-farm families employed in forest related industries. Some larger homes are being built in the county by commuters to jobs in nearby cities. Fredericksburg and Quantico are only 12 and 28 miles away, respectively. These homes are being located along the Potomac River (USDA SCS 74).

Land Use

Slightly over 62 percent of King George County is forested. The other 38 percent is divided between nonforest uses and water; 34 percent and 4 percent respectively (table 25).

Nonforest land uses at the time of the inventory in May, 1975 indicate that 10,420 hectares (25,748 acres) are used for agriculture. This is approximately 22 percent of the total county area and 65 percent of the nonforest land. Small villages, roads, highways, power lines and residential housing in the rural areas make up the bulk of the urban land use, or 3,143 hectares (7,766 acres). Marsh land along the Rappahannock River and in the northeast part of the county near Dahlgren amounts to 2,481 hectares (6,131 acres).

Forests

According to the 1966 inventory of Virginia, a large share of the forest industry is located in the coastal plain counties.[13] This is because the physiographic features and the pine timber resource are attractive to a variety of wood using industries. In 1966, there was one major sawmill and 6 smaller sawmills operating in

Table 25.--Area in forest types, land-use, and water.[1]

Resource or Land-use Class	Area[2]	
	- -Hectares- -	- -Percent- -
Conifer	12,605	26.59
Deciduous	17,008	35.88
Forest Total	29,613	62.48
Crops	4,714	9.95
Pasture	3,722	7.85
Idle	1,736	3.66
Other agriculture	248	0.52
Urban	3,143	6.63
Marsh	2,481	5.23
Industrial waste	0	0.00
Nonforest Total	16,044	33.85
Water	1,741	3.67
All land and water	47,398	100.00

[1]Areas of nonforest land were measured from a cluster sample on CIR photographs and adjusted by a regression developed from a ground subsample.

[2]Individual class percentages may not add to 100 percent because of rounding.

K[illegible] George County. Also, within a radius of 40 miles of King George County there were 12 major sawmills, 6 particle board plants, and 1 veneer plant. These facilities, plus the large proportion of forest land in King George County makes a forestry related [illegible] attractive.

Forest area is rather evenly dispersed throughout the county. One particularly large and contiguous forest area is located in the Sassafras-Aura-Caroline association and the Turbeville-Kempsville association in the northern part of the county (fig. 20).

Conifer type (pine) measured by a random-systematic two phase sampling design using LANDSAT and high altitude aircraft data was 12,605 hectares (31,147 acres) table 25. Conifers are primarily Virginia pine, Pinus Virginiana, and loblolly pine, Pinus Taeda. Virginia pine is well known for regenerating old abandoned fields and is generally acceptable for pulpwood but makes poor sawtimber because of its poor form. Loblolly is a superior species and is generally used for planting to regenerate cutover areas and abandoned land to pine. Surveys of the coastal plain in both 1966[13] and 1975[14] disclosed that conifer growing stock volume is declining. This is probably caused by a decline in conifer type area and from overcutting.

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[13] From Virginia's Timber, 1966. US Forest Service Resource Bulletin SE-8. By H.A. Knight and Joe P. McClure.

[14] From Forest Statistics for the Coastal Plain of Virginia 1976. USDA Forest Service Resource Bulletin SE-34. By Noel D. Cost.

Deciduous (hardwoods) occupy 17,008 hectares (42,027 acres) table 25. The 1975 inventory of the coastal plain showed that hardwood volume was increasing faster than at the two previous surveys.[14] This could be the result of an increase in the hardwood types, a reduction in cutting, or an increase in poor quality hardwoods.

The net cubic foot volume of wood in King George County is 121,223,000.[15] The net cubic foot volume of conifer and deciduous wood in the county is 56,378,000 (± 23 percent) and 64,845,000 (± 13.32 percent) respectively (table 16 and 17). It is apparent from the totals that despite the fact that the deciduous forest area exceeds conifer forest area by 35 percent, the volume of deciduous wood exceeds coniferous wood by only 15 percent. This could be reflecting differences in conifer sites or the fact that the growing stock volume of conifer stands is improving.

According to the latest resource inventory in 1976,[14] 24 percent of all commercial forest land in King George County has a site index of 3 (sites capable of producing 85 to 120 cubic feet per acre annually). The remainder of the commercial forest land (76 percent) grows wood on lands with a site index of 4 (sites capable of producing 50 to 85 cubic feet per acre annually). These productivity figures are based upon a limited ground sample and should not be taken to mean that there are no other sites better or worse than index 3 and 4. Generally speaking, however, these data support the inference that forest sites in King George County rate fair to poor.

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[15]Volume estimates and interpretations used here are for illustration only. Official forest statistics are reported by the Southeastern Forest Experiment Station, Box 2570, Asheville, North Carolina 28802.

Water

Water is very limited within King George County although 85 percent of the county boundary is either in or adjacent to water--Muddy Creek and Black Swamp on the west, the Potomac River on the north and northeast, and the Rappahannock River on the south. Regardless, only 3.7 percent of the total area in the county is water (Table 26). This amounts to 1741 hectares (4302 acres) of which 86 percent is in bodies of water less than 40 acres (16 hectares) in size.

Streams in King George County are estimated to be 384 kilometers (240 miles) in total length. These include 184 kilometers (115 miles) of intermittent (annual) streams and 187 kilometers (117 miles) of active (perennial) streams up to 1/8-mile (201 meters) wide.

The distribution of surface water and waterways in King George County by their utility is as follows:

Utility	Waterways (percent)	Surface Water (percent)
Navigation	14	25
Recreation	71	19
Residential	1	9
Farm	1	21
Fisheries	10	1
Industrial	2	2
Unknown	1	23

Roughly 40 percent of the surface water and 34 percent of the active streams are within 100 meters (328 feet) of an access road.

Transportation

There are two east-west primary state highways crossing the county. State route 218 connects Fredericksburg with Dahlgren and routes 3 and

205 connects Fredericksburg with Colonial Beach. Both routes have connections with north-south U.S. Highway 1 west of the Potomac and U.S. Highway 301 east of the Potomac. Both U.S. highways connect Washington, D.C. and Baltimore with King George County and cities to the south.

There are no active railroads through King George County. A 36-mile long railroad bed from Fredericksburg to Dahlgren (U.S. Naval Weapons Laboratory) has been abandoned. The nearest railhead is Fredericksburg 17 miles from the center of the county.

Management Alternatives

A resource manager or planner in King George County must consider a number of alternatives for every land use decision. The best alternative, or alternatives, for a unit of land must be a judgment based on the best available information. Information should include the physical characteristics of the area, climate, population requirements, land use (current), land ownership, natural resources, and transportation system. Some land use planning alternatives for King George might include:

Alternative 1. Plan for agricultural use. In considering this alternative it should be recalled that most soil in King George County lack nutrients, are generally acid, and lack organic matter. Fertilizers and other additives can be applied to increase productivity, however, the cost may outweigh the benefits. Organic matter can be increased by plowing crop residues back into the soil without great expense. The soils are subject to sheet erosion where there are slopes but good land management practices, if encouraged, will prevent [illegible] sedimentation in streams.

Alternative 2. Plan for wood production (forestry). The presence of a wood using industry in King George and neighboring counties should make forest management economically feasible on the better lands. The original tree growth in the county was white oak (*Quercus alba* L.), post oak (*Quercus stellata* Wang.), scarlet oak (*Quercus coccinea* Muenchh), black oak ((*Quercus velutina* Lam.), northern red oak (*Quercus rubra* L.), hickory (*Carya* sp.), and yellow poplar (*Liriodendron tulipifera* L.), on moist sites. Virginia pine and loblolly pine were originally scattered throughout the deciduous hardwoods. The present forest, however, is the result of natural and artificial regeneration of pines and less desirable deciduous tree species on old abandoned agricultural fields. These old fields are generally low in fertility. Site quality for tree growth for the most part rates only poor to fair. In considering the forestry alternative, suitability of land for wood production should be determined on an individual basis by each soil series (USDA SCS 1974).

Alternative 3. Plan for wildlife and fish. Inland streams and small water bodies provide habitat for large and small mouth bass, eastern pickeral, pream, crappie, catfish, and carp (USDA SCS 1974). The Potomac and Rappahamack Rivers also offer opportunities for both fishing and hunting. Ducks and geese visit the rivers every spring.

Basically a woodland area, King George County is an excellent habitat for woodland wildlife. White-tailed deer, wild turkey, and gray squirrel reside here in good numbers and wood ducks are found on small bodies of water within the wooded areas. Quail are abundant in pastures, hayfields, and brushland; as well as along wooded edges and clearings. Unfortunately, most of the land in the county is privately owned. Unless access is permitted to inland water and woodland areas by agreement, lease or purchase, hunting and fishing will be restricted.

Alternative 4. Plan for recreational use. Consistent with population requirements, recreation should be planned that is compatible with other land uses. Determine if water or land units are accessible to local residents and/or to people from nearby or distant cities. An abandoned railroad bed from Fredericksburg to Dahlgren could provide a pleasant hiking or biking trail, if accessible. Fishing, hunting, boating, water skiing, swimming, hiking and other outdoor recreational pursuits are available to most of the rural population of King George County. However, unless access is provided by agreements with land owners, many recreational opportunities will be unavailable to people in populated areas.

Alternative 5. Plan for urban development. Much of the present development in King George County is for residential dwellings along highways in rural sections. Thus major considerations in planning urban growth are predicated on a continuation of this trend. In this respect, and in the absence of sewage treatment facilities, limitations of soils for septic tank systems must be fully considered.

In 1970, the entire population of 8039 was considered rural. With the exception of sawmills and small woodworking industries that require a limited labor force, the labor force in King George County is probably not sufficient to support larger industries. However, the possibility of a mobile labor force from surrounding counties should be considered in decisions regarding industrial development.

Discussion

Area decision management plans (Land-Use Plans) can be designed for any management level. The resolution of information, however, become greater as the plan approaches the level of ground implementation. In this report we addressed the area decision management plan at the county level. This is usually the smallest political unit for implementing federal forestry and agriculture programs. Furthermore, Bureau of the Census land and water areas, populations and other statistics are reported by counties and the Forest Service, Agricultural Stabilization and Conservation Service, Soil Conservation Service, and other agencies as well, make resource information available at the county level. With the exception of some larger counties in western States, the county is a manageable unit of area for planning.

Before a county manager can either formulate or implement a plan, he or she must assemble the best information available. These three questions must be addressed: (1) what information does the manager need, (2) where can the manager find the information, and (3) what information gathering techniques are most efficient and cost effective?

The manager's needs for information depend on the variety of questions and problems he must face in the course of day-by-day management of land and water under his jurisdiction. These questions and problems, as well as their depth, will depend on the needs of the public the manager serves. Solutions can be reached only by public involvement.

Several sources of information are illustrated in this report. However, renewable resource information is often unavailable, out of date, not detailed enough, or it is not site specific. Some managers may have to fill their needs for renewable resource information using available maps, satellite data, aerial photographs, and samples on the ground.

The original hypothesis for the investigation reported here was that forest resources can be located, monitored, and inventoried by a sampling strategy using remotely sensed and ground acquired data. We proved this hypothesis to be correct within the limitations brought out in the discussions of results. For example, estimates of forest area and volume of wood are within acceptable sampling errors but these errors are generally higher than for current photo interpretation procedures. The cost of the experimental procedure was also greater. Higher sampling errors are primarily the result of the low resolution of LANDSAT data. The higher cost is the result of photogrammetric precision required in LANDSAT sample overlays

The extensive quasi operational forest inventory that resulted from this investigation provided total forest area and volume statistics for the county. An independent computer classification, mapping and analysis procedure provided a land use map delineating the conifer and deciduous forest, nonforest and water areas. A water resource map was made from U-2 photographs and estimates of stream length and surface water by size, accessibility, and utility classes were provided using a stratified random multilevel sample on LANDSAT, U-2 photographs and maps. Since there was no known water resource inventory as such, no cost or accuracy comparisons could be made. However, sampling errors were considered acceptable for most broad planning purposes.

A county manager preparing an area decision management plan would find the forest resource information in this investigation less than his needs. Non-the-less, the manager has the option of using this information in broad planning only, or he can make a more intensive inventory that will produce stand maps to a five or ten acre minimum. Stand maps would require forest type, stand size, crown closure and possibly broad volume classes interpreted on 1:60,000 or larger scale CIR photographs. Satellite data would not provide this information at present resolution limits.

What are the best techniques for renewable resource inventories and stand mapping? The cost and expected accuracy of three products using three procedures with LANDSAT, high altitude U-2 photography, and ASCS photography are shown below:

Inventory Product	Procedure	Data Used	Cost[1] Hectare	Expected Accuracy
			-Dollars-	-Percent-
Land-use area classification (Level I)	Photo interpretation	LANDSAT 1:125,000	0.0032	95
		ASCS 1:20,000	0.0020	98
Land-use map (Level I & II)	Computer classification	LANDSAT (CCT)	0.0170	80-95
Forest stand map (delineation only)[2] (Level II & III)	Photo interpretation	U-2 Photos 1:60,000	0.0153	80

[1] [illegible]

[2] Cost estimate based on land-use, forest type, and stand classification experience in the NASA/USFS Skylab investigation, Contract No. T-4106B.

Cost comparisons can be dangerous because often what appears on the surface to be a valid comparison is not. The above costs are valid because they include comparable operational costs. There are illustrations in the literature, however, where authors claim to make inventories of forest resources at a cost far below current operational costs. In reality, however, they compare inventories of forest area and gross volumes with inventories that include net volume, mortality, growth, tree quality, species, land ownership and many other parameters that cannot be measured by remote sensing. These details are required for local, state, regional and national assessments of the current condition and future trends in the forest resource base.

The greatest share of the forest inventory cost is borne by field samples; not area stratification made on aerial photographs or by remote sensing. For extensive state, regional, and national inventories these ground plot costs alone can be \$0.03 to \$0.05 per acre (\$0.07 to 0.12 per hectare) of total commercial forest area. The national average total inventory cost per acre of commercial forest land is \$0.09 and for all lands the cost is \$0.04 (\$0.22 and \$0.09 per hectare respectively). The number of field samples is usually determined by a combination of national precision standards for one-million acres of commercial forest land and for one-billion cubic feet of growing stock voluem; i.e. $\pm$ 3 percent and $\pm$ 5 percent respectively.

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APPENDIX A

Photographic Density Slicing Technique

For Water Inventory

by

Richard J. Myhre

Conventional photo interpretation of LANDSAT images, either black and white bands or color composites, is often difficult due to subtle differences in image signature. At these very small scales, tonal contrast or small changes in color is often the only information available for making a decision on how to classify a given area. The interpreter's capabilities can be increased if these fine differences are made more obvious through some image enhancement technique. Since most resource or land-use classes have a unique signature, portrayed by a density or a range of density, a method of density slicing the image seemed promising.

The term "density slicing" is used here to mean the separation or extraction of a given density level from all other densities existing within an image. The use of a high contrast photographic material (Kodalith Ortho Film) was selected as a medium for recording the density slices. Water was selected as the resource class for the first test of the density slicing technique because it has a density signature that is most consistent. If this technique proves successful, it could be applied to other resources such as forest, agriculture, marshlands/wetlands, and bare soil.

In order to make a determination as to the LANDSAT scene best suited for testing this technique, six scenes taken from different seasons of the year were compared. Based on image quality, resolution, and seasonal differences, the March 24, 1976 scene 5340-14402 band 7 was selected. Small streams and tributaries were more evident on this date, possibly due to hardwood defoliation.

A series of density readings were taken from the LANDSAT image comparing water density to gray scale values. Since the detail is very small on the 9 X 9 inch image, the film was placed in an enlarger and magnified eight times in order to create large enough targets for density readings. A MacBeth Quanta Log densitometer was used to obtain the readings at the base of the enlarger through a probe with a 3mm aperture. Twenty density readings were obtained for bodies of water 3mm and larger in size and then compared with density values on the 15 step gray scale that accompanies the LANDSAT image. The water readings all fell within the value of the 15th step (highest density) on the scale. To check the accuracy of the readings, a series of test exposures were made and evaluated. The test exposures were compared to the original LANDSAT image to determine the proper exposure for transferring all the water bodies from the original scene to the density slice. These exposures confirmed the readings showing the larger water bodies correspond to the 15th step. The test exposures also pointed out that the very small reservoirs and narrow streams that were less than 3mm were of slightly less density and therefore fell within the 14th step. Based on this information, the density slice of water (fig. 22) was made by contact printing the LANDSAT image (positive)

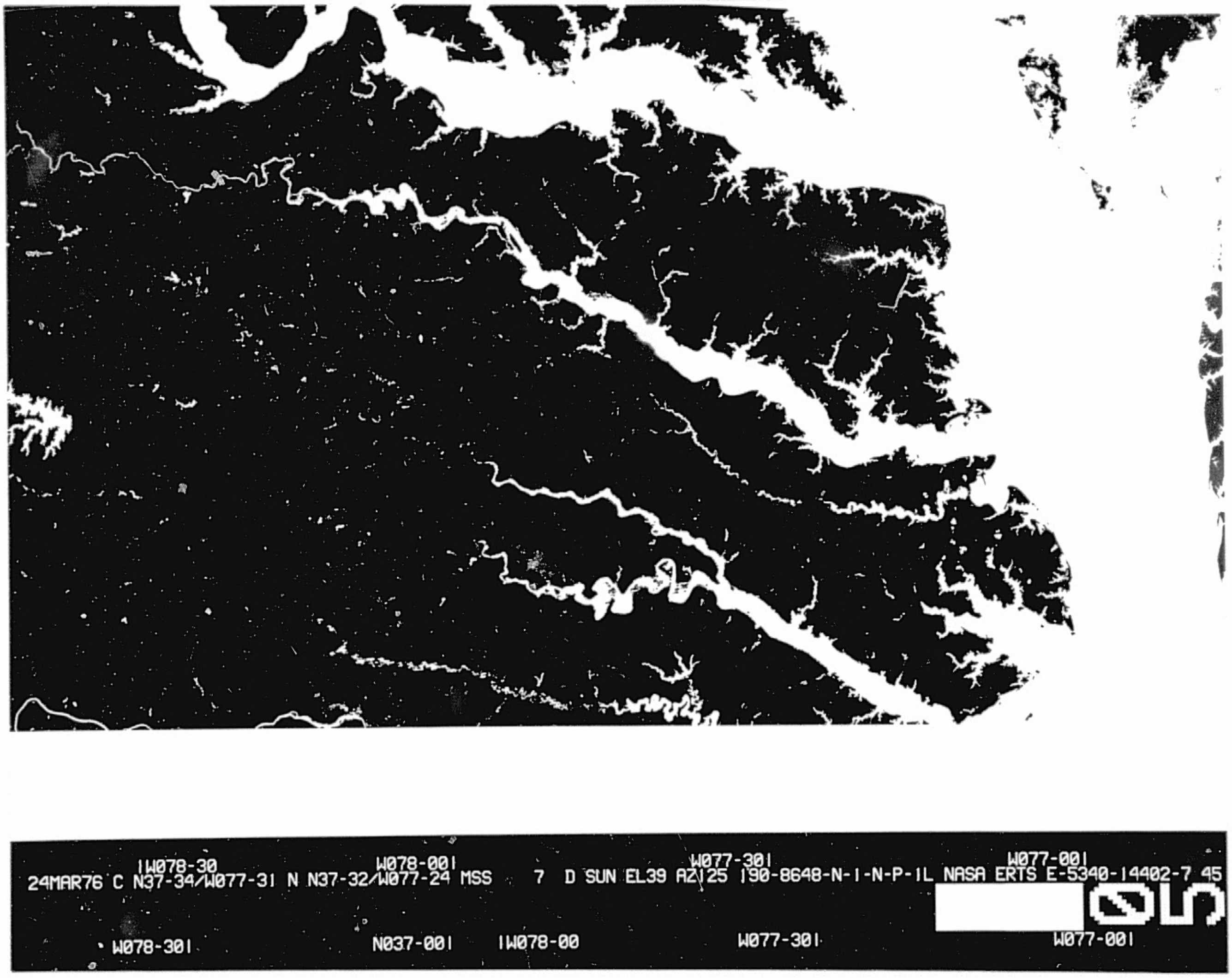

Figure 22 --This density slice of water was made from band 7 of LANDSAT, scene 5340-14402, March 24, 1976. The accompanying gray scale stepwedge was used to define the density of water.

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onto Kodalith Ortho film and processed in Kodalith Developer. Exposure and processing times were controlled to yield an image with the 14th and 15th steps clear and steps 1 thru 13 black (a negative image). From this negative image a positive transparency can be made by contact exposing the negative on Kodalith film or any other transparency material.

Applications of the Density Slice

The density slice of water may have a number of applications:

1. Can supplement conventional photo interpretation methods such as image evaluation on a Zoom Transfer Scope. The ZTS has the capability of illuminating two images simultaneously. One image can be the density slice of water while the other is a LANDSAT color composite in which water may be difficult to discriminate from marshland or wetlands.
2. Used to obtain area measurements--percentage of a given area occupied by water.
3. Can be enlarged and scaled to an existing map for updating water information. The density slice can be reproduced in the form of a color overlay--blue water on a clear film (acetate) background.
4. Useful for preliminary accuracy checking of automatic interpretation (computer classification) results. Density slice can be scaled to computer printouts as a quick method of comparison.

As discussed by Aldrich and Greentree in a previous section of this report (page 14), a water resource inventory was conducted by conventional photo interpretation methods. The different approaches to evaluating LANDSAT imagery for total area covered by water produced answers that disagreed with one another and with the Bureau of the Census. In order to resolve the question of which area measurements by county units were the most reliable, and also to check the accuracy of the density slice, a method was designed for utilizing the slice in a practical application. In addition to the LANDSAT density slice, hand-drawn maps of three counties (Lancaster, King George, and Northumberland) were made showing all surface water. They were included in the measurement method as a check against the other techniques. The hand-drawn map (fig. 23B) was prepared using NASA U-2 color infrared photography at a scale of 1:120,000 as a base for water ground truth.

Methods and Equipment

The method used to measure the percentage of the area covered by water for a given county comprised of a special photo composite image used in conjunction with a Spatial Data System image enhancer (fig. 24). A photograph is illuminated by the light box and scanned by a television camera. Computer circuits calculate the density gradient, the result of this computation being an enhanced picture that is displayed on the black and white monitor. The signal from the camera is also processed by a color analyzer and divided into density levels that are displayed on a color monitor in various colors controlled by a color keyboard.

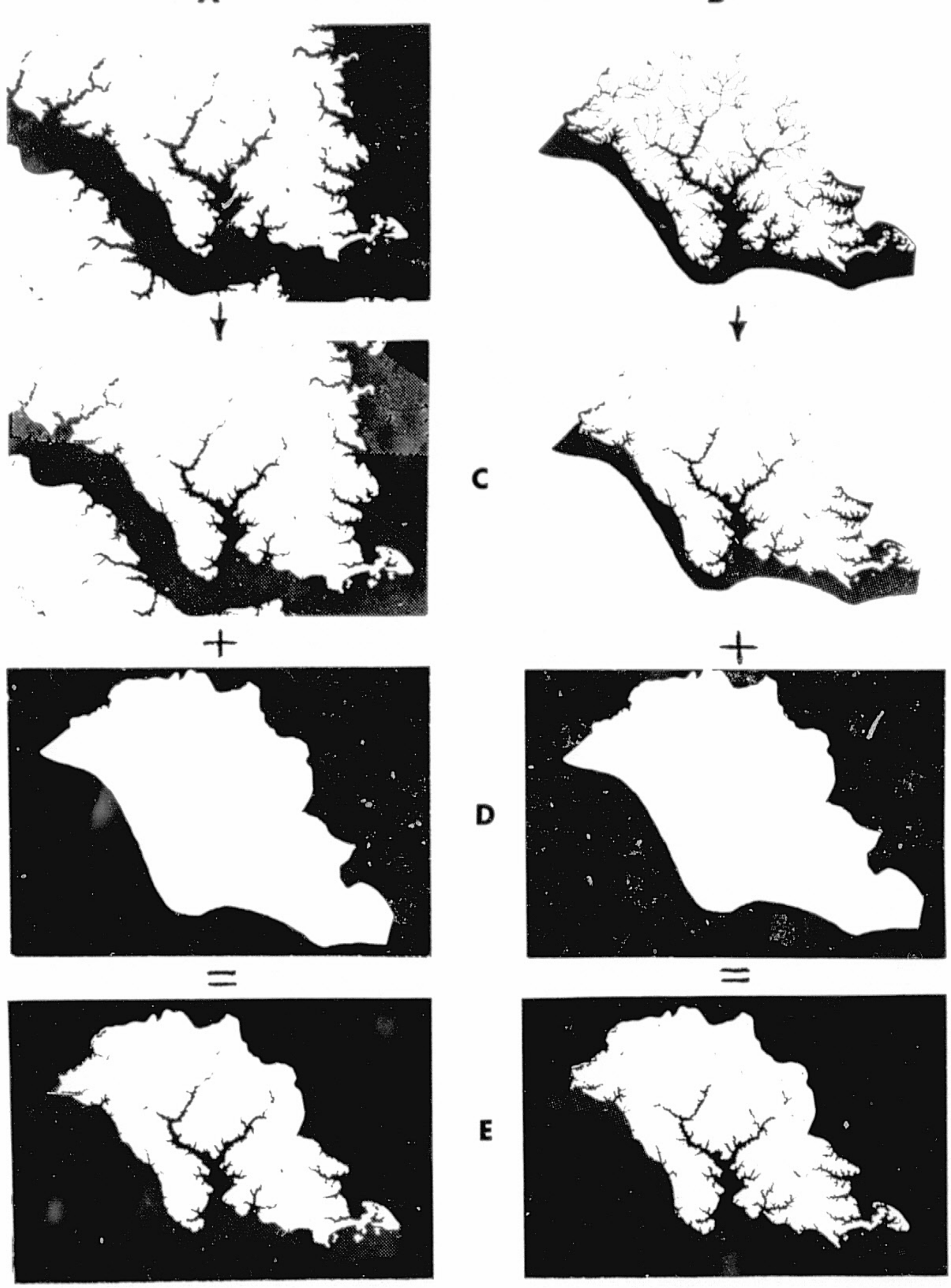

Figure 23.--These photographic products were used to make a composite image of a density slice to measure percent area on the Spatial Data System image enhancer: the county shown is Lancaster County, Virginia. The illustrations above show (A) density slice from LANDSAT imagery, (B) hand-drawn map from U-2 photography, (C) color transparency illustrating water, (D) county mask, (E) a sandwiched composite image of C plus D.

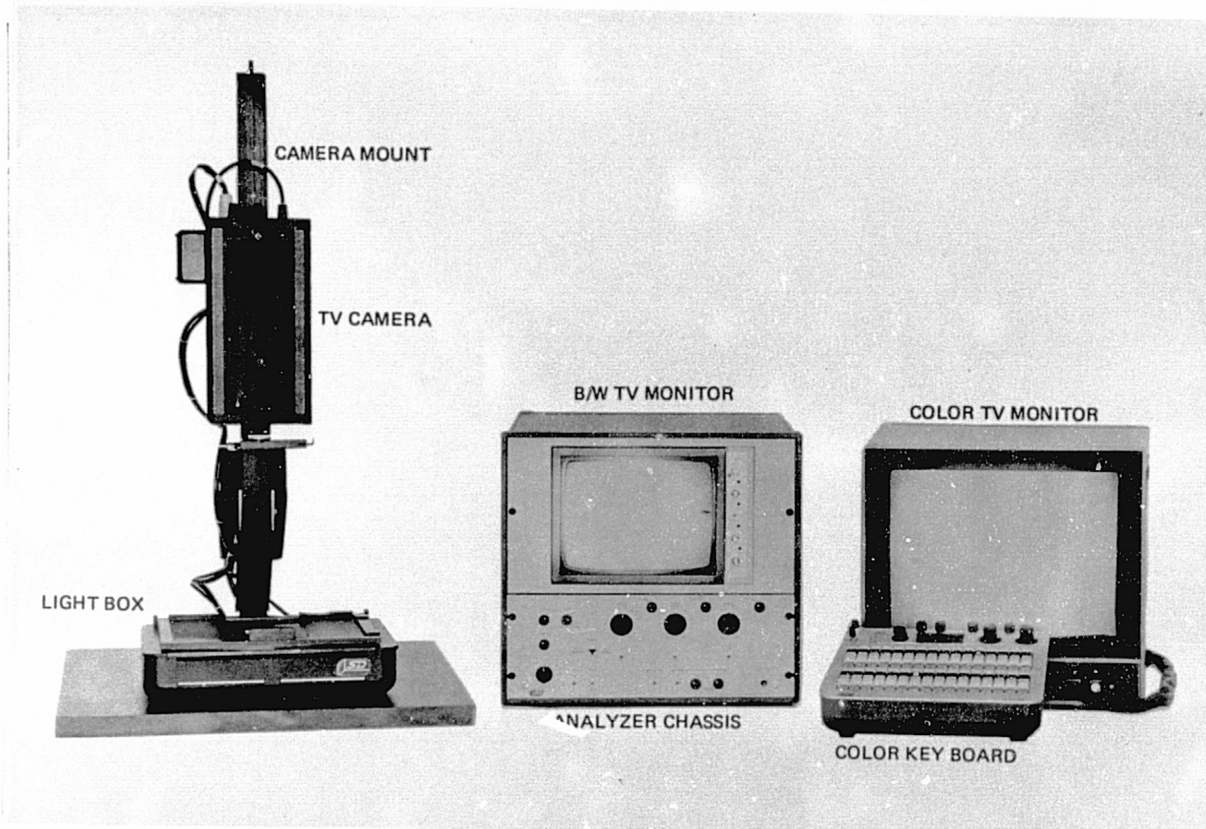

Figure 24 --A Spatial Data System image enhancer was used to measure the area in the density slice defined as water.

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Area measurements are made by utilizing special planimeter circuits in the system. Areas in percent are read from a digital display. Percentage readings indicate the area represented by each of the colors (representing a density level) relative to the total area of a masked picture.

FIGURE 23 illustrates the steps and photographic products involved in preparing the composite image that was later analyzed for area measurement on the image enhancer. Once the density slice was made and the water map photographed, the next step was to produce a positive color transparency from each of these images.

A contact color imaging material, "Color Key" produced by 3M Company, was selected to produce a color image of water (fig. 23C). The color transparency was made by contact exposing the negative images of the density slice and water map onto the "Color Key" material with an ultraviolet light source. The exposed color material was then processed with a special "Color Key" developer. The resulting transparencies illustrated all water as blue and all non-water as clear. The color blue was selected not only because it best symbolizes water, but the gray tone version of this color was important in a later step of this experiment.

The next step was to prepare a mask for each county (fig. 23D), blanking out everything outside of the particular county to be measured. The mask was made by taking a copy of the water map (fig. 23B) and blacking in the entire county. The water map was used for this since it was made from the official county lines. From the blacked-in map a negative photo image was prepared. The positive color transparency and county mask were then sandwiched together to produce a final composite image (fig. 23E) for evaluation on the image enhancer. A yellow sheet of "Color Key" material was placed on the back of the composite image to give a light gray background (on black and white TV monitor) to the non-water areas of the county.

The composite image was then placed on the light box and the image enhancer adjusted so that the density levels of water and non-water were within the limits of the analyzing system. The black masked areas (other counties) were of such a high density that they were beyond the range of densities that could be read by the planimeter circuits. The yellow background (non-water) gave one density range while the blue (water) plus yellow (background) produced a green image for water that resulted in a higher density range. The planimeter circuits were adjusted to give a 100 percent reading for the area within the county outline. The two density ranges representing the green and yellow were read independently ---the two readings represented the percent area occupied by water and non-water classes for a county. The sum of these two readings equalled 100 percent, or the total county area. This area reading procedure was carried out for all three counties (King George, Lancaster, and Northumberland) on both the density slices and ground truth maps of water.

Results of Water Inventory

The area measurement technique just described produced statistics for surface water in three counties. These statistics are shown in columns (1) through (4) in table 26. In addition, statistics gathered by other inventory methods are shown for comparison. Water estimates by conventional photo interpretation techniques in columns (5) and (6) were obtained using LANDSAT photo data and high altitude CIR photographs in

Table 26.--Area of water estimated by different techniques for three counties.

County	Density slicing method		Ground truth map (U-2 photo)		LANDSAT P. I. method		Bureau of the Census	Forest Survey[3]
	Orig. county line[1]	Adjust. county line[2]	Orig. county line[1]	Adjust. county line[2]	Strat. random sample	Unadjust. cluster sample		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	percent							
King George	7.0	7.0[4]	7.4	7.4[4]	3.7	4.5	3.8	5.3
Lancaster	31.7	12.9	37.7	20.3	30.2	31.3	10.5	12.8
Northumberland	15.5	12.5	23.2	18.5	11.3	15.8	14.8	17.4

[1]County lines obtained from official county maps.

[2]County boundary adjusted according to Bureau of Census specification for coastal water boundaries (water other than inland water).

[3]Forest Survey (RRE) reports Census water plus other water called land area by the Bureau of the Census.

[4]No adjustment required.

two sampling strategies (pages 13-64 of this report). Water statistics were also obtained from the Bureau of the Census (column 7) and from U.S. Forest Service, Renewable Resources Evaluation Unit, Asheville, North Carolina (column 8).

When comparing the different values for water by county, a large variation is apparent. Some of the variation is due to, (1) differences in defining the water to be measured, (2) differences in locating county boundaries, and (3) differences in resolution of the imagery used to measure water. Counties that border the coastline present problems because they usually have large river outlets, large embayments, and border large bodies of water such as the Chesapeake Bay. Whether to call this water in the county, or out, is the problem.

The Bureau of Census figures (column 7) for water may not include all of the water within the county boundaries. The Bureau has specifications for defining the limits of inland water and "water other than inland water" when coastal areas are encountered. As a base, or starting point, census water is water that falls within the Bureau's definition of "inland water". "Inland water" is defined as ponds, lakes or similar areas that are 40 acres (16.2 hectares) or more in size, and streams, rivers and canals that are 1/8 mile (201 meters) or more in width. Therefore, any water bodies or water-ways smaller than "inland water" are not measured and are not included in the figures in column 7. "Water other than inland water", such as the Chesapeake Bay that lies adjacent to the States of Maryland and Virginia, and falls under their jurisdiction, does not belong to any particular county, and is exclusive of "inland water". To make the outer limit of "inland water" conterminous with the inner limit of "water other than inland water" and Coastal water, headlands of embayments less than 10 and more than 1 nautical mile (18.7 and more than 1.9 kilometers) in width are connected. In this way much of the water within official county lines is thrown into "water other than inland water" and excluded from the county area. This water is tabulated separately by States and by primary bodies of water.

Based on these measurement criteria, a large portion of the water contained within the Lancaster and Northumberland county lines is not included in the Bureau's water data. Figure 25 shows the effect of removing "water other than inland water" from the total county area. Area measurements made from the density slices and ground truth maps (utilizing Spatial Data System) were carried out using the official county lines (column 1 and 3). Based on the Bureau's specifications for "water other than inland water", new masks were made for Lancaster and Northumberland counties excluding this type of water. King George county was not adjusted as all the water within that county met the definition of "inland water". Columns 2 and 4 of the table show the new water estimates after the county area had been adjusted.

Variations in measurement techniques can also occur due to the accuracy of plotting county lines that fall in rivers and at mouths of rivers and embayments. The Bureau of Census has specific rules for defining boundary lines where indentations occur along coastal areas but these rules are subject to individual interpretations.

Resolution of the imagery (LANDSAT, U-2, etc.) used in the inventory technique can influence the measurement results. Variations can occur depending on the amount of non-census water that is resolved. LANDSAT images will resolve water bodies 2.5 acres (1 hectare) and larger in

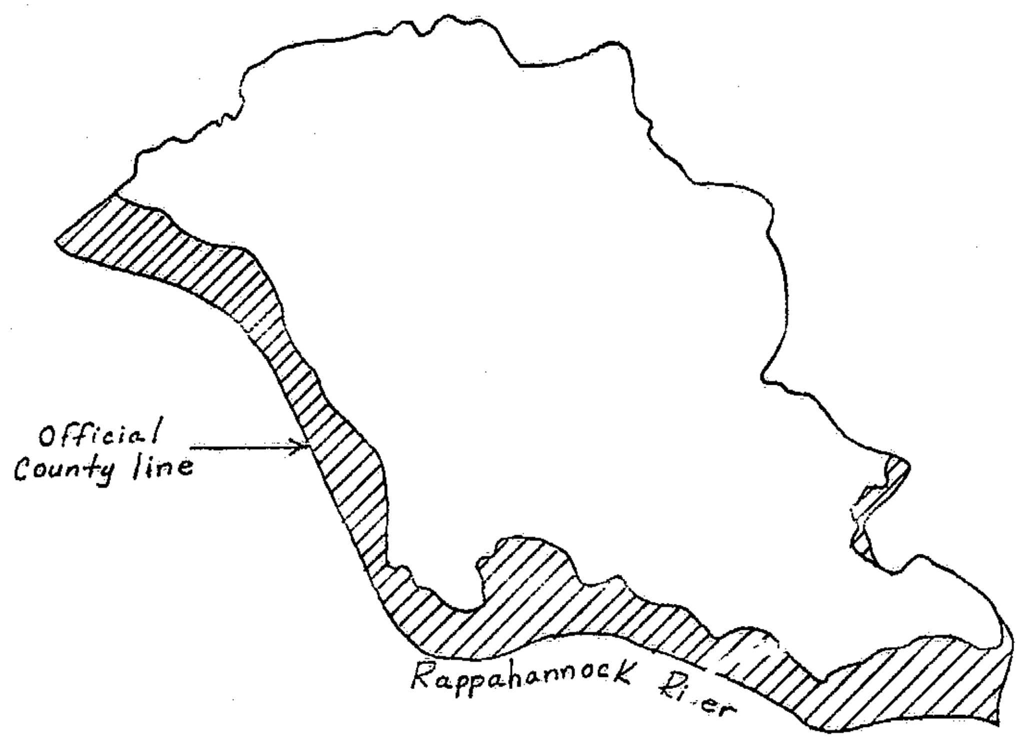

Figure 25 .--Defining county boundaries is a problem in measuring county land and water areas. In this example, the Lancaster County line is shown as it was on the official county map. The cross hatched area is excluded from the county area by the Bureau of Census specifications for "inland water" and called "water other than inland water". This water is included in the portion of the Chesapeake Bay assigned to Virginia.

area and streams must be at least 50 meters (164 feet) wide to be resolved. On the other hand, a U-2 photograph will resolve much more non-census water. Much of the differences between the density slices (column 1 and 2) and the U-2 maps (columns 3 and 4) are likely to be the greater number of small water bodies resolved on the U-2 imagery. The U-2 estimate is probably as near to ground truth as can be measured.

One major problem in water inventory techniques will be the problem of defining and delineating the water that is to be measured. A set of clearly understood national standards for delineating water types and boundaries is needed. Once these standards are developed and universally understood and accepted by all agencies, data from all sources can be aggregated and used in local, regional, and national resource inventories and assessments.

APPENDIX B

Four Channel LANDSAT Radiometer

by

Robert W. Dana

Several radiometric instruments have been developed for measuring terrain reflectance, vegetative constituent reflectance and transmittance or solar irradiance in support of satellite or aerial photo interpretation. DeWitt and Robinson (1975) described a battery powered, LANDSAT-matched radiometer useful for simultaneous field measurements of the four bands. A tower-tramway system for radiance and irradiance measurements in a variety of bandwidths has been developed by Berry and others (1977). Another field instrument using LANDSAT bands selected by a filter wheel was described by Rogers and others (1973).

This Appendix describes refinement of an aircraft rated instrument (Dana 1973) for data acquisition at higher rates than is usually performed in ground truth application. The four channel radiometer consists of an electronic module with self contained power source and an optical sensing head employing LANDSAT matched (or any one inch diameter) optical filters.

Electronics Module

The electronics module is a chassis box approximately one-half cubic-foot in size (fig. 26 and 27), containing batteries, interchangeable amplifier boards, an A/C battery charger and a digital

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Figure 26.--Four channel radiometer optical sensing head and electronic module.

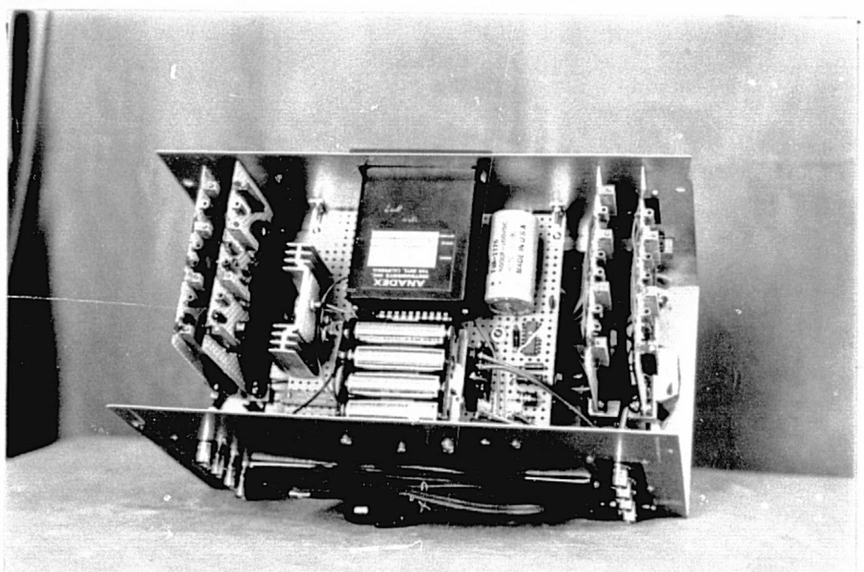

Figure 27.--Four channel radiometer electronic module showing amplifer boards on the ends with a panel meter over the battery charger board in the center.

panel meter. The front panel controls are for switching channels to the meter and a battery test function. Each channel also has zeroing (or low light offset) and gain controls. The minimum specifications of the instrument are:

Radiance: $2.0 \times 10^{-5}Wcm^{-2}sr^{-1}$

Field of view: 9.4° full angle

Radiant power on detector: $4.5 \times 10^{-7}W$

Detector current: $1.2 \times 10^{-7}A$

Voltage output: 3.0 V

Decades of sensitivity (above minimum): 4

Zero offset: ± 1mV

Dc drift: $10mVHr^{-1}$

Time response (rise and fall times): $1.5 \times 10^{-4}s$

(settling time: $4 \times 10^{-4}s$

High frequency noise (peak to peak): 5mV

A small 1.5 ampere-hour lead-acid gel cell was chosen over the higher priced nickel cadmium batteries for a power source. This 24 V. battery is easily charged overnight with the integral constant voltage charger and is capable of holding enough charge for four days of operation (8.5 hours per day).

Analog output voltages from the amplifiers can be monitored on a small three and one-half digit panel meter. The multiplexed LED display of this meter consumes only 100 mW, so that the meter can operate hundreds of hours on four penlight batteries.

For maximum stability, ruggedness, and linearity, diffused junction silicon diodes were chosen as the detectors in the system. They were used in an unbiased photovoltaic mode.

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Normally, silicon diodes used this way do not provide the high speed response required for aircraft applications, but we were able to achieve fast response using an FET input operational amplifier (A1 in fig. 28) in the first stage of amplification. The second stage (A2) utilized a 741 op amp to achieve the slightly higher sensitivities that might be needed in narrow bandpass or narrow field of view applications.

Optical Sensing Head

The sensing head (fig. 26) has four 25mm, F/1.8 lenses (the type used on closed circuit television cameras) threaded into an aluminum plate. Behind each lens is a chamber for one inch diameter filters and a field stop to limit the field of view. To reduce cross-talk between channels the detectors are electrically isolated. Therefore, an opaque, non-conducting plastic plate secures the silicon diode detectors to the rear of the lens plate. The microampere level signals from the detectors are carried to the electronics module in coaxial cables.

Filter Sets

Requirements for LANDSAT-matched radiance and irradiance measurements called for the acquisition of several matched sets of filters. Using spectral data on the six channels of each MSS band (Norwood and others 1972), we found the mean half power points to be at the following wavelengths in nanometers

LANDSAT	MSS BAND			
	4	5	6	7
1	494-598	604-700	693-799	808-987
2	497-599	606-709	695-801	805-989

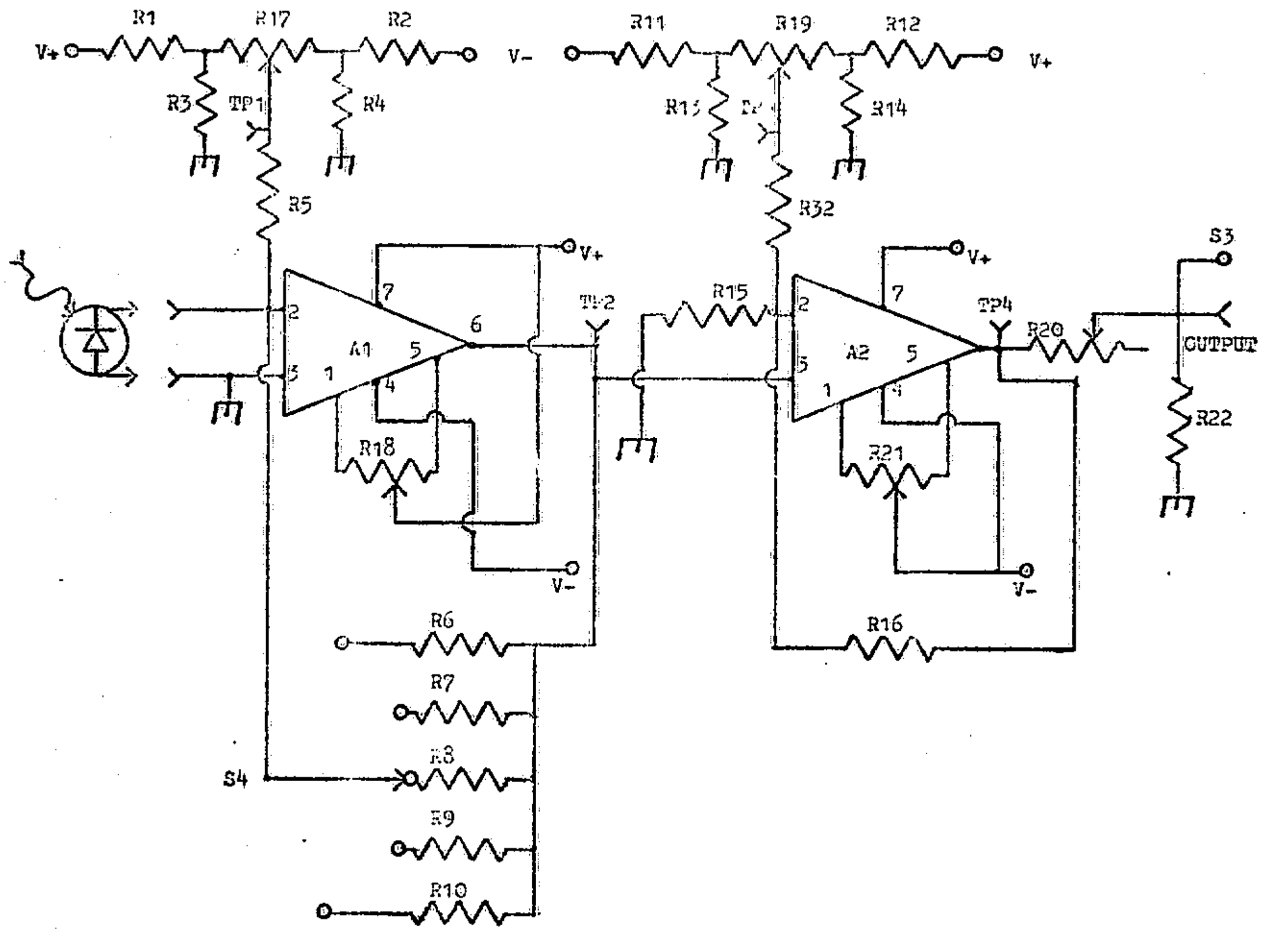

Figure 28 .--Schematic diagram of Four Channel Radiometer amplifier circuit.

We specified the bandwidths of LANDSAT 2 in a purchase of 3 matched sets of interference filters for band 4, 5 and 6. Although these cut-on and cut-off values are hard to produce within 10 nanometer tolerances, we used absorbing glasses to tune them, where necessary, and obtain the best known match to the LANDSAT bands (fig. 29). The bandpass for band 7 is formed by an absorbing glass cutting on in the 800 nm region and the reduction of the silicon detector sensitivity in the 1000 nm region. For bands 4, 5, 6, and 7 the half-power points achieved are respectively 495-592, 607-700, 697-797, and 820-997 nm.

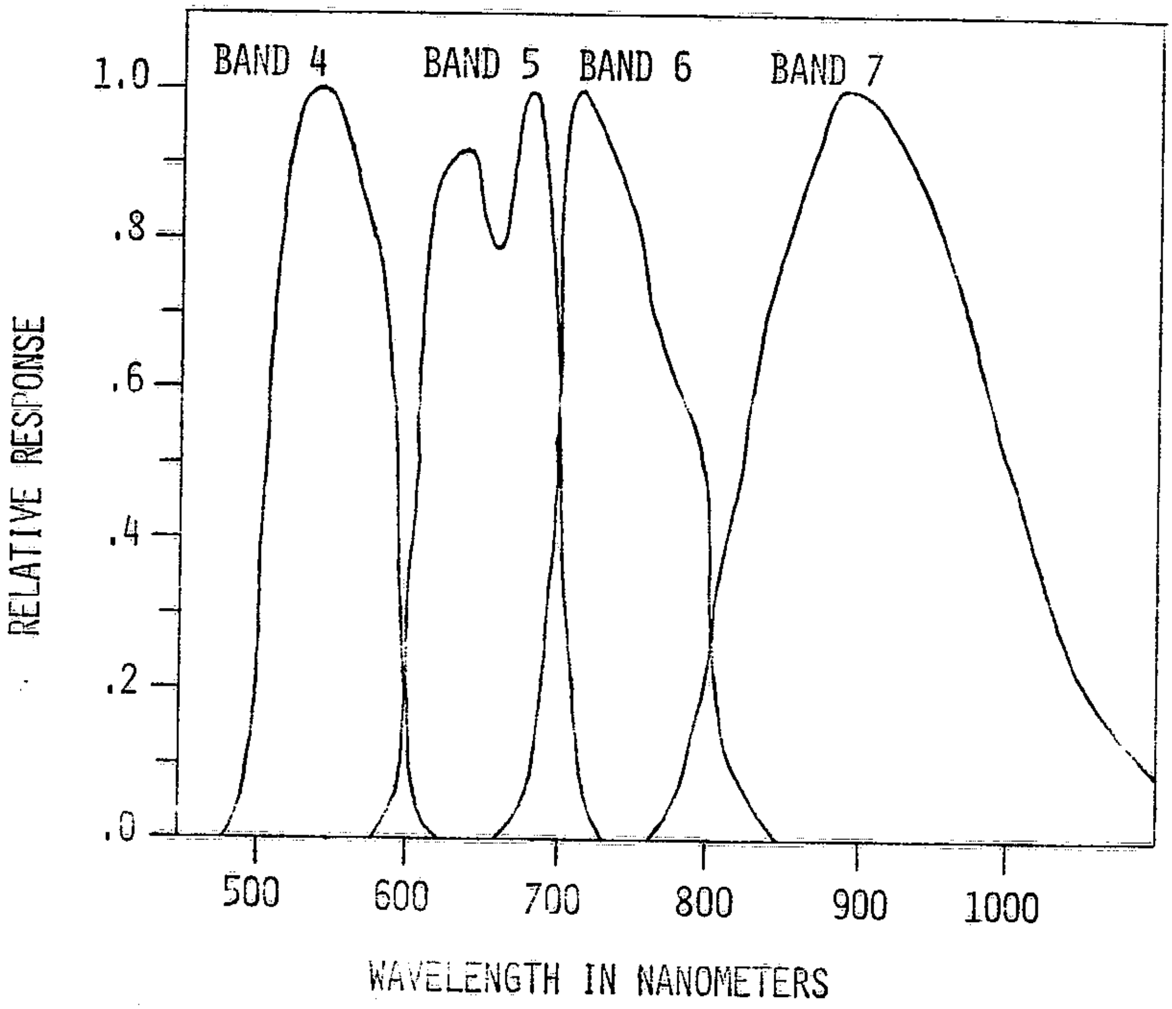

Figure 29.--Separately normalized spectral response curves of Four Channel Radiometer to match LANDSAT II MSS bands 4, 5, 6 and 7.

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