LAND USE CHANGE DETECTION FROM SATELLITE IMAGERY*

by

John T. Cygul, James E. Harston,
Wesley N. Musser, and Fred C. White

University of Georgia

*Cygul and Hairston are Information Analysts and Musser and White are Assistant and Associate Professors, respectively, at the University of Georgia. A grant from the U.S. Environmental Protection Agency supported the research presented in this paper.

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One of the more important recent technological advances for scientific research has been the development of a satellite specifically designed to gather information about the earth's resources. Two satellites launched by the National Aeronautics and Space Administration and known as LANDSAT 1 and 2, currently orbit the earth in a systematic fashion every nine days gathering data for virtually every point on the globe. This new source of data has important implications for research on natural resource use.

Researchers interested in monitoring natural resource use have applied LANDSAT imagery to many problem areas. The U.S. Department of Agriculture, the National Oceanic and Atmospheric Administration, and NASA have created LACIE (Large Area Crop Inventory Experiment) to help accurately forecast harvests on a global scale. After one year of operation, the system implemented to handle and analyze LANDSAT data demonstrated promise (MacDonald, Hall and Erb). In the state of Washington, researchers have found that computeraided interpretation of LANDSAT data offers natural resource land planners an unparalleled opportunity to examine land cover of large areas (Scott and Harding). In another application, Klemas and Bartlett used satellite imagery to map and inventory the significant ecological communities of Delaware's coastal zone and concluded that data products were accurate and could be easily used by researchers, planners, and government officials.

The purpose of this paper is to report on the applicability and cost-effectiveness of using LANDSAT remote sensing data to determine changing rural land use patterns in Georgia. This study focuses on the practical utility of using satellite imagery as a primary source of information for determining land cover changes on an intertemporal basis. The research experience reported here should be helpful to other researchers contemplating implementation of LANDSAT imagery for similar purposes.

The first part of this paper will outline the major objectives of the Georgia research project and how the use of LANDSAT imagery relates to these objectives. Next, the relevant technical aspects of LANDSAT will be discussed. The third section of the paper will deal with procedures adopted in applying and utilizing the satellite data. The cost-effectiveness of using LANDSAT imagery to determine land use is compared with traditional inventory methods in the last part of this paper.

Georgia Study

In the last several years, farmers in Georgia have responded to the favorable profit situation for row crops by increasing acreage of a number of commodities. As a result, land that was formerly not in cultivation is now being used for crop production. It is a reasonable hypothesis that much of this increased acreage is on marginal and submarginal land which is more subject to erosion thus compounding the environmental impact of increased production.

To evaluate the magnitude of environmental problems associated with increased agricultural production, the Agricultural Economics and Agronomy Departments at the University of Georgia have jointly undertaken a research project funded by the U.S. Environmental Protection Agency. The overall objective of the research is to estimate the environmental and economic impact of land that has been brought into crop production in the state.

The greatest methodological problem in this study that had to be overcome was to estimate recent land use changes between 1972 and 1976 in relationship to land capability class and soil associations. The only published data on land use in this form was reported in Soils Needs Inventory compiled by the Soil Conversation Service (SCS) in 1958 and 1967. The next SCS inventory has not yet been initiated. Such inventories require hundreds of man-months of labor and many years to complete. Thus the present research effort had to explore an alternative method for estimating land use changes--LANDSAT remote sensing.

LANDSAT

Central to any decision to implement LANDSAT data, of course, is a basic understanding of how the satellite works, what kind of information it collects, and a knowledge of its' advantages and limitations. On Board the spacecraft is a multispectral scanner (MSS) that records reflected energy from the earth and channels it through a telescope to detectors sensitive to four different bands of the spectrum (three of the bands are in the visible portion of the electromagnetic spectrum and the fourth is in the near infrared). The detectors measure the light intensities of 1.1-acre picture elements which are called pixels and convert the reflected light from these pixels into electric voltages. A digitizer then translates the impulses into computer-digestible number values from zero to 63 and the data are transmitted to receiving stations, recorded on tape, and shipped to a central processing facility at Goddard Space Flight Center.

These LANDSAT data are grouped into LANDSAT scenes. Each scene is approximately 115 by 115 miles and covers an area of 8.5 million acres or 13,225 square miles. LANDSAT surveys one scene in 25 seconds which is quite remarkable since one scene contains over 7.5 million pixels per band or approximately 30 million pixels for all four bands. Computer compatible tapes and 9 inch by 9 inch transparencies that correspond with a particular scene can be ordered from the EROS (Earth Resources Observation System) facility in Sioux Falls, South Dakota.

In agriculture, researchers can identify several different types of crops with considerable accuracy in fields as small as twenty acres. Success in classifying land cover using the LANDSAT data depends to a large degree on the quality of "ground truth" information. The ground truth is land cover that is actually identified by fieldwork. When this information is compared with the satellite image of a small area, researchers can verify what the pixels in the image represent and can then extrapolate those results to much larger areas with computer analysis (Bishop).

Aside from the almost limitless number of possibilities and applications in resource management, technical advantages of LANDSAT are that the data are multispectral, temporal, synoptic, and near-orthographic.[1] Thus they have properties not previously available in aircraft photography. However, limitations of LANDSAT data include lower resolution than aircraft imagery, atmospheric attenuation and, since data are collected at fixed intervals, no chance of avoiding cloudy or stormy weather. Additional information on the technical aspects of LANDSAT data is discussed in Westin and Frazee's article on the use of satellite imagery in a soil survey program.

Procedures Used to Implement LANDSAT Data

Arrangements were made to have the LANDSAT digital data analyzed using the specialized computer facilities at Georgia Tech.[2] The major responsibilities of researchers at the University of Georgia included acquisition of all LANDSAT tapes, ground truth acquisition, and determination of training field locations and geographic control points on the computer system.

In ordering the computer tapes, special consideration was given to the dates of the satellite images. Mid-summer was judged to be the best time to distinguish between the major land uses of crops, pasture, and forestry. At that date most crops in Georgia would exhibit enough growth so that cropland could be distinguished from bare land or pastureland. Also, no crops would be harvested by that date. Imagery with no cloud cover or haze is, of course, the best imagery to obtain. However, imagery with 10 or even 20 percent cloud cover may be used if the clouds are not over the area to be analyzed. Initially, change detection was planned for the period 1972 to 1976, but since there was no good cloud-free imagery available in 1972 (only one satellite was in orbit at that time), computer compatible tapes (CCT's) covering four LANDSAT scenes in Georgia were ordered for 1973 and 1976. Acquisition of the LANDSAT (CCT's) was one of the most time consuming activities. Once appropriate tapes were selected and ordered, it took about six weeks for them to be delivered.

Ground truth information was collected and delineated on U.S. Geological Survey topographic maps (7.5 min. quad sheets) so that accurate UTM (Universal Transverse Mercator) coordinates for specific fields could be noted and entered into the computer. The ground truth information consisted of several large fields of each major type of land cover. Experience obtained from interacting with the computers revealed that large fields which were located near salient land features such as rivers, lakes, and crossroads provided the best ground truth.

Since LANDSAT scenes for two different time periods do not exactly correspond, the data must be geographically referenced to the UTM coordinate system. This procedure allows the data to be superimposed to determine areas in which land cover changes have taken place between the dates of two LANDSAT passes. Researchers located prominent ground features on black and white photographs that were supplied with each scene, found their UTM coordinates, and assisted the computer scientist in locating these points on an image display screen. After a LANDSAT scene was geographically referenced on the computer, "training samples" were identified. Homogenous areas such as center of lakes, woodland, and corn fields were selected from the image display screen for input into computer programs which can statiscically determine these various land cover types for other areas in the scene. Accurate ground truth information was essential in the process of selecting most of the training samples since the computer would classify a much larger area based on the samples.

Cost Analysis

This section presents the cost estimates for using LANDSAT remote sensing data and the computer facilities at Georgia Tech to determine land cover changes. These costs are compared with the estimated costs of inventorying land use through a field survey method that makes use of low altitude photography. The estimates associated with the field survey technique are based on the experiences of researchers in the Georgia study and the personnel at the Soil Conservation Service in Athens, Georgia.

A detailed cost breakdown for inventorying three rural counties in South Georgia (approximately 1095 square miles) is shown in Table 1. In the field survey method, low altitude photography would be used to help the surveyor locate and measure representative fields in each land use category. The estimated amount of time it would take to inventory each land use is shown. Assuming that $130/day would cover the enumerator's salary and expenses, inventorying these three counties for two different time periods would cost $17,160. It must be emphasized that it is assumed that low-

Table 1. Cost Breakdown for Inventorying Three Counties in South Georgia

Low Altitude Photography and Field Survey

Cost of professional enumerator including travel expenses, per day — $130 (estimated)

Number of days needed to survey land use using aerial photography for average size county (233,750 acres)

Woodland	3 days
Cropland	3 days
Pastureland	3 days
Wildlife and Other	7 days
Compilation of data and analysis	6 days
Total	22 days

Multiply by 3 (3 counties)	22 x 3 = 66
Multiply by $130/day	66 x $130 = $8580
Multiply by 2 (survey for 2 time periods)	$8580 x 2 = $17,160

LANDSAT Digital Processing

Cost of image acquisition (CCT's) for 2 time periods	$400	
Set up cost on computer	$750	
		Total cost $1150

Processing cost

Geo reference data	.30/sq. mile
Training samples	.30/sq. mile
Classification	.40/sq. mile
Map product	.10/sq. mile
Total	1.10/sq. mile

Multiply by 1095 (# of sq. miles in survey area) 1095 x $2.20 = $2409

Cost of Ground Truth Acquisition
Cost of enumerator per day (all expenses) $130

Number of days needed to gather adequate ground truth per county	2 days	
# of counties	x 3	
	6 days	
Preparation of Data for Computer Analysis	6 days	
Analysis of data and interaction with computer operator	5 days	
	17 days	
@ $130/day		$2210
Total Cost		$5769

altitude aircraft photography is available. Researchers have found that low altitude photography is available for most areas of Georgia but is outdated in many cases. If this photography was not available, the cost of aircraft mobilization would substantially increase costs.

The estimated cost of processing LANDSAT digital data at Georgia Tech is shown in the second part of the table. Fixed costs include $400 for acquisition of computer compatible tapes and $750 for computer set up. The figures shown under each of the processing costs include an amount to compensate the computer scientist. Adding the cost of gathering ground truth information yields a total cost of $3771. It should be noted that processing costs at Georgia Tech were lower than those of a private corporation. Quotes from private companies were two to three times higher than those reported in Table 1. The lower cost at Georgia Tech was due in part to the fact that several other governmental agencies in Georgia allocated funds to Georgia Tech to cover overhead of analysis of LANDSAT data.

Data in Table 2 summarizes the costs of the two inventory techniques for different sized geographical areas. The costs of the field survey method are based on professional time which is largely variable, the cost per square mile decreases slowly from $38.52 for 81 square miles to $15.67 for 1095 square miles. In LANDSAT, the costs are largely fixed for larger areas within a particular geographical area: costs of ground truth information and CCT's are fixed at a total of $3360. Variable costs then involve only the processing time. As a result, costs per square mile decreases more than under conventional methods, falling from $43.68 for 81 square miles to $5.26 for 1095 square miles. Because of the higher component of fixed costs with LANDSAT than field survey methods, LANDSAT is more expensive for small areas but is considerably less expensive for larger areas.

Table 2. Costs of Land Use Change Detection for Selected Areas by Traditional Field Survey and LANDSAT Digital Processing

Land Area	Method						
	Field Survey			LANDSAT Digital Processing			
(Square Miles)	Days	Total cost[a] ($)	Cost/square mile ($)	Fixed costs[b] ($)	Variable costs[c] ($)	Total costs ($)	Cost/square mile ($)
81	24	3,120	38.52	3360	178	3538	43.68
162	36	4,680	28.89	3360	356	3716	22.94
500	66	8,580	17.16	3360	1100	4460	8.92
1095	132	17,160	15.67	3360	2409	5769	5.26

[a]Cost per day = $130.

[b]Sum of CCT and Ground Truth Costs in Table 1.

[c]$2.20 Processing Cost per Square Mile.

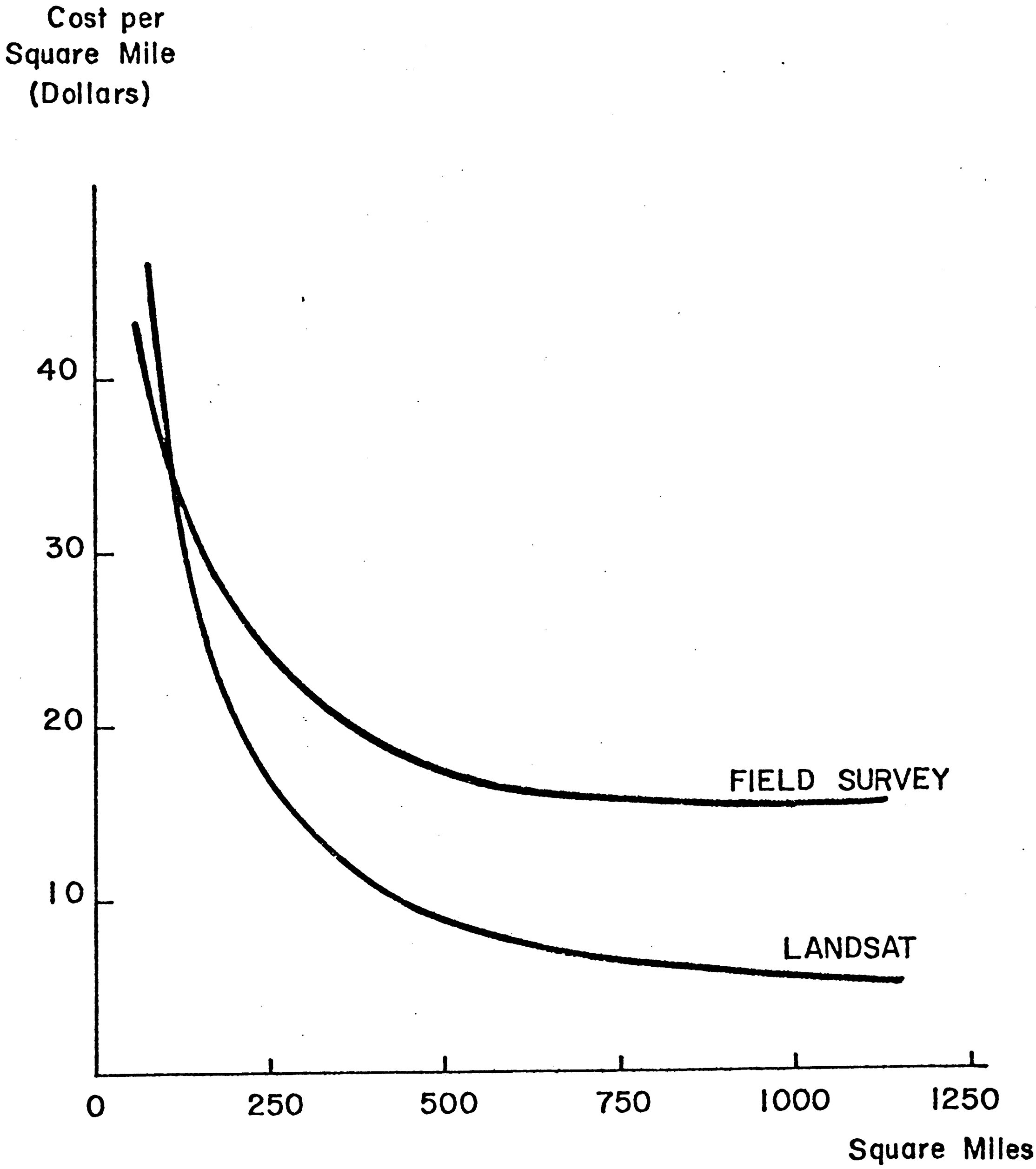

Figure 1. Cost-effectiveness of Field Survey vs. LANDSAT Inventory Methods

The savings from using LANDSAT would even be more for areas larger than 1095 square miles. Jensen, Tinney, and Estes, in a study inventorying cropland in California, supports this viewpoint in finding that LANDSAT analysis required only 3-5 percent of the cost of conventional methods.

Conclusions

The research discussed in this paper demonstrates that LANDSAT data is more efficient then conventional methods of land use inventory for areas larger than about 100 square miles. The basic economic principle underlying this result is that LANDSAT methods have a large proportion of fixed costs which generate significant economies of scale. In contrast, conventional methods have a high proportion of variable costs and less economies of scale. It must be stressed that the budgeting in this study presumed that aerial photography was available; if this photography was unavailable, LANDSAT would probably be more efficient for even small areas.

A final observation concerning LANDSAT is that it increases the feasibility of research on many land use questions. Because data are available on nine day intervals for all geographical areas, *ex post* studies of land use changes are greatly facilitated. Previous methods of using available aerial photography on surveying landowners are less flexible, more expensive and/or subject to the problems of recall validity. LANDSAT, therefore, greatly increases the possibility for effective land use research.

FOOTNOTES

[1]The synoptic character of LANDSAT images refers to the fact that LANDSAT imagery covers enough area to show a wide range of land characteristics. The near-orthographic quality of LANDSAT images means that overlays of controlled base maps fit the images with minimum of distortion.

[2]LANDSAT data is being processed on the Earth Resources Data Analysis System (ERDAS) and the Georgia Tech Cyber 74.

[3]The 5' x 10' quad area is presented here because it was used in gathering ground truth information.

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