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National Aeronautics and
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**National Space Technology Laboratories
EARTH RESOURCES LABORATORY**

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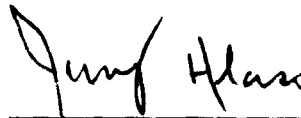(NASA)   63 p HC A04/MF A01   CSCL 05B

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25th Anniversary
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ANNUAL REPORT FY1983

PREFACE

The purpose of this report is to
present the accomplishments of the
National Space Technology Labora-
tories Earth Resources Laboratory's
R&T Program for Fiscal Year 1983.

The report includes program
activities sponsored by the NASA
Office of Space Science and Applica-
tions and Space Station planning
projects associat... with the Space
Station Task Force. All Laboratory
activities directly support overall
NASA goals and objectives.

JERRY HLASS
Director
National Space Technology Laboratories

ABOUT THE COVER

_The lower Mississippi/Louisiana-Gulf of Mexico area is represent-
ed in Landsat 4 Thematic Mapper sensor data acquired on
September 16, 1982. The data have been subjected to principal
component processing in order to create the high-contrast black
and white image. The insert is an expanded data segment cover-
ing the NSTL. The canal system associated with the Shuttle
Engine Testing Complex is clearly delineated. The brighter ele-
ments in the upper portion of the insert indicate the recent con-
struction area of the U.S. Army Mississippi Ammunition Plant._

CONTENTS

INTRODUCTION

The role of the National Space Technology Laboratories Earth Resources Laboratory (NSTL/ERL) encompasses:

- Research and analysis leading to systematic methodologies for converting remote sensing digital data into useful, earth-related information.
- Design, development, and operation of advanced airborne sensors.
- Development and utilization of state-of-the-art data processing hardware and software systems.

This FY83 Research and Technology Annual Report documents NSTL/ERL's continued eminence in multisensor utilization, software development, and digital data analysis. The numerous ERL investigations reported on contribute to the overall NASA capability to acquire and use remotely sensed data in specialized areas of research. The joint research projects provide continued interface with the non-NASA user communities in testing the technology for defined problems/solutions. Space Station support activities provide an indication of NSTL/ERL functional flexibility. The report is divided into six major sections:

- Sensors and Data Systems
- Agriculture and Resources Inventory Survey through Aerospace Remote Sensing (AgRISTARS)
- Applied Research and Data Analysis

- Joint Research Projects
- Test and Evaluation
- Space Station Support Activities

Within NSTL/ERL's realm of program activity, Fiscal Year 1983 can be characterized as a year of transition in a number of ways:

- A major thrust over the past decade for the NASA earth resources remote sensing program has been the development of analysis techniques for applying Landsat Multispectral Scanner (MSS) derived information to resource planning and management. This era has witnessed a growth in the remote sensing community and a significant enhancement in the application of the technology to resource management issues in the future. However, the earth resources program is at the edge of a quantum leap in capability with the availability of Landsat Thematic Mapper (TM) data. The improvements in sensor performance, inherent in 30-meter spatial resolution, seven spectral bands (both the number and location in the spectrum), and eight-bit digital resolution, portend a new era of technology advancement, potentially as dramatic as the operational use of MSS data. The ERL is utilizing its opportunity to put the new TM capability to the test, as evidenced in portions of this report.

- In the past, the earth resources program has been somewhat pragmatically oriented toward domestic applications. Starting in FY83 there has been a positive shift in emphasis with the development of a new programmatic theme focused on Land-Related Global Habitability Science Issues. The objective of this Office of Space Science and Applications (OSSA) program is to investigate long-term physical, chemical, and biological trends and changes in the earth's environment, including its atmosphere, land masses, and oceans. The ERL recognizes the defined science issues and has set about reorienting its R&D to be in concert with the emerging program.

- In the past year, selected capability of NSTL/ERL has been brought to bear on NASA's next potential major mission—the Space Station. Participating in working groups and technology studies of the Space Station Task Force during FY83, NSTL plans continued support of these activities and a meaningful role in Space Station development once it becomes an approved program.

In summary, FY83 has, to a large degree, been a year of change. As the contents of this Annual Report indicate, the NSTL is in concert with these transitions.

- SENSORS AND DATA SYSTEMS

  - SENSOR SYSTEMS

    - Thermal Infrared Multispectral Scanner
    - Advanced Sensor Design and Operation

  - DATA SYSTEMS

    - Software Development and Management

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SENSORS AND DATA SYSTEMS

NSTL/ERL's sensors and data systems development program incorporates evolving technological advancements into the design and development of advanced airborne sensors and interactive data analysis systems in support of overall NASA requirements and all research activities conducted by the Earth Resources Laboratory.

NSTL/ERL's activities in the development of interactive information system capabilities combine rapidly evolving hardware technology with state-of-the-art software systems to support both research activities conducted at NSTL/ERL and operational applications of remote sensing technology. Program emphasis during FY83 focused on upgrading hardware and software system capabilities for accommodating TM and microwave data and multichannel classification procedures which take advantage of array processor technology. In addition, very low cost system configurations based on microprocessor technology were developed and checked in support of multilevel information requirements.

The following subsections highlight some of the more significant activities under the Sensors and Data Systems element of NSTL/ERL.

THERMAL INFRARED MULTISPECTRAL SCANNER

FY83 marked the first full year under which the Thermal Infrared Multispectral Scanner (TIMS) performed in an "operational" status, although the late FY82 flight program and subsequent laboratory tests had revealed a few significant sensor problems. Consequently, even though FY82 had officially concluded the R&D phase of TIMS activities, FY83 saw an equal number of laboratory tests and analyses that identified the two most important sources of data degradation in the system.

TIMS is a six-channel thermal multispectral scanner capable of measuring target radiation in 400 nanometer intervals from 8.2 through 9.4 micrometers, and in 800 and 1,000 nanometer intervals from 9.4 through 12.2 micrometers. Under laboratory conditions, noise equivalent temperature differentials of 0.05°C to 0.30°C are achievable. The system is operated in a Lear 23 aircraft at altitudes ranging from 6,500 feet to 40,000 feet above the target, producing ground resolutions of from 5 to 30 meters.

TIMS' uniqueness lies in its multispectral nature. Each of the six detectors measures thermal radiation, often as temperature in degrees Centigrade, of the target. Were thermal radiation the only contributor to the detected energy, then all six bands would produce the same results. However, the emissivity of the target being overflown is also a contributor to the energy being detected. Because the emissivity of any given object is not constant across the 8.2-12.2 micrometer range, slight variations in signal levels, primarily attributable to target emissivity, are in the output data. These small variations allow investigators to determine, by remote means, the apparent spectral emissivity differences of selected targets.

A secondary benefit of TIMS results from its very high thermal sensitivity. High sensitivity was designed into the system because the contributions of emissivity are so small, and with a thermal sensitivity of 0.3°C or worse, apparent spectral emissivity detection would be virtually impossible. Consequently, the TIMS consistently produces sensitivities on the order of 0.1°C or less. Thus, this allows single-band usage for detecting very subtle thermal variations. Detection of boat wakes, thermal effluents, thermal shadows, and archaeological phenomena are examples of this secondary aspect of TIMS.

Laboratory tests during FY83, in progress since system delivery in 1981, isolated the sources of data degradation caused by microphonic noise. The two areas slated for improvements during FY84 are the preamplifiers and the optical system.

The original design for the preamplifiers utilized a single circuit board, with six preamplifiers, located some 18 inches from the detectors. This circuit board also housed the circuits for providing the proper bias currents to each detector. The long cable runs, dictated primarily by a lack of space in the aircraft enclosure for a closer mounting location, produced excessive electronic noise susceptibility. A new preamplifier design, tested in late FY83, demonstrated marked improvement to noise rejection, and will be incorporated in FY84. Rather than using a single circuit board design, the new effort will utilize discrete preamplifiers

SENSORS AND DATA SYSTEMS

located on the detector/dewar housing itself. Sensitivity improvements of 2X to 3X are anticipated.

The TIMS optical system is very large, with many optical components. Incoming energy must pass a rotating mirror, a focusing parabola, a 90° reflector, a collimating parabola, a diffraction grating, and a very fast imaging lens before reaching the detector array. The array, at 0.017 inch in width, is situated on a focal plane only 0.015 inch wide. Movement of any single component in the optical path that will produce a change in excess of 0.001 inch at the focal plane will result in a decrease in signal level. Normal aircraft low-frequency vibration can cause movement of the array, because of the required detector cooling dewar design, far in excess of this critical amount. Numerous system modifications, including structural strengthening of the dewar, were undertaken in FY-83. These modifications, when coupled with rigid control of aircraft speed and aerodynamic loading, have produced excellent quality flight data. Further modifications will take place in early FY84 to produce a final configuration which will produce satisfactory results independent of aircraft flight induced vibration.

TIMS had acquired data over 38 test sites as of August 1983. During a 15-flight-day period in July and August, 28 successful missions were accomplished. Total coverage is represented in Figure 1, which shows the locations of study sites covered during the current fiscal year.

ADVANCED SENSOR DESIGN AND OPERATION

During FY82, the Earth Resources Laboratory undertook four advanced sensor design studies, utilizing Center Director's discretionary funds. The four design studies were as follows:

- Design of a Variable Resolution Multilinear Array (MLA) Pushbroom Scanner Prototype
- Design of an Active (Target-Illuminating) Multispectral Scanner
- Design of a Scanning Terrain Profiler
- Design of a Microprocessor-Controlled Field Spectrometer

The Advanced Sensor Design activity for FY82 was formulated to take each study to a point which would allow the selection of one activity to be pursued, during FY83, to the point of production of prototype hardware.

The first design study was selected for the FY83 effort. As projected in late FY82, the purpose of this activity was to complete the design of a prototype MLA simulator and to fabricate and flight-
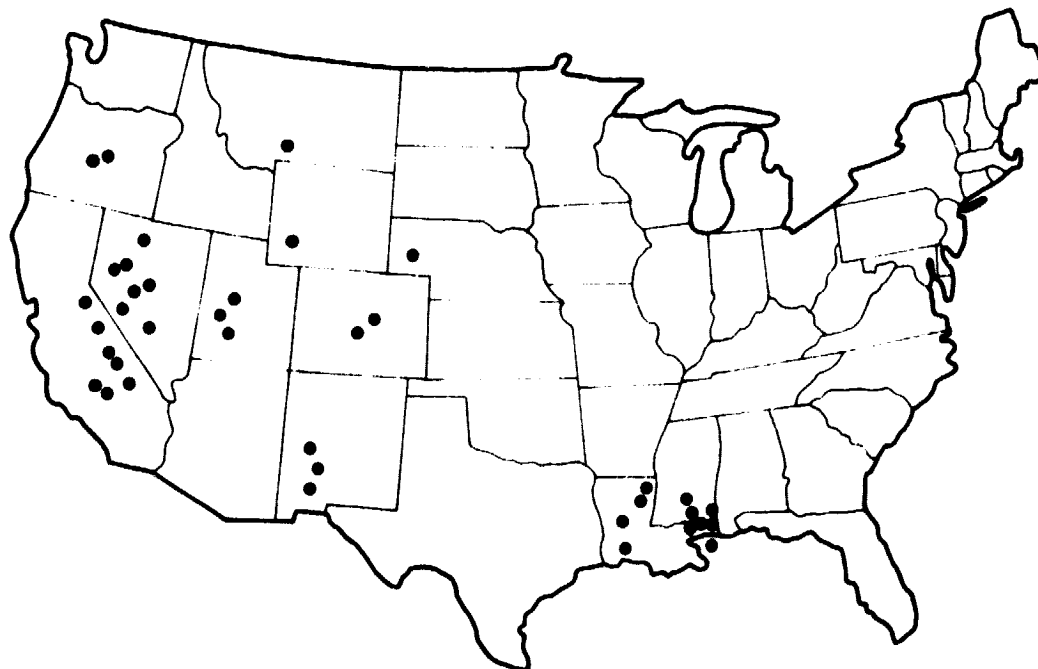

Figure 1. FY83 TIMS Missions

evaluate the resulting sensor. The sensor was to be used to simulate the data anticipated from future satellite-borne MLA sensors, and to explore linear array technology as it applies to airborne remote sensing.

Three spectral bands were selected to correspond to those projected for the future SPOT-satellite-borne instrument. Spectral bands, however, were to be preflight selectable, and utilize thin-film bandpass filters in screw-in mounts. A broad selection of filters, with both very narrow and very wide bandpasses, was envisioned. Overall detector spectral sensitivity would be limited to approximately 500-1,050 nanometers.

Early in FY83, it became obvious that the state-of-the-art for linear array charge-coupled devices was moving rapidly. The number of manufacturers of linear arrays had increased dramatically, with 1,728-element arrays being offered as production units. NSTL elected to purchase a preproduction 3,456-element Texas Instruments array for testing. This unit demonstrated excellent characteristics under laboratory test conditions. With individual elements only 0.00042 inch square, the array appeared to be ideal for the variable resolution application.

The prototype array was delivered without thermoelectric cooling, so the initial testing was conducted only at room temperature. Significant variations in detector sensitivity were noted as temperature changes took place, confirming not only the need for thermal control, but for accurate, thermally dependent calibration.

Based on the complexity of the 3,456-element array and the resulting detail which must be applied to thermal testing, a concept of variable focal length foreoptics was

dropped in favor of electronic control over resolution. This meant that all data acquired from an aircraft altitude of 40,000 feet would produce ground resolutions of 5 meters over an 8.7-mile-wide flight path. The sampling rate would be controlled on board, using additive buffers, to produce the required 10-, 15-, 20-, 25-, and 30-meter ground cells. Operation at lower altitudes would still produce ground cells of approximately 1 meter. While this approach would complicate the on-board electronics, it would greatly simplify the optical design.

By mid-August 1983, the design concept had produced the following definitions, cost projections, and schedule:

- The prototype MLA device would consist of three 3,456-element linear array devices coupled to fixed focal length lenses to produce 5-meter data from 40,000 feet over an 8.7-mile swath, or 1-meter data from 6,500 feet over a 1.4-mile swath.
- Spectral bands would coincide with those of SPOT, with alternate bands between 500 and 1,050 nanometers available at the investigator's discretion.
- Projected hardware costs were $28.5K.

In September 1983, NSTL was requested to investigate a change in scope of the overall MLA development project to determine its applicability to bidirectional reflectance measurements. Although modest off-nadir (fore/aft) viewing by one array for stereo effect had been designed into the original prototype, the bidirectional concept called for three channel simultaneous viewing of nadir and off-nadir angles rang-

ing to 45° fore or aft. Additional complexities lie in the control of geometric distortions introduced by: (1) the large off-nadir viewing angle, and (2) the impact of aircraft motion on the data.

A short, intensive study into the feasibility of fabricating a multi-linear array based bidirectional scanner and the associated data management and utilization complexities was concluded by mid-September, and produced the following definitions, cost projections, and schedules:

- The Bidirectional Reflectance Imaging Array Radiometer (BRIAR) would consist of six 3,456-element linear array devices coupled to fixed focal length lenses to produce 5-meter data from 40,000 feet over an 8.7-mile swath, or 1-meter data from 6,500 feet over a 1.4-mile swath.
- The six linear array lens units would consist of two spectrally matched pairs of three each. One of the pairs would be nadir looking, while the other set of three sensors would be capable of preflight selectable pointing angles of up to 45° either fore or aft of nadir.
- Spectral bands would coincide with SPOT for both nadir and off-nadir pairs. Alternate bands between 500 and 1,050 nanometers would be available at the investigator's discretion. With both pairs pointing at nadir, six discrete spectral bands could be utilized.
- Projected hardware costs were $53.0K, as follows:
  - Arrays $ 9.0K
  - Lenses 12.0K
  - Circuit Boards 12.0K
  - Mechanical Parts 7.5K

- Thermoelectric
  Coolers   9.0K
- Miscellaneous   3.5K
- Flight tests were projected as being possible during the tenth month after adequate resources are made available and the project is formally initiated.

Should the NSTL Earth Resources Laboratory elect to pursue the BRIAR approach, additional discretionary funds will be sought in FY84 to augment existing funds presently assigned to the prototype MLA effort. It is anticipated that additional Research and Technology Operating Plan (RTOP) funds would also be required to complete the bidirectional reflectance measurement task. Required manpower is currently being sought to complement the existing design team.

SOFTWARE DEVELOPMENT AND MANAGEMENT

The Earth Resources Laboratory, over a number of years, has developed a transferable set of software for processing imagery data from the Landsat Multispectral Scanner, Seasat Synthetic Aperture Radar, airborne Thematic Mapper Simulator, and other remote sensors. These data can be combined with topographic, soils, rainfall, and other data to produce resource management and socioeconomic information. ELAS, an acronym for Earth Resources Laboratory Applications Software, is an operating subsystem that functions under a computer's standard operating system. ELAS includes state-of-the-art capabilities for disciplinary user analysis, and was designed so that it can be transferred easily to most computers with 16- and 32-bit ar-

chitecture. Thus, ELAS uses a common data file format with common system interface routines, making the addition of new program modules relatively simple.

ELAS is structured to provide a single point of contact between the computer and the user. As such, ELAS incorporates the necessary operating subsystem software with application software to accomplish a variety of tasks associated with the processing of remotely sensed and other data types. The various modules address applications in agriculture, forestry, and range resources, geology studies, as well as land use, change detection, and wetland inventory assessment and monitoring projects.

ELAS is used by discipline-oriented scientists and resource managers and is fully documented. It has been installed on most popular minicomputers used by universities and State and Federal agencies, and is in use in the private sector. The fundamental ELAS source code for several different brands of computers (e.g., Perkin Elmer, Varian, SEL, VAX) has been made available to the public through COSMIC, NASA's software dissemination facility. The Perkin Elmer version of ELAS provides approximately 200 separate executable programs designed to be user-friendly, and is easily expanded to address a variety of remote sensing processes and applications. The processed data that are output may be displayed on a line printer, CRT display, electrostatic printer plotter, or color film product.

Considerable effort has gone into the development of techniques to process selected remote sensor data through mathematical models. Several models have been developed,

such as multitemporal registration, computation of statistical signatures, maximum likelihood classifiers, georeference mapping, principal components, stepwise regression analyses, and terrain analyses. In addition, several models have been developed at ERL to assist the investigators in applying wetland habitat technology (shoreline length, shoreline density, and distance to water), change detection, and spatial analysis techniques.

The software capabilities of ELAS are ever-changing in order to meet NASA's research and development requirements, and the capabilities will continue to expand due to ERL's commitment to research and development activities. During FY83, 22 new ELAS modules were under development by the ERL. The module names and current status are listed below:

- Modules currently under development:
  - TIRO — Reformats data from NOAA 6 and 7 satellites.
  - GRAN — Gaussian random number generator.
- Modules currently undergoing user-oriented validation:
  - TEXT — Performs texture analysis of data.
  - TDIM — Generates filter weights and their response.
  - FIL3 — Non-array processor version of FILT, 65 x 65 elements.
  - TERT — Calculates effective radiant temperature from TIMS "housekeeping" data with no atmospheric correction.
  - SPED — Performs spectral editing on polygons contained in PGF subfile.
- Modules recently placed in

8

production use:

- TOPO — Reformats NCIC tapes to ELAS format.
- BLAP — Array processor version of FLAP, 65 x 65.
- FLT5 — Frequency occurrence of count values for channel of sensor data (ID1) and for individual cover type (ID2).
- COMP — Compresses data from widely scattered areas of interest into the smallest possible data file.
- TACT — Calculates target temperatures from TIMS data with atmospheric corrections applied.
- TIMREF — Reformats decommutated TIMS data to ELAS format.
- TCCT — Reformats Landsat 4 Thematic Mapper data tapes (6250 or 1600 BPI) to ELAS data file format.
- VPLT — ELAS plotting module for Versatec Plotter.
- SGDZ and SIDD — Digitizing modules for generating point identification data (georef control points and polygon identifying points).
- LOWTRAN — Calculates atmospheric transmittance and radiance for a given atmospheric path based on user inputs such as altitude, pressure, temperature, etc.
- MISP — Grids partially gridded or random input data.
- COLOS — Locates minimum cost path between two cells in a study area.
- CSCRIBE — Contours and plots data from MISP.
- CSVF — Converts ELAS data files to single value file (SVF) for input to COLOS. Also converts output file to ELAS format for further processing.

In addition, three modules—COMD, LABL, and PDDD—received significant upgrades during FY83. COMD and LABL now have the added capabilities for multi-image addressing, multi-image display, true-color definition, and image-to-image copying. PDDD was modified to have plot axes inserted on frontal views, shading done only on axes in frontal views, and the vertical Z axis removed. These modules are also currently in the validation state.

The modules described above were developed under a production software Configuration Control Procedure implemented in May 1983 to ensure that changes in production software are made in an orderly manner. The procedure ensures that the programmer and scientific user validate the software for technical accuracy, completeness, and documentation adequacy. Additionally, it requires all software to be approved by the Configuration Control Board (CCB), which consists of six members representing software/hardware, scientific user, and contractor personnel.

Three software libraries are maintained at NSTL/ERL: (1) Development and Modification Library, (2) Production Processing Library, and (3) Master File Library. All software development efforts are contained in the Development and Modification Library. The Production Processing Library contains the modules necessary for all data processing activities. The Master File Library is a restricted account containing the master source files and companion files for all modules used in either of the other two libraries.

With the implementation of the Configuration Control Procedure, an environment for the development of software in an orderly and timely manner has been created, with the assurance that any modifications or additions to ELAS represent improvements in the utility of the overall software package.

- AGRICULTURE AND RESOURCES INVENTORY
  SURVEY THROUGH AEROSPACE REMOTE
  SENSING (AgRISTARS)

    - Large Area Land Cover Estimation
    - Land Cover Change Detection and Monitoring
    - Inventory and Monitoring Applications
    - Sensor Implementation and Evaluation
    - Conservation Practices Inventory
    - Soil Erosion Modeling

AgRISTARS

AGRICULTURE AND RESOURCES INVENTORY SURVEY THROUGH AEROSPACE REMOTE SENSING (AgRISTARS)

AgRISTARS, a research program designed to benefit agricultural concerns by using aerospace technology, is a joint program of NASA and the United States Departments of Agriculture (USDA), Commerce, Interior, and State (Agency for International Development). The focus of the program is to develop satellite remote sensing techniques for a variety of agricultural applications and mapping of general land use and vegetation.

NSTL/ERL participation in AgRISTARS began through two of the seven major AgRISTARS projects. During FY83, all NSTL/ERL AgRISTARS research tasks were consolidated under one major project entitled the Land Resources Research Project. In cooperation with the USDA Statistical Reporting Service (SRS) and Soil Conservation Service (SCS), this project is comprised of six specific research tasks:

- Large Area Land Cover Estimation
- Land Cover Change Detection and Monitoring
- Inventory and Monitoring Applications
- Sensor Implementation and Evaluation
- Conservation Practices Inventory
- Soil Erosion Modeling

LARGE AREA LAND COVER ESTIMATION

The USDA Statistical Reporting Service regularly provides agricultural estimates of crops and livestock production. They employ an elaborate ground sampling scheme to estimate agricultural production. Various investigations have reported improved crop estimates by integrating remotely sensed spectral data into this process. Additionally, there is an advantage to producing estimates of total land cover as well as cropland area from this routine operation for other agency information needs both within SRS and in USDA (e.g., SCS). The goal of this research is to improve these statistical sampling techniques and to increase the precision of full-frame, statewide estimates for the total range of land covers, while maintaining the full definition of substate and county-wide areas.

Previous research (NSTL/ERL Report 196/AgRISTARS Report DC-Y1-04089) under this task indicated that the spectral diversity among the land cover types was

under-represented by the study sample, which represented 0.2% of the subject land area. Subsequently, research was conducted in Robeson, North Carolina, which utilized segment data corresponding to about 10% of the land area. This research also analyzed the results of using single-date versus multidate Landsat MSS, and the results of stratifying by soils. The results of all four classification approaches (unitemporal, multitemporal, stratified, and unstratified) were presented at the December 1982 AgRISTARS technical symposium (Stoner 1983). The analysis of the results revealed the stratified, multitemporal procedure to have the highest overall accuracy. The addition of a June Landsat MSS data set to an August data set had about the same effect on overall classification accuracy as the stratification of the August data set by soils, although the unstratified, multidate approach was clearly better for crop discrimination.

Another activity under this research task included the use of Landsat MSS data acquired over Kansas to (1) expand the SRS methodology of crop area estimation to include forest, urban, rangeland, and water, and (2) determine the utility of such land cover information to State agencies. The latter activity included the production of various map products for review by State agencies. The results were presented at the AgRISTARS technical symposium (May, et al., 1983).

The collective experience gained from the North Carolina and Kansas studies will be applied to a statewide land cover classification for Missouri during FY84. During this activity, 67 additional segments from nonagricultural strata, mainly

forestland, will be added to the regular SRS sample comprising 450 segments. Multitemporal analysis will be conducted rather than the unitemporal analysis conducted with Kansas data. Methods to better describe the spectral diversity of land cover will be investigated. The use of a priori probabilities for providing additional land cover information will be investigated and presented in the form of a cover-type odds map. This will provide a reliability index for each pixel.

LAND COVER CHANGE DETECTION AND MONITORING

Change detection investigations have been conducted with USDA SRS under the Land Resources Research Project of the AgRISTARS Program to develop methods for updating resource surveys as changes in land cover and use occur. These methods were developed and tested with Landsat MSS data in an area of east-central Louisiana (Burns 1983) where forest land is being converted to cropland and pasture. The methods involve co-registering multispectral data sets for each study area into a multi-date, georeferenced data base. The radiometric differences between equivalent ground areas are then characterized in terms of land cover and/or land use change through various analytical techniques. These results are brought into the same data base along with digitized land cover change maps derived from interpretation of aerial photography acquired contemporaneously with each set of Landsat MSS data. The results from each change detection technique can then be evaluated

relative to this ground reference to demonstrate the performance of each under the conditions present.

During FY83 the methods were extended into Kansas where rangeland is being converted to irrigated cropland, and into Arizona where cropland is being converted to urban residential areas. Results in Kansas indicate that within the one-degree by one-degree study area more than 60,000 acres of new cropland were established upon previous rangeland over a six-year period. Final results within the Arizona study area are expected in early FY84.

Additionally, these experiences have suggested that area sampling frames could be updated by integrating the basic SRS geographic references unit (i.e., frame unit boundaries) with the most recent MSS-derived land use classification. This procedure eliminates the time-consuming process of reconstructing the entire sampling frame and was accomplished for the Louisiana and Kansas study areas. This computer-assisted land use stratification was demonstrated in conjunction with the operational update of the Arizona area frame for parts of Maricopa County in FY83 and is being evaluated by SRS personnel as a replacement for current methods.

Other activities under this investigation in FY83 included evaluating Advanced Very High Resolution Radiometer (AVHRR) data from the NOAA-7 polar orbiting satellite for large area reconnaissance and targeting of problem areas. Data corresponding with the Louisiana verification data base indicate a high potential for discriminating and mapping the major land covers

in that area as well as flood plain and urban delineation using nighttime thermal data. In FY84, tests will include merging these data with Landsat 4 MSS and TM data in a resampled data base updated for a nine-year interval to compare the capabilities of each sensor for large area change detection surveys.

INVENTORY AND MONITORING APPLICATIONS

Missouri Land Use Inventory and Monitoring

The objective of the Missouri Land Use Mapping Project is to use remotely sensed and ancillary data, in cooperation with the USDA Soil Conservation Service (SCS), to identify and measure the change in agricultural land use in areas impacted by urban and suburban growth. Changes in land use over a 10-year time span, July 1972 to August 1982, will be measured. The areas selected for the study are St. Charles and St. Louis Counties, Missouri, which encompass approximately 1,000 square miles. Studies in other parts of the United States have revealed that urban and suburban encroachment into rural areas and the subsequent land conversion have had a deleterious effect on agricultural systems and rural land use. Changes in agricultural land use will include the following studies:

- The loss of prime and important agricultural land to other land use
- The conversion of land use from wooded and pasture lands to cropland

- A measure of potential soil erosion from agricultural land conversion

In order to conduct these studies, a 10-year land use classification of the study area has been initiated using Landsat TM (August 1982) and MSS (August 1972 and 1982) data, aerial photography, and ancillary data. The ancillary data include digitized soil maps, digital terrain tapes, digital Primary Sample Unit (PSU) data from the SCS National Resource Inventory (NRI), and ground verification data.

Landsat TM data (August 1982) and NRI-PSU digital data have been processed to produce a land cover classification. Aerial photography (July 1982) of St. Charles County was obtained from that county's SCS representative, and it has been processed for use in the digital image classification procedures. Plate 1 shows land cover details depicted in the Landsat TM data as compared with older sources of land cover information. Landsat MSS scenes, aerial photography for St. Louis County, and ancillary data are presently being obtained for the project.

Data processing during FY84 will entail geographic registration of sensor and ancillary data sets. Both supervised and unsupervised statistical class development and maximum likelihood classification will be performed on multichannel data sets. Ground truthing procedures will be conducted to verify designated land use classes. A soil erosion data base will be created for the study area using data values for each of the Universal Soil Loss Equation fa

Inventory and Mapping of Rangeland Brush

The USDA Soil Conservation Service has identified rangeland brush inventory as one of its foremost information needs which might be met using remote sensing techniques. This research task was undertaken to determine the potential utility of Thematic Mapper data for determining brush type and density, and to evaluate different techniques for extracting rangeland brush information from data acquired over New Mexico.

A 6- by 35-mile area in Lea and Roosevelt Counties in southeastern New Mexico was selected by SCS personnel for intensive study. This area has considerable variety in brush type and density, with snakeweed, shinnery oak, mesquite, yucca, sand sage, and catclaw being the important species. When it became apparent that Landsat TM data would not be available for New Mexico, Thematic Mapper Simulator (TMS) data were acquired on May 1, 1983, as a substitute.

Ground truth data were collected from 105 sites during the first week of August. Canopy cover was estimated for each brush species and for grass. Analysis of these data will determine which band combinations and data transformations will yield the greatest separability of brush types and density classes. The benefits of including additional information on range site and spatial heterogeneity will be investigated. The effect on separability by reducing resolution will also be determined.

AgRISTARS

SENSOR IMPLEMENTATION AND EVALUATION

SAR Procedure Development

During FY83 continued effort was placed on data processing and analysis to assess the utility of Synthetic Aperture Radar (SAR) data for crop and land cover estimation and mapping. X-band SAR data had been acquired on March 10, 1981, for a truck garden area in Dade County, Florida; on June 15, 1981, for a rice paddy area in Acadia Parish, Louisiana; and on June 29, 1981, for a forest area in Kershaw County, South Carolina.

The first steps in the data processing task consisted of a visual inspection of the optically correlated image film, the digitization of image film, and the radiometric correction of the digitized data to reduce speckle noise and across-track striping. The next step was to integrate (register or overlay) Landsat MSS data and aircraft-acquired X-band SAR data with three polarizations (HH, HV, and VV) to form a multisensor data set for analysis. Subsequently, spectral signatures were developed and the data classified through multichannel pattern recognition using existing ELAS software. Information synthesized from field observations was used to evaluate the classification.

The investigation of the forestry-oriented Kershaw County data sets was documented in NSTL/ERL Report 213 (AgRISTARS Report DC-Y2-04374), "Analysis of Data Acquired by Synthetic Aperture Radar and Landsat Multispectral Scanner over Kershaw County South Carolina During Summer Season" (Wu 1983c). The accuracy evaluation of the three classifications using SAR, MSS, and SAR/MSS data sets for the Kershaw County study area is given in Table 1. The results were presented as a poster display at the AgRISTARS technical symposium in December 1982. The results were also presented as a part of the paper titled "Analysis of Synthetic Aperture Radar Data Over a Variety of Land Cover" at the 1983 International Geoscience and Remote Sensing Symposium (IGARSS '83) on September 2, 1983, in San Francisco, California (Wu 1983a).

The investigation covering Dade County, Florida, and Acadia Parish, Louisiana, data is documented in NSTL/ERL Report 218, "Analysis of Data Acquired by Synthetic Aperture Radar Over Dade County, Florida, and Acadia Parish, Louisiana" (Wu 1983b).

Also, in FY83 Shuttle Imaging Radar (SIR-A) data over Chickasha, Oklahoma, have been acquired and converted into computer-compatible tapes. During FY84, the SIR-A data and Landsat 4 TM data will be employed to delineate surface features related to soil conservation practices.

TM Procedure Development

During FY83, analysis of the correlation between Thematic Mapper Simulator spectral response and percent closure in the forest canopy was completed for the San Juan National Forest, Colorado, study site. The analysis showed that the correlation coefficient was highest for the relationship between TMS Band 5 and canopy closure. Detailed results were presented at the December 1982 AgRISTARS technical symposium, and in an AgRISTARS Technical Report (Butera 1983).

Two TMS data sets of Kershaw County, South Carolina, were also analyzed at NSTL/ERL during FY83. The TMS data were collected during spring (May 1981) and winter (January 1982) seasons. The objective of the project was to conduct a supervised classification of each data set and to assess the ac-

TABLE 1
Kershaw County Land Cover Classification Accuracy

LAND COVER CLASSES	DATA SET USED		
	MSS 4-BAND	3 POL X-BAND SAR DATA	SAR & MSS BANDS 5, 7
DECIDUOUS FOREST	79	79	89
PINE FOREST	60	44	67
PINE FOREST WITH SLASH	65	22	68
CLEARCUT	63	39	79
PASTURE/FALLOW FIELD	64	35	77
CROPLAND	84	59	91
WET FIELD	70	67	86
WATER	98	92	99
OVERALL ACCURACY	72	59	82

Inventory and Monitoring Applications

*Landsat 4
Thematic Mapper Image
August 1982*
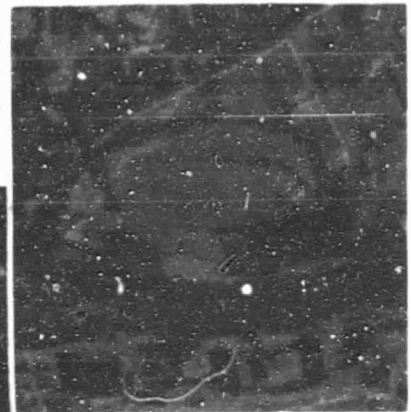
MISSOURI RIVER ▶
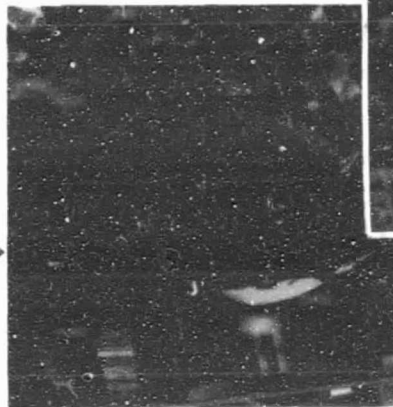
*CIR Aerial Photography,
September 1974*

St. Charles County, Missouri. Land use change along the Missouri River—
woodland to cropland.

*CIR Aerial Photography,
September 1974*

◀ HIGHWAY 40

*Landsat 4
Thematic Mapper Image
August 1982*

St. Louis County, Missouri. Land use change—woodland and cropland to
suburban development. The completed Chesterfield Mall and new housing
development are seen along Route 40 on the TM image.

MISSOURI LAND USE INVENTORY AND MONITORING

curacy of TMS land cover classification with special attention to the accuracy of classifying various forest types in both seasons.

Field work was conducted in the spring of 1982 to describe homogeneous land cover areas. These areas were located in the TMS data in order to generate training statistics which guided the supervised classification of both data sets. A separate set of verification polygons, reviewed in the field, will be used to assess the forest and land cover classification accuracy in early FY84.

Thematic Mapper data collected during a November 16, 1982, Landsat 4 pass were received in late FY83 at NSTL/ERL. In FY84, the TM data quality will first be evaluated to determine if the data (representing the fall season) can be processed and subsequently compared to land cover classification accuracies of the spring and winter TMS data.

Submission of a final report addressing the results of the seasonal land cover and forest classification accuracies is anticipated in December 1983.

CONSERVATION PRACTICES INVENTORY

The goal of this research task is to determine the utility of remotely sensed data for the identification and inventory of existing soil conservation practices. Five watersheds selected for the Rural Clean Water Program have been chosen as study sites in Mississippi, Oklahoma, Kansas, Illinois, and Idaho. Aerial photography (intermediate-scale and small-scale) and Landsat MSS data have been acquired for all five

study sites. One set of Landsat TM data has been acquired for each of the first four sites. SIR-A data have also been acquired for the Oklahoma study site.

Preliminary data analysis during FY83 indicates that some conservation practices can be successfully detected in Landsat 4 Thematic Mapper data (Plate 2). However, a number of existing practices are of such size and definition that present sensors and standard techniques cannot detect them with great accuracy. During FY84 special image enhancement techniques will be employed with the hope of improving detection capabilities by highlighting patterns and properties of conserva-

tion practices. Digitized soils and topographic data have been integrated with remotely sensed data bases, and will help focus attention on areas of critical interest.

In addition, high-resolution photography at the two different scales has been evaluated for the Mississippi, Oklahoma, and Kansas test sites. A matrix (Table 2) has been developed from the results of that interpretation which indicates the requirements for identifying a number of different practices. Aerial photography from the Illinois and Idaho test sites will be evaluated for additional conservation practices indicative of those regions and results will be reported in FY84.

TABLE 2
Photo-Interpretive Matrix for Conservation Practices

CODE	CONSERVATION PRACTICE	INTERPRETERS Skill	FILM TYPE COLOR	COLOR IR	B&W PANCHROMATIC	B&W INFRARED	1:15000	1:5000	1:12000	1:4000	1:8000	THEMATIC MAPPER	LANDSAT MSS	STEREO NEEDED	SEASONAL DATA	SUPPORTING DATA
560	ACCESS ROAD	B	1	1	2	3	X	X	X	X	X	X	X	X	D
310	BEDDING	B	1	1	2	3	X	X						R	R	D
314	BRUSH MGMT.	B	1	1	2	3	X	X	X	X				D	D	D
322	CHANNEL VEG.	B	1	1	2	2	X	X	X	X				R	R	
324	CHISELING AND SUBSOILING	B	1	1	2	2	X	X						D	R	D
326	CLEARING AND SNAGGING	B	1	1	2	2	X	X	X					D		D

A - NOVICE   1 - MOST DESIRED PHOTO.   R - REQUIRED
B - EXPERIENCED   2 - ACCEPTABLE PHOTO.   D - DESIRED
                   3 - LEAST DESIRED PHOTO.

AgRISTARS

SOIL EROSION MODELING

The goal of this task is to survey the feasibility of using remote sensing techniques for providing various inputs to an erosion model using the Universal Soil Loss Equation (USLE). Four areas experiencing large soil loss rates have been chosen as study sites in Alabama, Mississippi, Oklahoma, and Kansas. Remotely sensed data from Landsat MSS and TM are being integrated with digitized soils and topographic data bases as input for determining the values of the various factors that make up the USLE.

All remotely sensed data have been acquired and construction of digitized soils and topographic data bases has been completed in FY83. Preliminary use of the USLE model with Landsat MSS data in Mississippi (Plate 3) and Alabama have been reviewed with the USDA Soil Conservation Service personnel of those States and results indicate great promise. During FY84, results obtained from the model by using Landsat MSS data will be compared with results obtained when using TM data (or TMS as needed). A sensitivity analysis will be conducted to determine the influence and accuracy of the factors employed in the USLE model, whether they be derived from remotely sensed data, a soils data base, or a topographic data base. Results will be reported in FY84.

AgRISTARS
Conservation Practices Inventory

PLATE 2
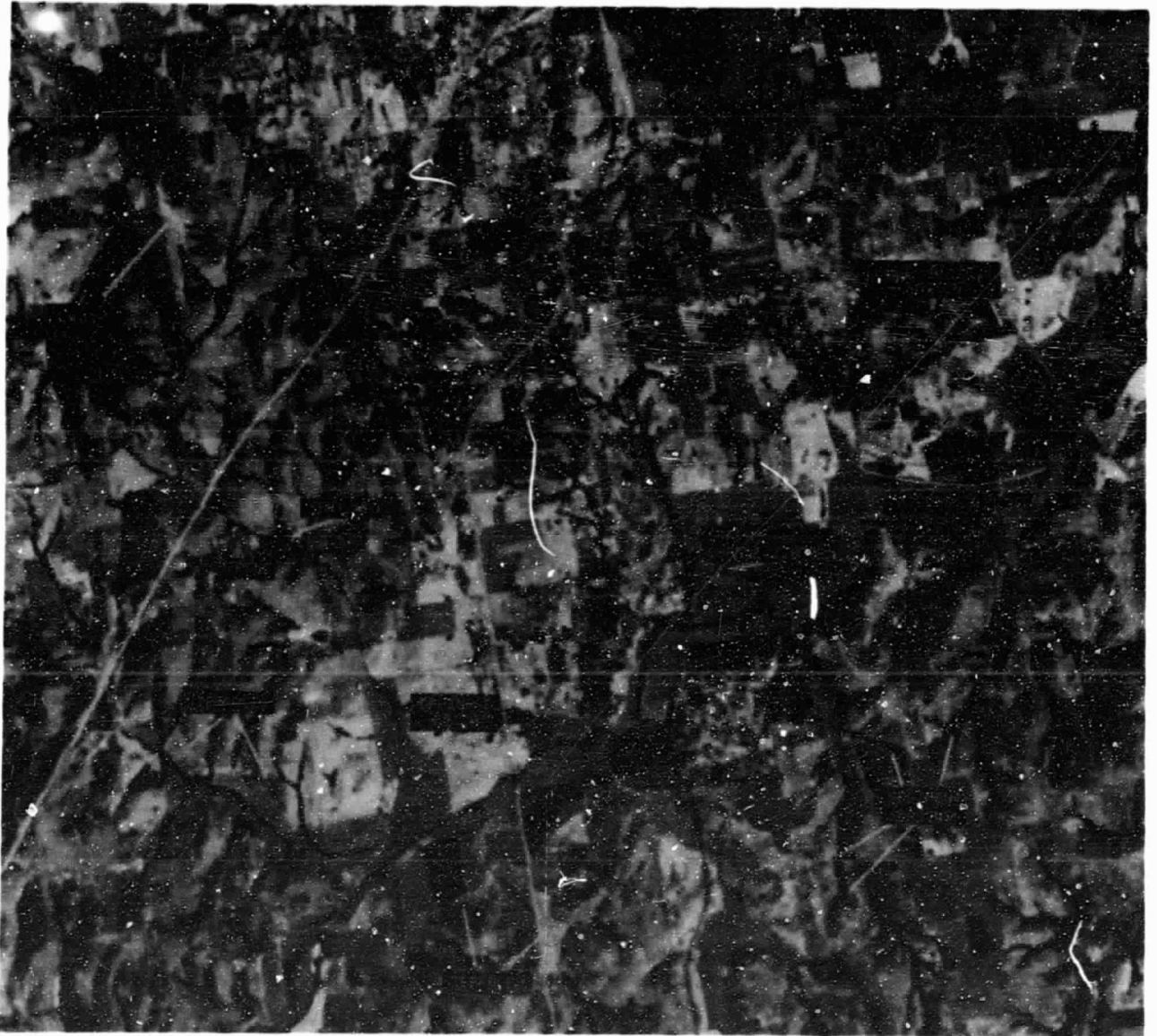
Landsat Thematic Mapper scene 40136-16362 acquired November 29, 1982. Image is a computer-generated color composite using Bands 3, 4, and 5 to highlight soil conservation practices and erosional effects.

LITTLE WASHITA WATERSHED CONSERVATION PRACTICES

AgRISTARS
Soil Erosion Modeling

PLATE 3
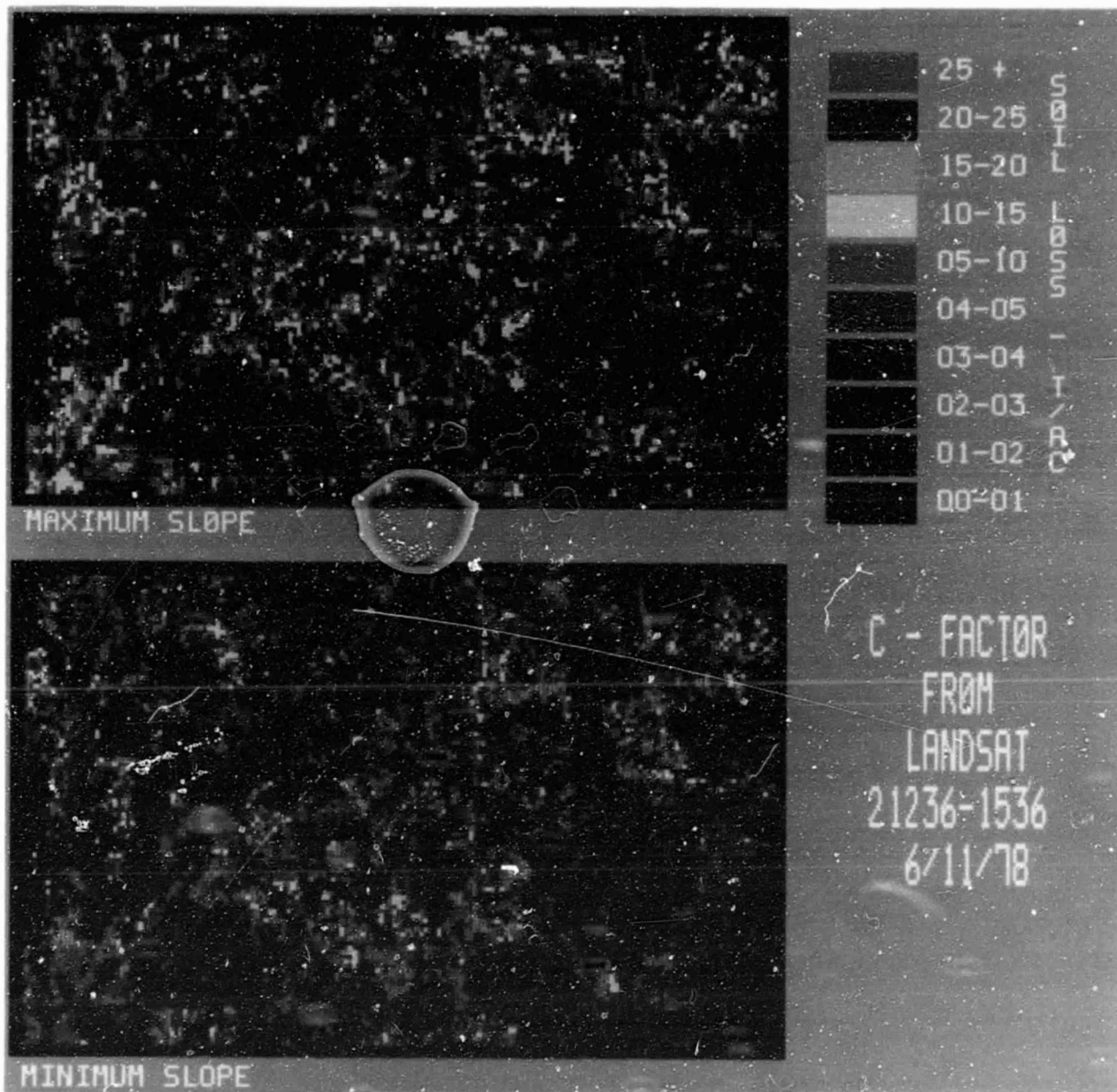
These images portray soil loss in tons/acre/year as determined by the Universal Soil Loss Equation (USLE) for the Goodwin Creek Watershed in Mississippi. The images use the maximum and minimum slope values within soil mapping units to demonstrate the effect of slope on the USLE. In general, values greater than five tons/acre/year exceed tolerance limits.

GOODWIN CREEK WATERSHED EROSION HAZARD

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- APPLIED RESEARCH AND DATA ANALYSIS

  - Monitoring Semi-Arid Rangeland Degradation
  - Discrimination of Small Heterogeneous Mine Features
  - Soil Delineation Research
  - Archaeological Investigation
  - NSF Long-Term Ecological Research
  - Geological Mapping
  - Scene-To-Scene Registration
  - Topographic Corrections
  - TM Preprocessing Technique
  - Geobotanical Application
  - Scene-To-Map Registration
  - Microwave Sensor Analysis
  - Mid/Thermal IR Remote Sensing Data Analysis
  - Vegetation Stress Assessment

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OF POOR QUALITY

APPLIED RESEARCH and DATA ANALYSIS

APPLIED RESEARCH AND DATA ANALYSIS

NSTL/ERL's Applied Research and Data Analysis activities concentrate on research to understand the factors that affect or influence measurements made with remote sensors; i.e., the manner in which these factors manifest themselves in the data. During FY83, attention was focused on the middle and thermal infrared, and microwave regions of the spectrum. The Landsat Thematic Mapper (TM) and Shuttle Imaging Radar (SIR-A) sensors were drivers of this research, although some emphasis was placed on ground and airborne sensors such as the Barnes 12-1000 multiband field radiometer and the airborne Thematic Mapper Simulator (TMS) and Thermal Infrared Multispectral Scanner (TIMS).

Investigations were conducted with both fundamental and applied research orientations. Fundamental research tasks included studies of plant and soil temperatures, leaf water content and altering factors, vegetation stress, topographic corrections, atmospheric modeling, and data registration. Applied research tasks were directed toward soils mapping, arid vegetation monitoring, geological/geobotanical applications, and archaeological investigations.

MONITORING SEMI-ARID RANGELAND DEGRADATION

The goal of this research is to develop techniques for applying remote sensing to the assessment, monitoring, and prediction of semi-arid rangeland degradation.

During FY83, field studies funded by ERL were conducted by the Arid Lands Institute (University of Arizona) to determine degradation trends and to select vegetation parameters that were both useful as indicators and potentially monitorable by remote sensing. Results were reported in a paper entitled "Indicators of Rangeland Change and Their Potential for Remote Sensing" (P. L. Warren and C. F. Hutchinson, 1983 Journal of Arid Environments).

The utility of MSS spectral indexes for monitoring rangeland vegetation was determined by analyzing correlations between spectral indexes and critical vegetation parameters and by determining relationships between temporal changes in spectral indexes and changes in vegetation. MSS Band 5, albedo, and the Kauth-Thomas brightness component appear to be useful for monitoring total vegetation cover. Multiseasonal green vegetation indexes could be used to estimate change in the shrub/grass ratio. In the analysis of change in spectral indexes and vegetation over a four-year interval, spectral index change appeared to be offset from true change. Apparently the methods commonly used to standardize data sets for differences in solar elevation effects and sensor radiometric response were not completely successful. Details of this study were presented in a report entitled "Assessment of MSS Spectral Indexes for Monitoring Arid Rangeland" (Musick 1983).

DISCRIMINATION OF SMALL HETEROGENEOUS MINE FEATURES

Research continued during FY83 on the extension of the thematic masking technique, developed in FY82 for the extraction of surface mine features in eastern Kentucky, from MSS data to TMS data collected for the same study area. A ratio of the first and second principal components derived from the data sets has been used to define spectral signatures exclusively for mined areas, with all other non-mine signatures "masked out." These spectral signatures were then used to produce a thematic classification of surface mines within the eastern Kentucky study area.

For an additional test of its spatial and temporal extension characteristics, the thematic masking technique was applied to two dates of MSS data over a study area in the western Kentucky coal field. A thematic extraction of surface mines has been produced from April 1979 and May 1973 MSS data. The results show that surface mines within the western Kentucky study area have been successfully delineated and classified using the thematic masking procedure.

This technique applied to extraction of surface mine features was presented at the Association of American Geographers Annual Meeting held in Denver, Colorado, in April 1983. These final results will be formally documented in early FY84, which will complete this research investigation.

APPLIED RESEARCH AND DATA ANALYSIS

SOIL DELINEATION RESEARCH

The primary goal of this research is to develop remote sensing techniques capable of delineating soils in a manner which would serve to expedite the preparation of higher order soil surveys.

Controlled ground-based experiments relating soil properties and field conditions to variations in soil spectral response form the basis for studies aimed at correlating remote-ly sensed data with soil map units and soil properties. Laboratory and *in situ* field measurements of reflectance are taken with a Barnes Model 12-1000 modular multiband radiometer, covering the six reflective bands of the Landsat Thematic Mapper in addition to a near-IR band from 1.15-1.30 micrometers.

Test sites were selected in arid, semi-arid, subhumid, and humid climatic regions to ensure that a variety of soil and climatic conditions would be represented (see Figure 2). Results from FY83 research at these sites are discussed below.

New Mexico Site

Sandy soils in this area are generally more reddish than most fine-textured soils and are therefore separable from most other soils by their spectral signatures in the TMS visible bands (Bands 1, 2, and 3). However, reddish clay soils are confused with reddish sands if only the visible bands are used (Section A of Plate 4).

TMS Band 5 (1.55-1.75 micrometers) appears to be useful in separating sandy from fine-textured soils. Compared to sands, fine-textured soils have generally lower reflectance in Band 5 relative to visible and near-IR bands. A combination of Band 5 with two visible bands thus separates soils by both texture and color (Section B of Plate 4).

In FY84 tests will be conducted to determine the utility of this band combination and others for soil mapping. Additional work will examine the relationships between ground-based reflectance measurements and soil properties as determined by laboratory analysis. Also, correlations between Thermal Infrared Multispectral Scanner signatures and soils will be investigated.
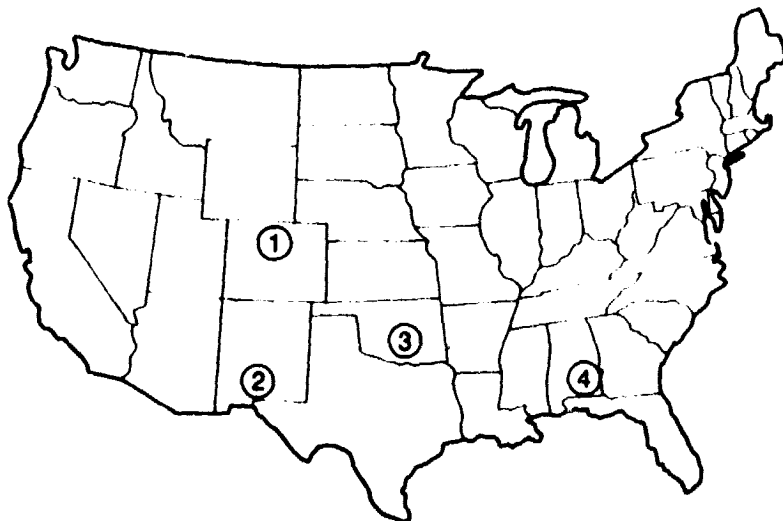
Colorado Site

TMS, TIMS, and ground truth data were acquired for this site in late FY83. In this area of shortgrass steppe there is less exposure of bare soil than in the more arid New Mexico site. A major goal of investigations at this site in FY84 will be to determine the extent to which partial vegetation cover alters the intrinsic spectral response of soils.

Alabama Site

Laboratory spectral response measurements of the surface and subsoil samples from four benchmark soil series of the humid region indicated a high correlation between Band 7 (2.08-2.35 micrometers) and clay content (Figure 3). *In situ* field measurements of the same four soils series at the Alabama site were obtained at approximately the same time that TMS data were acquired over the area in Spring 1983 during a period of maximum bare soil exposure. A comparison will be made in FY84 of spectral responses from laboratory, field, and remotely sensed measurements.

Oklahoma Site

Digitization of the soils data base for Oklahoma was completed and

1 — PAWNEE NATIONAL GRASSLANDS, COLORADO
2 — JORNADA EXPERIMENTAL RANGE, NEW MEXICO
3 — LITTLE WASHITA WATERSHED, OKLAHOMA
4 — GENEVA COUNTY, ALABAMA

Figure 2. Soil Delineation Research Study Sites

(A)

ORIGINAL PAGE
COLOR PHOTOGRAPH

(B)
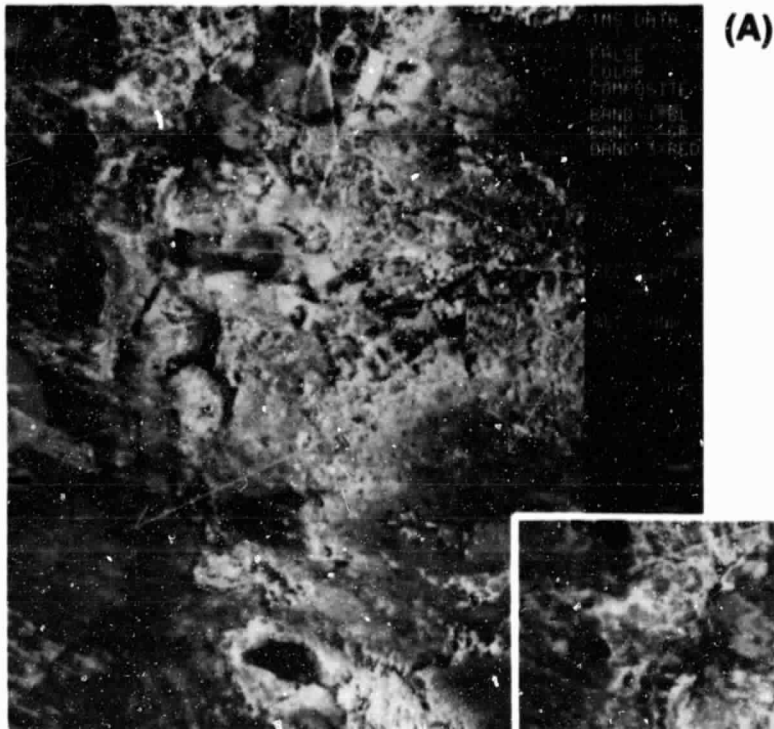
In these false color composites, Bands 1, 2, and 3 (Image A) and Bands 5, 2, and 3 (Image B) are simultaneously projected as blue, green, and red, respectively. Red clay and red sand have similar signatures in the 1/2/3 composite (A), but are readily separated in the 5/2/3 composite (B) because Band 5 reflectance, relative to visible and near-IR bands, is generally high for sandy soils and low for clay soils.

FALSE COLOR COMPOSITES FROM TMS DATA

Figure 3. Plot of Percent Clay Content and Band 7 Spectral Response Values from Laboratory Data

TM data acquired in FY83. Laboratory and field measurements from the Barnes radiometer are expected to be conducted in FY84, with emphasis placed on the effect of crop residue in influencing soil spectral response.

ARCHAEOLOGICAL INVESTIGATION

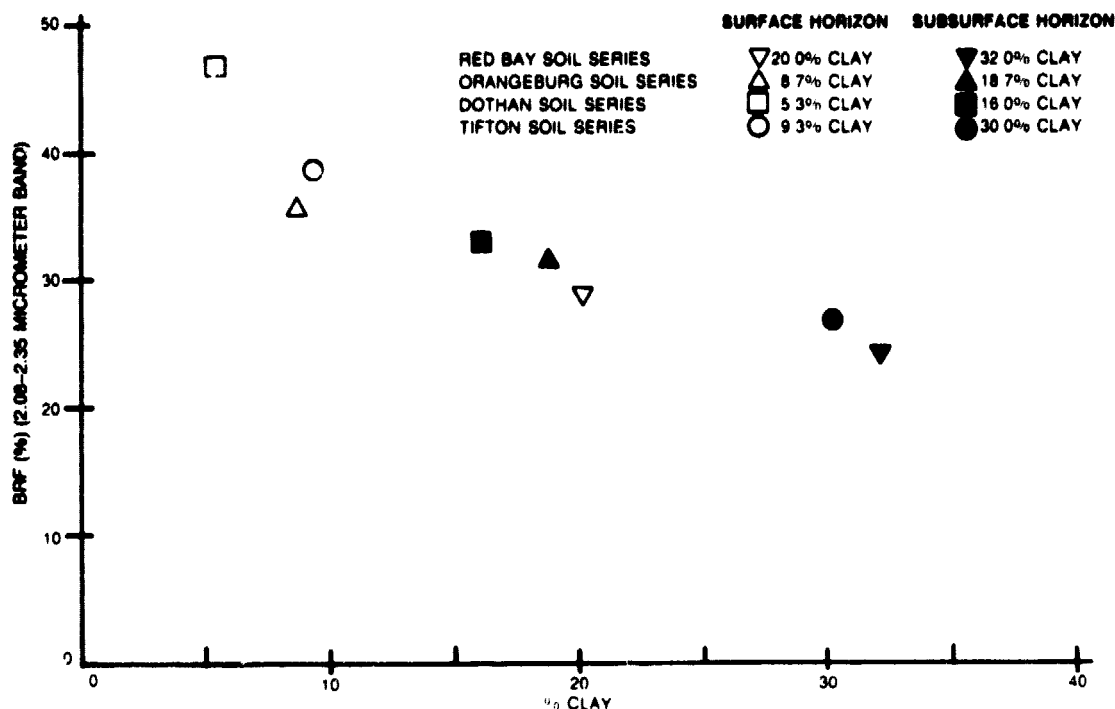In an era of dwindling budgets, remote sensing offers a rapid and inexpensive way to record and analyze data previously unattainable through conventional archaeological survey methodologies. This type of data analysis is of major importance in a scientific discipline which destroys its own data. Traditional methodology requires that exploratory trenches be dug randomly within an area of interest, which

basically results in a hit-or-miss process. Remote sensing improves this technique by rendering a t˛seline understanding of the study area before expensive survey and excavation strategies are initiated. Although remote sensing has only recently been applied to archaeology, it promises to become a fundamental part of the investigator's scientific methodology in the 1980's, much as ceramic analysis and Carbon-14 dating advanced archaeological research in the 1950's.

During FY83, NSTL/ERL continued its study to determine the feasibility of applying remotely sensed data from the Thematic Mapper Simulator and Thermal Infrared Multispectral Scanner to archaeological applications. The Chaco Canyon region in northwest New Mexico was selected as the primary study area because it

encompasses the largest concentration of prehistoric ruins in North America. Particular emphasis was placed upon determining the location of prehistoric roadways, which are usually undetectable through standard archaeological survey techniques. These roads are generally 10 meters wide and were constructed by the Anasazi culture around 900 A.D. The reason for the existence of the roadways remains a mystery since the Anasazi did not possess the wheel nor beasts of burden. Active mineral exploration and development in this area of northwest New Mexico threaten to destroy the surviving remnants of the roadways within the next 5-10 years.

Determining the location of the roadways is difficult from ground level. At dawn or dusk during certain times of the year, some roadway segments stand out against the

APPLIED RESEARCH AND DATA ANALYSIS

landscape for a few brief moments. Despite the difficulty in viewing the roadways, their existence is nevertheless supported through direct association with stairways, causeways, roadcuts, ramps, walls, curbs, changes in vegetation, ceramic artifact distribution, and alignment with outlying structures. Perhaps the major characteristic of the roadways is their straightness of linearity regardless of the surrounding terrain. Through erosion, compaction, and vegetation differences, the roadways have, at best, survived as faint lines or segments of lines radiating out from Chaco Canyon across the surrounding desert.

Image enhancement techniques using high-pass Gaussian filters were developed in order to accentuate the Chacoan roadways on 5-meter TIMS data. The Chacoan roads run predominantly in a north-south direction. To accentuate this phenomenon, directionally biased high-pass filters were used. These filters emphasized north-south heterogeneous features and de-emphasized homogeneous features. A smoothing filter was subsequently used on the high-pass filtered data to remove noise and other non-associated roadway artifacts. The final product as presented in Plate 5 reveals a well-defined Chacoan roadway network, although the roads are invisible to the human eye and are barely observable in the raw TIMS data. Results of the high-pass filtering techniques dramatically demonstrated the ability of a directional filter to selectively remove noise along one axis of an image and extract desired information along the other axis.

The development of filtering techniques offers unlimited potential in the analysis of prehistoric roadway and canal investigations around the world. High-pass filtering techniques applied to remotely sensed data can reveal the nature of trade networks and farming practices of ancient cultures in diverse environmental settings and consequently render a broader understanding of a civilization's socioeconomic base. Recent discovery of Maya Canals and ridged fields in the Yucatan/Peten have revised conventional interpretations of Maya subsistence patterns. Potential areas for application of linear analysis techniques include Inca roads in Peru, Roman roads in Palestine/Israel, ridged fields in Honduras, Maya roads in the Yucatan, and Megalithic roads in Britain.

Documentation of the FY82 and FY83 research results will be available in the first quarter FY84 as required for NSTL Director's Discretionary Fund reporting and will include the work accomplished to date in Chaco Canyon, Poverty Point, Louisiana, and the Jackson Purchase area of Kentucky. Archaeological investigations will continue during FY84 in cooperation with the American Schools of Oriental Research, Boston University, the American Institute of Archeology, National Park Service, and other prominent archaeology organizations.

NSF LONG-TERM ECOLOGICAL RESEARCH

The National Science Foundation (NSF) funds research on long-term ecological phenomena at a national network of sites under the Long-Term Ecological Research (LTER)

Program. LTER projects involve groups of investigators working at large, secure, and biologically diverse sites. Systematic collection of comparative data on the biotic and abiotic components of these ecosystems will support investigations of long-term hypotheses and questions in a series of core research topics.

In FY83, two LTER projects were selected for coordinated remote sensing/ecological research:

- Shortgrass Steppe: LTER. W. K. Lauenroth, et al., Colorado State University. Site: Central Plains Experimental Range, Colorado.
- Interactions of Time and Space Variability in a Chihuahuan Desert Ecosystem: LTER. W. G. Whitford, et al., New Mexico State University. Site: Jornada, New Mexico.

In such projects, NSTL/ERL acquires remotely sensed data and develops techniques for extraction of information on vegetation and soil conditions. LTER investigators provide access to their data and evaluate the extracted information with respect to their information needs.

At the Central Plains site, color infrared photography acquired by NSTL/ERL is being used by LTER investigators in their intensive survey of the surface geology, land forms, soils, and vegetation of the study area. Products from recently acquired TM and TIMS data will be used in this intensive survey, and variations in soil and vegetation parameters will be correlated with TMS and TIMS spectral signatures.

TMS, TIMS, and color infrared aerial photography have been collected for the Jornada, New Mex-

APPLIED RESEARCH AND DATA ANALYSIS
Archaeological Investigation

PLATE 3

Pseudocolor composite image from TIMS high-pass filtered data, low-pass filtered data, and raw channel 3 (9.0-9.4 micrometers) data, assigned to the blue, green, and red colors, respectively. The TIMS data were acquired at 5-meter resolution in August 1982. This image reveals prehistoric roads in Chaco Canyon, New Mexico, which were constructed by the Anasazi culture around 900 A.D. Although these prehistoric roads are not visible from ground level, they demonstrate the ability of high-pass filters to extract information along one axis of an image using digital data.

Chaco Canyon National Monument
• Santa Fe
• Albuquerque

NEW MEXICO
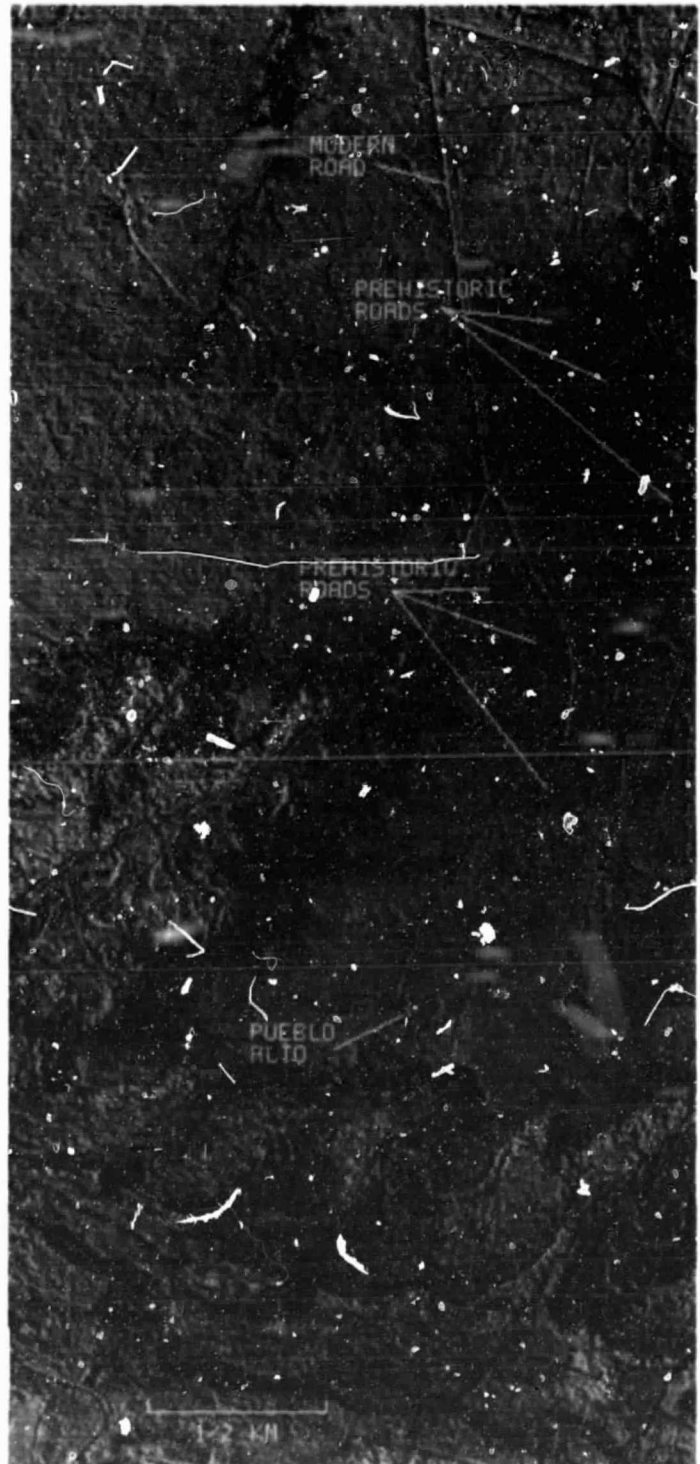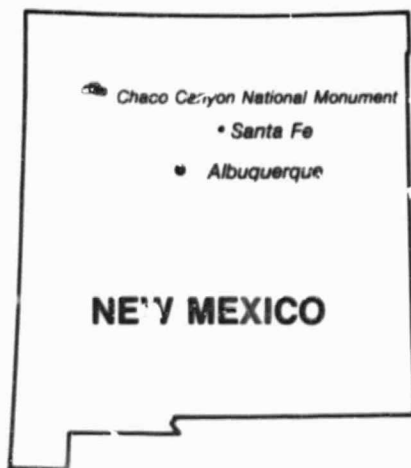
PREHISTORIC ROAD DETECTION

ico, site. The synoptic coverage of remotely sensed data will be used to extend the analysis of spatial and temporal variation from the intensive study site (a 3-km transect) to a larger area comprising the NMSU College Ranch, the Jornada Experimental Range, and adjacent private and public grazing lands.

During FY84, in addition to continuing research with NSF investigators in arid and semi-arid rangeland ecosystems, cooperative research will be initiated in forest ecosystems with NSF-funded investigators using the Andrews Experimental Forest (Oregon), Coweeta Hydrologic Laboratory (North Carolina), and Mt. St. Helens (Washington) Long-Term Ecological Research study sites.

GEOLOGICAL MAPPING

This project, now in its second year, was designed to determine the utility of Thematic Mapper data (initially through simulation) in the detection and mapping of hydrothermally altered rock that is characteristic of specific types of ore systems. Emphasis is being placed on problems associated with extremely rugged terrain and varying degrees of vegetative cover. A second objective is to develop the ability to integrate the TM(S) data with other geologic data sets in a data base, interactively manipulate the data, and evaluate the results for their utility as a coherent whole.

The study site chosen, in cooperation with AMAX, Inc., as part of the NASA/AMAX research project, was Mt. Emmons in Colorado. With more than 5,000 feet of relief in the area, and a very large, un-

disturbed ore deposit, the study site is ideal for this project.

In FY83, preliminary results of the project were published in Rickman and Sadowski (1982) and Rickman (1983). These papers addressed some of the practical problems and considerations in processing such data and some of the very preliminary products. Field work completed since the last yearly report strongly demonstrated the extremely high overall quality and precision of the product images. Using these field observations as a base and guide, new images were generated to improve and supplement those previously created. Statistical analysis of the data has also revealed some apparent relationship between vegetation density and several digital ratios. This relationship was examined in detail in fourth quarter field work. If it can be quantified, the relationship may be used to develop an ability to "see through" some vegetation to the rock and soil beneath.

As this research effort nears completion, a review of results clearly shows the dramatic potential TM-type data have for those engaged in mineral exploration and mining. Using techniques detailed in Rickman (1983), a number of images were generated from the same basic data, each fulfilling separate needs. For example, based on *a priori* knowledge of reflectance spectra, zones of anomalous hydroxyl and ferric iron concentration, free of vegetation, were detected by appropriate ratioing techniques, as shown in Section A of Plate 6. Such zones are known to correlate strongly with ore-bearing rock. A principal component composite (Section B of Plate

6) emphasized zones that spatially correlate with known areas of mineralization. Other areas were also emphasized; field checking and a literature review have shown these to also be zones of mineralization. A vegetation map (Section C of Plate 6), developed from supervised statistics on ratios, functions both as a basic scientific tool and as a baseline environmental study. This image is more accurate and more detailed than the vegetation map filed as part of the AMAX exploration Environmental Impact Statement (EIS). Significantly, the image took a fraction of the time and effort used to produce the map generated for the EIS.

For the photo interpreter, the enhanced decorrelated composite (Section D of Plate 6) combines, in a near optimal presentation, information about all of the ground cover types. For the field worker, an excellent mapping base is provided by the image in Section E of the plate. Here the geometrically corrected scanner data have been integrated with digital elevation data expressed as contour lines, stream drainages, 7½-minute quadrangle boundaries, and 2,500-meter tick marks based on the Universal Transverse Mercator (UTM) grid. Of general utility for a better understanding of an individual site, any of the products mentioned above can be presented in a perspective view (Section F, Plate 6). This dramatically demonstrates the physical or topographic position of any area of interest. Such a presentation can significantly ease the problems of visualization.

In FY84, with the expiration of the AMAX/NASA Letter of Agreement, the project will be concluded

with documentation of results and accomplishments in technical papers. The TMS data set will be retained as a baseline or reference, but new processing is not anticipated unless actual TM data become available. At that time, the process and techniques developed and used on the aircraft data will be applied to the satellite data, and the results will be compared.

SCENE-TO-SCENE REGISTRATION

In October 1981, NASA released an Applications Notice announcing the opportunity for participation in the Landsat D Image Data Quality Analysis Program. The objectives of the LIDQA Program were to quantify Landsat D sensor and systems performance from a user applications point of view. As its commitment to the LIDQA program, the Earth Resources Laboratory has conducted scene-to-scene

registration assessment research using Landsat 4 MSS data.

The purpose of temporal registration, using data from a sensor such as the Landsat MSS, is to produce a single multichannel data set from two or more individual multichannel data sets separated in time. The data from one date are used as a base and all other data are fitted or mapped onto them. It is generally accepted that by producing such a temporal data set, researchers can capitalize on changes which occur (or do not occur) over the time frame encompassed, thus gaining an added dimension that will lead to improvements in the utility of the data being examined.

Results obtained from the use of temporal data are related to the degree to which two or more data sets can be registered one to another; the better the registration, the better the expected results, all other things being equal. Of particular interest to this study were errors introduced by differences in the

sensors being used; i.e., Landsats 1, 2, and 3 versus 4.

Findings from analysis conducted in this study are summarized in Table 3. The results obtained from the temporal registration of the 1981 Landsat 2 MSS data to the base 1980 data set are typical of temporal registrations obtained in the past at ERL when using Landsat 1, 2, or 3 data sets. The scan line and pixel (element) errors are quite similar, with no trends noticed in either magnitude or direction (based on a detailed analysis of overlay control points). Thus, a particularly uniform fit was achieved.

The registration utilizing the 1982 Landsat 4 MSS data (registered to the 1980 Landsat 2 data set) exhibited uncharacteristic error magnitude in the pixel direction (when compared to both the corresponding scan line error of the same registration and the pixel error of the Landsat-2-only registration).

The source of this error was

TABLE 3
Results Obtained for the Registration of Three Scenes of Landsat
P-Format MSS Data to a Common 1980 Landsat 2 Base Data Set

COMPONENT	1981 LANDSAT 2 (METERS)	1982 LANDSAT 4 (METERS)	1983 LANDSAT 4 (METERS)
Pixel Error	20.42	40.32	20.04
Scan Line Error	26.70	26.45	26.65
Model RMS Error	33.61 (74)*	48.50 (65)*	33.35 (72)*

*Values in parentheses represent the number of points used to generate the corresponding statistic.
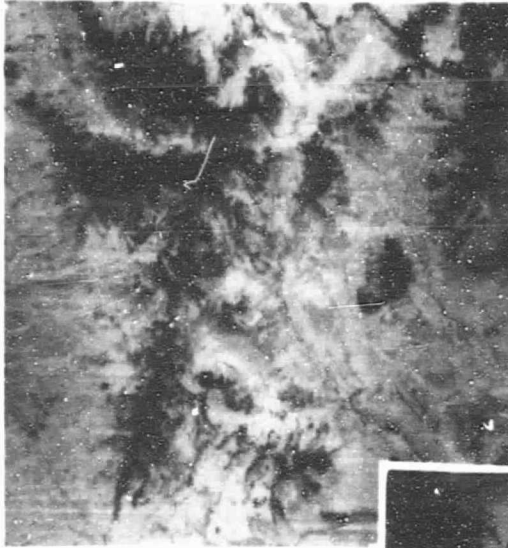
(A) RATIO COMPOSITE

TM Ratio	Color
5/6	Blue
4/2	Green
5/1	Red

Dark Magenta Indicates
Mineralization

(B) PRINCIPAL COMPONENTS

Principal Components	Color
6	Blue
4	Green
3	Red

Yellow Is Associated with Rock
Alteration
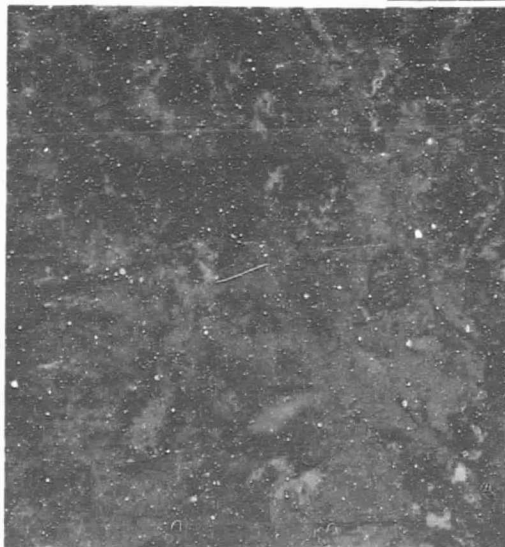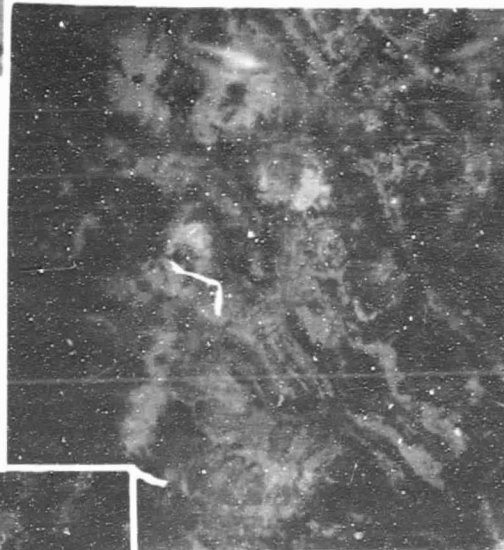
(C) VEGETATION CLASSIFICATION

Class	Color
Trees	Greens
Meadows	Blues
Rocks	Reds/oranges
Rock/Vegetation	Black

UTILITY OF THEMATIC MAPPER

(D) DECORRELATION

Channel	Color
6	Blue
5	Green
4	Red

(E) MERGED SPECTRAL AND TOPO DATA

Item	Color
TMS Channel 5	Gray
Streams	Blue
UTM Grid	Yellow
7.5' Boundary	White
Contours	Brown

(F) RATIO COMPOSITE PERSPECTIVE

Perspective View of Ratio Composite (A) Viewed Toward the Northwest
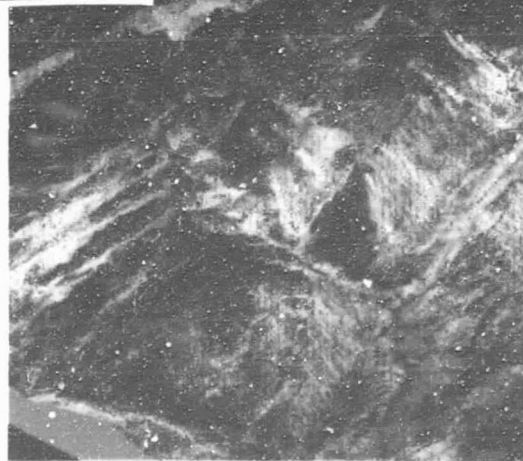
DATA FOR MINERAL EXPLORATION

traced to scan mirror motion modeling coefficients in the Goddard Space Flight Center (GSFC) ground segment software. The problem was subsequently corrected at Goddard and the results are evident in the 1983 Landsat 4 column of Table 3 (post-coefficient correction), where the errors are in line with the Landsat-2-only values.

It is concluded, therefore, that temporal registration of Landsat 4 MSS P-format digital data with historical data obtained by Landsat 2 can be performed to a degree of precision equal to that obtained when Landsat 2 data are used as both components of the temporal registration.

Details of this study are contained in Anderson (1983).

TOPOGRAPHIC CORRECTIONS

Of necessity, the processing of remotely sensed imagery requires some assumptions about the data. Very important among these assumptions is that of uniform illumination—the belief that all targets receive exactly the same irradiance. In any but the flattest of terrains, this is a very dubious assumption. Indeed, the amount of illumination received directly from the sun can vary by a factor of two in moderately hilly areas. Variation of this magnitude has obvious impact on the ability to successfully classify or analyze the data. For this reason ERL has engaged in a project to define the magnitude of the problem, and adapt or develop practical techniques to correct the digital values in the imagery.

An extensive literature review and analysis conducted in FY83

revealed that the problem could be broken down into three major constituents: (1) the contribution to the recorded digital values due to atmospheric haze (the additive path radiance), (2) the variation of direct solar irradiance with slope and aspect, and (3) the percentage of the total irradiance from the sky hemisphere.

From this understanding it was necessary to develop appropriate corrective software and evaluate its impact on the data. For this purpose, a data set covering the Lolo National Forest in western Montana was obtained. This package is an integrated data base including MSS data, 1:24,000-scale digital terrain information, and extremely detailed surface cover observation data. Using this data set and capabilities inherent in ELAS, the radiative transfer process was modeled and the raw MSS data (Plate 7, Section A) was modified based on the three constituents' effects. This resulted in the image shown in Section B of the plate, which appears much "flatter" to the observer. The

results of a more rigorous evaluation of the correction's effect can be seen in Figure 4 and Table 4. In principle, after correction is applied to a given, specific land cover type, the digital values in an image should be independent of (lack correlation with) the angle of incident illumination (i.e., the cos i effect). Lolo ground truth identified one representative class as being 95% tree and 5% shrub. Before correction, the digital values for this class are strongly correlated to cos i (have a significant slope and R value). In other words, the measured reflectance for a homogeneous reflecting cover type appears to be varying with the angle of illumination. After correction the correlation is almost totally gone, as evidenced by the R values (a measure of correlation) in Table 4 and the horizontal shifting of the originally sloped scattergram in Figure 4.

These and similar results suggest that the corrective processing is working appropriately. Further work is planned, both to further

TABLE 4

Lolo National Forest Ground Truth Sample
Before and After Correction for Topographic Effects

CLASS	MSS BAND	BEFORE CORRECTION		AFTER CORRECTION	
		R	SLOPE	R	SLOPE
95% Tree 5% Shrub	4	0.58	0.083	0.22	0.032
	5	0.58	0.094	0.30	0.051
(244 Pixels)	6	0.74	0.326	0.14	0.052
	7	0.75	0.410	0.17	0.077

APPLIED RESEARCH AND DATA ANALYSIS

document the incremental value of each step in the formative correction process and to study those results that appear anomalous.

TM PREPROCESSING TECHNIQUE

Extensive research has been conducted dealing with the application of feature selection techniques designed to facilitate the processing of Landsat MSS data. With the advent of the Thematic Mapper on Landsat 4, the implementation of multitemporal land use classification schemes or the use of band ratioing techniques to enhance the information in a unitemporal classification will stretch the capabilities of many existing data processing systems. This will necessitate the development of feature selection techniques which reduce the dimensionality (number of channels) of TM data, while at the same time preserving the infor-

mation content inherent in the raw data. Subset selection and feature extraction represent two different approaches to the dimensionality reduction problem.

Subset selection employs multivariate techniques to select the subset of original channels which produce the best classification of a given data set. Feature extraction employs multivariate statistical methods to transform the raw data into new "axes" that are independent of one another (orthogonality condition) and to classify the transformed data set based on the transformed values. The subspace of reduced dimension produced by either of these techniques is the feature space. By statistically comparing the accuracy of the classification produced from the original measurement space with that generated from the feature space, it is possible to choose the method that minimizes the probability of misclassification. The other factor of

concern is the cost (Central Processing Unit time utilized) inherent in classifying the feature space versus that incurred for the original measurement space.

This study initiated in FY83 employs multispectral scanner data from the Landsat 4 Thematic Mapper collected over a study site that surrounds the National Space Technology Laboratories in Hancock County, Mississippi. The study site includes urban and residential areas, agriculture and pasture, forests, various types of fresh and brackish water, and a variety of wetland vegetation communities. TM data were collected in October 1982. Extensive ground truth data have been gathered over this study site so the distribution of land use categories is well understood.

The experimental design requires the comparison of the land use classification produced from six channels (visible and mid-IR) of raw TM data with the classification
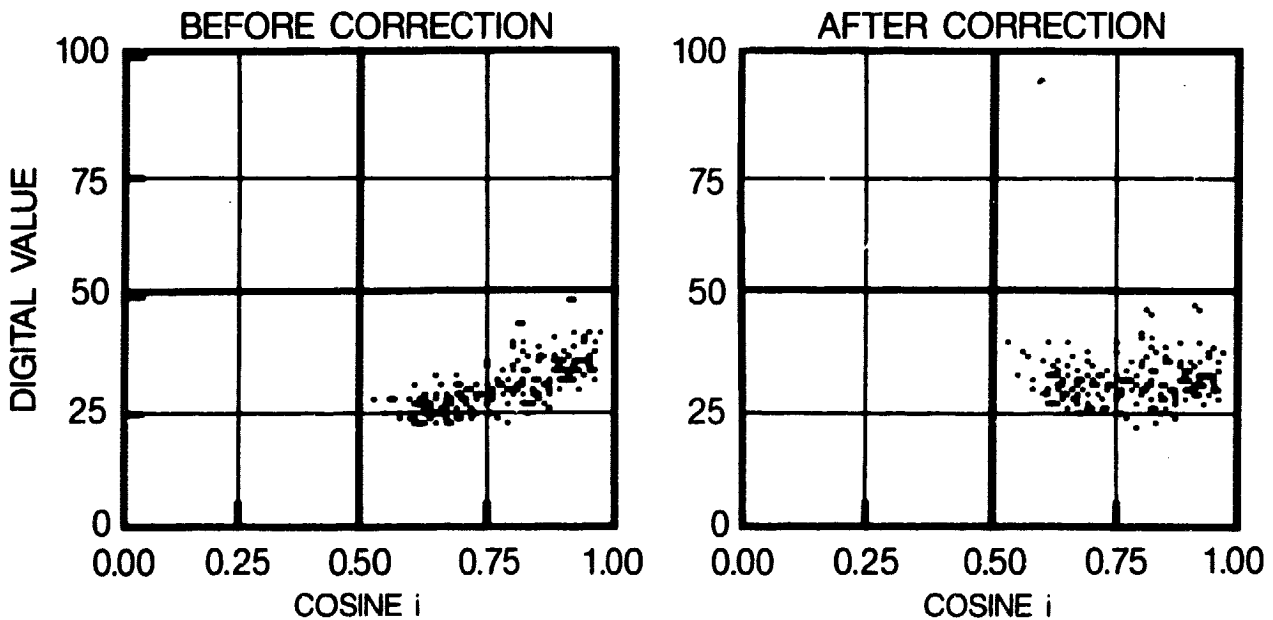

Figure 4. Cosine of Incident Angle of Illumination (Band 6)

APPLIED RESEARCH AND DATA ANALYSIS
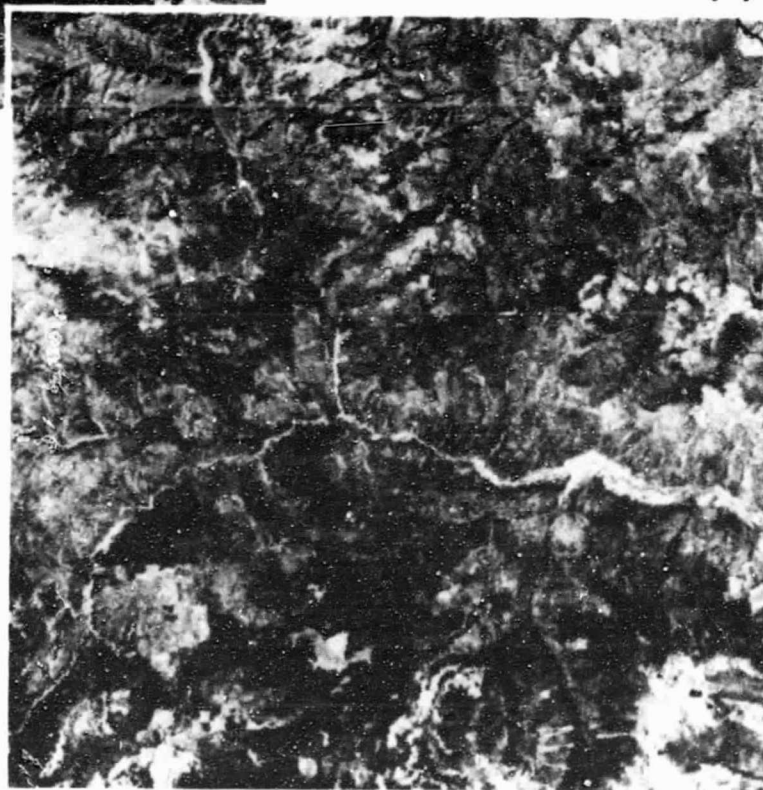**Topographic Corrections**

PLATE 7

(A)

*Raw MSS Band 6,
Lolo National Forest,
Montana*

(B)

*After correction for
atmospheric haze and
angle of incident
illumination*

ILLUMINATION CORRECTION FOR TOPOGRAPHIC EFFECTS

generated by processing the reduced number of channels resulting from the application of different techniques of feature selection. Subset selection methods, which allow the investigator to choose those channels required to delineate the land use classes of interest, will be examined, based on the raw TM data that have been grouped into training statistics for known land use classes. Feature extraction methods will also be used to transform the raw TM data into new variables in a reduced feature space, which will then be classified utilizing the techniques available at the Earth Resources Laboratory.

FY83 accomplishments include the following:
- Receipt in March 1983 of a TM data set suitable for processing (data collected in October 1982).
- Location and spectral editing of more than 160 ground truth sites in the TM data set, representing all the major land cover types of interest in the study. Spectral editing was necessary to ensure spectral homogeneity of land cover within the polygons used to delineate the ground truth sites.
- Classification of the raw six-channel data (the thermal channel was not used), and initiation of accuracy verification of the resultant product.
- Generation of a principal components transformed data set (six axes) and initiation of ground truth site integration.

Anticipated FY84 activities include:
- Completion of the evaluation of the six-channel raw data classification.
- Completion of the principal components analysis.
- Initiation and completion of canonical analysis and subset selection.
- A comparison of all three approaches

GEOBOTANICAL APPLICATION

This investigation, under FY83 RTOP 677-42-04, was initiated to develop and evaluate techniques for using the Thematic Mapper (initially through simulation) and other air- and space-borne systems for geobotanical mapping. The emphasis is on ore-bearing terrains in areas which are moderately to heavily vegetated. Specifically, emphasis is placed on differences in the vegetative cover that appear to relate to the surficial geology. These variations can be either differing vegetation types due to geologic structure or perhaps subtle differences in canopy spectral reflectance caused by varying mineralization in the soil.

The area of investigation centers around the Haile gold mine which is located near Kershaw, South Carolina. Thematic Mapper Simulator data were acquired over this area in April and October 1982. Preliminary processing of these data removed noise and bad scan lines and corrected for overscan. The data were then georeferenced so that each raw data channel could be assigned to a channel in a geographic information system. Geologic map data were also digitized and included as a channel of data. Processing the data using a classifier whose output simulates a three-band color composite, where the

digitized intensity of each assigned color is dependent on the intensity values in each channel, yields a false color image with 256 distinct classes. An example of this is shown in Plate 8.

The plate consists of the three-color composite image from the October TMS data in which the data channel containing the digitized geologic map data has also been superimposed. In the digitized geologic data, divisions between major formations are shown in yellow, while narrow linear features, such as diabase dikes, are shown in white.

In this plate, four major lithologic divisions can be seen. The reddish area in the lower right quadrant corresponds closely to the Cretaceous sediments (unconsolidated quartz sand), whose boundary with the underlying felsic metavolcanic rocks is shown in yellow. Note that the areas of felsic metavolcanic rocks are well depicted by the greenish areas of this image. The darker areas in the upper right quadrant correspond well to the prophyritic, coarse-grained adamellite of the Carboniferous Pageland pluton, while in the extreme upper left quadrant, the medium-grained, foliated, and metamorphosed metatonalite is shown in darker green and darker reddish coloration. This area is also separated from the felsic metavolcanic rocks by the yellow boundary. Diabase dikes are depicted in the geologic overlay as the linear northwest-southeast trending features shown in white. In the original data, a number of such features were visible (usually as some shade of green) but here are overlaid by the geologic graphic.

FY84 studies will include the

APPLIED RESEARCH AND DATA ANALYSIS

analysis of products of data enhancement techniques which have been applied to this area, utilizing specialized filtering techniques which will directionally enhance linear features. Additionally, similar data processing and analysis efforts will be concentrated on the northern portion of the study area (Uwharrie National Forest) where there is much less disturbance to the natural vegetation as a result of man's activities.

SCENE-TO-MAP REGISTRATION

The objective of this Fundamental Research project is to assess the geometric accuracy of Landsat MSS and TM sensor products. A second facet of the project is to develop improved procedures for the registration and rectification of Landsat data.

An evaluation of the accuracy of U.S. Geological Survey (USGS) EROS-generated P-format (geometrically corrected) data for Landsat MSS scenes from Kansas and Louisiana was conducted in FY83 using the approach of Graham and Luebbe (NSTL/ERL Report 197/ AgRISTARS Report DC-Y1-04069, 1981). The row bias was 251.8 pixels for the Kansas data and –219.4 for the Louisiana data, while the column bias was 100.3 pixels for Kansas and –95.6 for Louisiana. These results suggest that the P-format data for Kansas and Louisiana are not accurately georegistered. Georegistration of P-format data utilizing Earth Resources Laboratory Applications Software (ELAS) for whole Landsat scenes utilizing 32 ground control points (GCPs) reported row bias values of 0.03 pixel for Kansas and 0.17 for

Louisiana; the column bias was –0.07 pixel for Kansas and –0.14 for Louisiana. A similar study of A-format (radiometric corrections only) data, georegistered using ELAS software, gave a row bias for 32 GCPs of 0.09 pixel for Kansas and –0.09 for Louisiana, with a column bias of –0.15 pixel for Kansas and 0.44 for Louisiana. This work suggests that ELAS software provides a more accurate georegistration product than does the EROS P-format-generated product. This work is reported in the Proceedings of the NASA Symposium on Mathematical Pattern Recognition and Image Analysis (Dow 1983).

Current work involves empirical studies to evaluate the influence of the number and spatial distribution (random, uniform, or clustered) of GCPs on the geometric accuracy of the scene-to-map registration process for selected portions of an A-format Landsat MSS scene. The A-format scene is georegistered using ground control points; the accuracy of the scene-to-map registration process is evaluated by comparing the location of known ground reference points (GRPs) with the projected location of the points using the mapping equation produced in the georegistration process. The accuracy of this analysis is expressed in terms of the bias and standard deviation descriptors of Graham and Luebbe (1981). The goal of this work is to determine the optimum number of points and spatial distribution of GCPs required to georegister a given proportion of a Landsat scene.

Future work includes analyzing the scene-to-map accuracy of TM data from the R&D phase of the NASA LIDQA program. This analysis would proceed with an ex-

perimental design similar to that employed with the P-format Landsat MSS data. An artificial data set has been obtained from Purdue University which can be employed to evaluate the influence of GCPs' number and spatial distribution on scene-to-map registration accuracy. This study design would be similar to that employed with the A-format Landsat MSS data analysis.

MICROWAVE SENSOR ANALYSIS

Under an Applied Research and Data Analysis (ARDA) RTOP task addressing Multisensor Technique Development, radar land cover analysis research objectives emphasized the understanding of microwave attributes. The potential utility of radar imagery for surface feature identification and mapping establishes a need for a basic understanding of the radar signatures for various surface cover types and the use of this knowledge in the development of techniques oriented toward meaningful terrestrial information extraction. ERL obtained ascending and descending orbit pass data acquired over Baldwin County, Alabama, by the Shuttle Imaging Radar (SIR-A, L-band) and analyzed the data in conjunction with ground truth information to determine which basic land cover physical and/or biological properties affect microwave backscatter. SIR-A data were also integrated with Landsat MSS data to quantify the improvements in using a multisensor data set.

Analysis of results indicates that cropland/pasture and water classes contain low digital count levels (related to radar backscatter), while

APPLIED RESEARCH AND DATA ANALYSIS
Geobotanical Application

PLATE 8

In this presentation, with the digitized boundary and linear feature data superimposed in the image, major geologic formations are shown in shades of red and green.

THREE-COLOR COMPOSITE OF OCTOBER 1982 TMS DATA

mixed pine/hardwood and urban/ inert classes contain high count levels for SIR-A data. The count levels of three pine forest classes are highly correlated with tree height and canopy structures. The use of MSS data improved separation of cropland/pasture classes from water and pine regeneration classes. The results of classification accuracy using SIR-A, MSS, and SIR-A/ MSS data are given in Table 5. These results are included as part of a paper entitled "Analysis of SAR Data Over a Variety of Land Cover," published in the 1983 International Geoscience and Remote Sensing Symposium (IGARSS '83) Digest (Wu 1983a).

After the launch of Landsat 4, data acquired by the Thematic Mapper over the Baldwin County study area in October 1982 were co-registered with SIR-A data to form a SIR-A/TM data set. The processing and analysis of these data to evaluate the complementary role of TM data in delineating forest and urban cover types will be continued and completed in FY84. In September 1983, a data acquisition aircraft mission using the Jet Propulsion Laboratory (JPL) L-band multipolarization SAR system was conducted. Analysis of these data from the agriculture- and forestry-oriented study area will be the major thrust in FY84.

MID/THERMAL IR REMOTE SENSING DATA ANALYSIS

In order to effectively utilize information derived from the mid- to thermal infrared regions of the electromagnetic spectrum (0.76–14.0 micrometers), research needs to be conducted dealing with the basic factors associated with land covers that influence mid/thermal IR reflectance and emissivity. Fundamental to such research is an understanding of the relationships between the life processes or physical state of a land cover and the phenomena that are measured in the mid/thermal IR region.

Two areas of interest are being investigated in this ARDA RTOP project. The first deals with thermal studies (3.0–14.0 micrometers) and will focus on the estimation of plant temperature, which is not an end in itself but rather an initial point from which other studies requiring a knowledge of temperature can begin. The second area of interest, based at least in part on a target's physiological or chemical response to radiation with wavelengths between 0.76 and 3.0 micrometers, is the determination of relationships that exist between leaf water content and data recorded by Earth-orbiting satellites.

It has been demonstrated by numerous researchers that the potential exists to extract valuable information from data collected in the mid-IR region for plant/environment interactions, including research dealing with the reflectance changes due to leaf maturation and senescence, leaf type (gymosperm versus angiosperm), plant nutrition, site salinity, and water stress. In summary, the major influence on mid-IR reflectance by plant leaves is tied to the leaf water status, and any organism or condition which alters this status will have an effect on the reflectance as measured by a mid-IR-sensitive device.

Interest in the thermal IR region of the electromagnetic spectrum is founded in part on the relationship that a target's temperature has with its physical or physiological state, and how well the temperature can be used as an indicator of that state. The effect of temperatures can be related to the state of agro-

TABLE 5
Baldwin County Land Cover Classification Accuracy

LANDSAT COVER CLASSES	SIR-A DATA	LANDSAT MSS DATA	SIR-A AND MSS DATA
Urban/Inert	6.7	35.7	72.5
Mixed Pine Hardwood	77.9	24.5	83.3
Native Pine	91.0	78.4	83.0
Pine Regeneration	66.4	41.0	78.8
Cropland/Pasture	74.4	82.8	93.1
Water	64.9	98.5	99.8
Overall	67.0	68.0	89.2

nomic crops: soil surface temperatures reaching 50-60° can kill emerging plants; soil surface temperatures collected in the winter and early spring months may indicate the need for freeze protection practices; and plant temperature increases with decreasing soil moisture availability and canopy temperatures can be used as an indicator of the relative need for irrigation. Temperature is also a useful quantity to know in other fields, such as thermal discharge studies, soil-related investigations, geology, oceanography, geomorphology, atmospherics, snow field studies, and urban studies.

In the past, temperatures were obtained by making direct measurements of the target of interest, using thermometers, thermistors, or thermocouples. However, use of these devices may, in fact, alter the thermal nature of the surface, resulting in questionable temperature measurements. Also, the number and frequency of measurements can be prohibitive for large-area phenomena. An alternative to direct measurement of target temperature is the use of a radiometer designed to measure electromagnetic energy in the thermal IR region. Based on certain known or determinable properties of the target, measured energy can be converted to temperature through the use of established equations.

In FY83, the following activities were accomplished:

- A report summarizing the underlying theory, as well as providing a detailed bibliography dealing with mid/thermal IR research, was completed (Anderson 1983). The FY83/FY84 experiment design is contained in this report.

- Lowtran-5, an atmospheric model developed by the Air Force Geophysics Laboratory, was implemented on the NSTL/ERL mainframe computer, thus providing the processing capability for estimating atmospheric parameters required for this investigation.

- Thermal channel ratioing software (post-atmospheric corrections) was generated, as well as software which permits the calculation of effective radiant temperature from the Thermal Infrared Multispectral Scanner airborne data collection system.

- A study site was selected in the vicinity of NSTL. Acquisition of ground truth data, using PRT-5 radiometers, was scheduled in conjunction with a TIMS overflight in the late fourth quarter FY83.

FY84 activities will at least continue the thermal portion of the study:

- Initial analysis of 1983 TIMS data from the study site will be completed. The results of the analysis will demonstrate the applicability of the band-ratioing model to a homogeneous land cover.

- The model will be verified using TIMS data to be collected in 1984 covering a less homogeneous land cover type (e.g., pine plantation).

VEGETATION STRESS ASSESSMENT

This RTOP investigation was initiated to detect plant stress in a situation in which some of the variables relating to stress in a pine plantation can be identified and measured.

The additional data available in the mid-IR region of the spectrum (1.0-1.3 and 1.55-2.35 micrometers) from TM and other experimental scanners require that research be conducted to determine the contribution these regions of the spectrum will have on the analysis of vegetated areas. In some non-natural vegetated areas such as pine plantations, many biological variables (uncertainties) are removed by the uniformity of planting and by maintenance procedures.

The detection of plant stress is of importance since, in some cases, it is possible to remedy the stressed condition. This RTOP examines areas within an experimental planting of pine near NSTL where there are positive indications of differing degrees of stress. Within these areas, planted in 1960, differing amounts of fertilizer were applied the first season after outplanting, and some plots were not fertilized at all. Although 22 years have elapsed since this single fertilization treatment, certain fertilized plots exhibit more than twice the wood volume of the non-fertilized areas. Several strong indications link this wood volume increase to differences in mycorrhizal involvement between the fertilized and non-fertilized plots. Ample evidence suggests that this type of stress can be detected through remote sensing.

Thematic Mapper Simulator data were acquired in December 1982 and March and May 1983. Primary emphasis, however, has centered on the acquisition of field information, since this must be acquired over a relatively long time base to be statistically valid.

Wood volume data for each tree in each plot were calculated, as were the average wood volumes per plot (each plot is 120 feet square). In all areas, a wood volume of the once-fertilized plot is about twice that of the non-fertilized plot. There is strong evidence which suggests that this continuing increased growth observed in the fertilized plot is the result of an increased mycorrhizal involvement. Field studies to date substantiate this concept. Mycorrhiza is a symbiotic relationship between higher plants and various fungi. It is mutualistic in that neither organism (pine or fungi) can exist without the other. There may, however, be differences in the degree, extent, and efficiency of this partnership. In cases where the relationship is not fully exploited, the higher plant partner will be under more stress than if this were not the situation.

The fungi which are involved in this partnership may not be evident for much of the time. Under favorable conditions, the fungi reproduce by producing sporophores which can be seen in the vicinity of the tree with which this fungus is a partner. Weekly inventories were taken during favorable weather in the plots, and the 10-foot by 10-foot square formed by each four of the row-planted trees was used as the study's inventory unit.

Two such inventory sheets, summed up over the entire season of appearance, are shown in Figure 5. The groupings of numbers within adjacent blocks suggest the extent of the mycelium of the fungus (this is the usually underground vegetative phase of the fungal organism). Note that with both *Laccaria Laccata* and *Cortinarius semisanguineus*, there appears to be a tendency for each mycelium to be exclusive of the other. This suggests that, even within given plots, it may be possible to relate individual sporophore counts for each 10 x 10 quadrant to determine what correlations may exist between these field-derived data. These correlations will be checked in FY84 against the TMS data and will be used to determine which trees should be sampled with a portable field spectrometer.

Table 6 suggests differences in both mycorrhizal speciation and extent between the fertilized (high) and non-fertilized (low) plots. For example, *Cortinarius semisanguineus* is much more prevalent in the high plots (653 specimens) than in

Species **Laccaria laccata**

West	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13
N1													
N2	2		1										
N3													
N4	2												
N5	2	1											
N6	12	4	1				28	17					
N7			2										
N8	9				1		4	5		2			
N9	12					19		1					
N10	4						6	2	2		1		
N11	1						1			9			
N12	1			1	4					3			
N13													

TOTAL: 160

Species **Cortinarius semisanguineus**

West	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13
N1						20	25		1		5	1	
N2			3			1			7	1	1		
N3						5			14				
N4						2	3						
N5				6	20	4	5	3	3	6			
N6				4	28	15	5		5	19			
N7			2				3	2	22	9	1		
N8							10	2	12	7	15		
N9			11				6	1	8	45	36	34	
N10	7	5	10				2		7	26	28	18	
N11		6					14	1	5	1	1		
N12							2	2	2	7	3	36	
N13													

TOTAL: 653

Figure 5. Sample Sporophore Inventory Sheets

the low plots (104 specimens), while *Suillus decipiens* is much more abundant in the low (1,103) than in the high (148). These data for the first time suggest that *C. semisanguineus* may be more efficient for the tree in the mycorrhizal symbiosis than *S. decipiens*.

TABLE 6
Fertilization Plot Study Area, Harrison Experimental Forest
(Loblolly Pine Plots)

SPECIES	BLOCK IV PLOT 1 (LOW)		BLOCK IV PLOT 4 (HIGH)	
	Summer	Winter	Summer	Winter
Amanita flavoconia	62	---	31	---
A. rubescens	307	---	66	---
Boletus edulis	5	---	1	---
Gyroporus castaneus	8	---	---	---
Tylopilus (indecisus)	1	---	---	
T. plumbeoviolaceus	2	---	---	---
Cantharellus cibarius	26	---	---	---
C. Cinnabarinus	24	---	---	---
Cortinarius cinnamomeus	---	15	16	36
C. semisanguineus	---	104	---	653
Laccaria laccata	---	323	---	160
Thelephora terrestris	5	---	---	---
Russula (emetica)	---	1	---	1
Suillus cothurnatus	---	2	---	2
Suillus decipiens	1,103	13	148	---
Amanita vaginata	---	---	2	---
Amanita vaginata var. alba	---	---	3	---
Boletus projectellus	---	---	6	---
Collybia maculata	---	---	---	6
Hydnum imbricatum	---	---	---	1
Rhizopogon sp.	---	---	---	2
Tricholoma flavovirens	---	---	---	19

- JOINT RESEARCH PROJECTS

  - Crop Mensuration and
    Mapping
  - Timber Resource Inventory
    and Monitoring
  - Wetlands Productive
    Capacity Modeling
  - Crop Condition Assess-
    ment and Monitoring

JOINT RESEARCH PROJECTS

JOINT RESEARCH PROJECTS

Joint research projects represent a NASA program area within which applied research is conducted jointly with selected non-NASA user communities who have a requirement to incorporate remote sensing-derived information into their decision-making processes. Research projects are selected through announcements in the Commerce Business Daily and subsequent proposals submitted by interested organizations. The major criteria for selection include: (1) the research requirements must be of mutual interest to NASA as well as the non-NASA organization, and (2) the organization cooperating in the research must be representative of a broader community of users.

During FY82, four joint research projects were initiated at NSTL/ERL; the following pages present the FY83 accomplishments for each project.

CROP MENSURATION AND MAPPING

The Crop Mensuration and Mapping joint research project is a cooperative effort between NSTL/ERL and International Harvester as a representative of the farm implement industry. The objective of the project is to evaluate Landsat Thematic Mapper data for mapping crop types and estimating crop acreages.

The first year of this project (FY82) addressed the development of a baseline surface cover inventory with Landsat MSS data to compare with TM-derived inventory results. Work completed during FY83 focused on the capabilities of the Thematic Mapper to discriminate between crop types in Poinsett County, Arkansas, and the feasibility of reducing the quantity of data analyzed while maintaining high mapping accuracies.

Two methods of spectral signature development were employed during initial TM analysis: unsupervised and supervised. The ELAS module SEARCH was used to generate unsupervised spectral statistics over the Powers Slough and Otwell quadrangles study site by sliding a 3- x 3-pixel window through the data. With the higher resolution of TM data, statistics derived in this manner are based on a sampling unit of 0.8 hectare (2.0 acres) as compared to 4.0 hectares (10.0 acres) when the same technique is applied to MSS data. Fifty-seven spectral signatures were developed over the test site, which correlated with the following seven land cover categories:

- Rice
- Soybeans
- Fallow
- Hardwood
- Emergent Vegetation
- Water
- Clouds

The resulting classification was assessed for accuracy with a file of verified ground truth polygons. Target crops of rice and soybeans were classified correctly at levels of 98.50 and 98.08 percent, respectively.

Supervised spectral signatures were developed with ELAS module SUPE and the class-naming, ground truth data file. Spectral statistics developed with this technique were used to classify the entire data set and resulted in an overall mapping accuracy of 92.49 percent correct. The target crops, rice and soybeans, were classified at 96.64 and 96.30 percent accuracy levels, respectively.

Additionally, the supervised statistics developed from the seven channels of TM data were used to examine the utility of each subset of channels. The purpose of subset selection is to determine the best channel combination for any given application of the data and reduce the number of channels required for analysis. The most desirable subset of channels was determined to be that subset exhibiting the least reduction in average transformed divergence (ATD) from the original channels analyzed. Initially, the subset selection routine was applied to all seven channels. During this analysis, Channel 6 (thermal IR) was found to heavily weight the ATD of each subset. This weighting was determined to be a function of random noise in the data and was not due to spectral heterogeneity. Thus, Channel 6 was deleted for the remainder of the analysis. The over-

all ATD for six channels was computed at 0.25091. The best five-channel subset was obtained by deleting Channel 3, causing only a 5.72 percent reduction in ATD. A reduction in ATD of 11.19 percent was shown by deleting Channels and 3 to yield the best overall four-channel subset—2, 4, 5, and 7.

The assessment of each subset of TM channels for discriminating crops will be completed during FY84 by conducting both supervised and unsupervised classifications with each subset. The resulting classification accuracy figures for each subset will then be comparatively analyzed with a test for variance to determine the significance of each subset test result.

TIMBER RESOURCE INVENTORY AND MONITORING

The objective of the Timber Resource Inventory and Monitoring joint research project with International Paper Company (IP) is to determine the information content of Landsat Thematic Mapper data for mapping forest stands and identifying silvicultural activities. A forest stand is defined as "an individual body of timber occupying a specific area and sufficiently uniform in species composition, age, site, and degree of stocking." In addition, a stand must be "separable from other areas in the forest." Silvicultural activities include planting and restocking, precommercial thinning, harvest, site preparation, and controlled burning.

International Paper Company is a large-scale forest products industry operating in North America,

where it manages some 8.4 million acres of forest land. Their current inventory is updated on a three-year cycle using aerial photography and field surveys, which result in detailed forest data bases. For the purposes of this project, a study area in Baldwin County, Alabama, was selected as a representative area of southern forest types to take advantage of IP's *in situ* field data. The IP data base for the study area includes 240 descriptive parameters on forest stands as well as silvicultural activities.

Past success with Landsat MSS data for industrial forest applications has been limited to a general forest association level. Even the separation of deciduous from coniferous forest has required the analysis of seasonal data sets. Overall, Landsat MSS data have been considered too coarse to provide the type of inventory information required by industrial forest managers.

During the first phase of this joint project, an MSS classification was developed using seasonal data sets to establish a baseline against which the TM classification results will be compared. While the overall accuracy of the MSS classification was verified to be 79.2% correct, the level of forest information derived from MSS data was limited to general associations, such as mixed coniferous and deciduous forest communities, and basically substantiated earlier findings.

The purpose of the second phase of the project is to test existing pattern recognition techniques using Thematic Mapper Simulator data. During FY83, several techniques were applied to a winter TMS data

set acquired in February 1982. Supervised, unsupervised, and band ratioing analysis procedures were tested, with the supervised signature development technique providing the best overall results. The classification resulted in the separation of even-aged, single-composition stands of loblolly, slash, and long leaf pines. Atlantic white cedar, occupying the very low areas along major drainages, was also discriminated from other bottomland hardwood stands.

The verification process employed for the accuracy assessment used IP timber stand maps, color infrared photography, and field information to identify additional independent polygons representative of the forest information of interest. These polygons were input as a separate data file and automatically compared to the classification data file. The overall accuracy for the supervised classification is 88.5%. A matrix displaying the interclass classification success is presented in Table 7.

The results presented are encouraging in that the TMS data are capable of delineating the major merchantable timber species of the study area and thus address an important component of the forest stand. These results are made even more interesting in that only a single winter TMS data set was used in analysis. During FY84, a Landsat TM data set acquired in late January 1983 will be used to verify the TMS results and to develop new information extraction techniques or combinations of analysis procedures, if necessary, based on IP's evaluation of the results thus far.

WETLANDS PRODUCTIVE CAPACITY MODELING

The four-year Wetlands Productive Capacity Modeling joint research project, initiated in FY82, encompasses the research and development of Thematic Mapper satellite technology to determine the value of wetlands to living marine resources. The project is a cooperative endeavor between the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS), through NMFS's Southeast Fisheries Center (SEFC), and NASA/NSTL/ERL.

The remote-sensing-based Wetlands Productive Capacity (PC) Model (Figure 6) is being refined, tested, and analyzed to determine if derived results can provide quantitative information about the value of wetland habitats to the production of estuarine-dependent fishery resources. TM technology is being directed toward primary productivity assessment and detrital export estimation, as interrelated variables influencing the determination of the trophic values of wetlands. The Calcasieu Lake Basin in Louisiana is the selected study area for the model development. The resulting model will interface with another model being developed by SEFC to describe the energy flow of an estuary and relate detritus exported from the wetlands to the standing stocks of juvenile fish and shrimp. This NMFS estuarine model will involve a shrimp productivity index and a detritus availability index.

Because Landsat 4 TM data have not been acquired for the study area, emphasis was placed on (1) testing of the PC algorithms with Landsat MSS data, and (2) analysis of Thematic Mapper Simulator data that had been acquired by aircraft during September 1982 and May 1983. The PC algorithms exist as computer programs included in ELAS and permit the following measurements to be derived from digital remotely sensed data (program acronym is indicated in parentheses):

- Surface cover classification (MAXL)
- Water body identification (WBOD)
- Shoreline identification and length (SLIN)
- Distance-to-water (DIST)

The preliminary analysis of the September TMS data was presented at IGARSS '83 in San Francisco in August 1983 in a paper entitled "Assessment of Wetland Productivity Capacity from a Remote-Sensing-Based Model—A NASA/NMFS Joint Research Project" (Butera and Frick, 1983). The most important preliminary findings were as follows:

- Regression analyses of TMS data showed a stronger relationship with percent vegetation cover (living and dead) than with biomass for esti-

mating the source of organic detritus.
- Land/water discrimination, fundamental to the measurement of the hydrographic variables, was accomplished more accurately with TMS than with MSS data as compared to a standard established through aerial photo interpretation.

FY84 analysis of TMS data will focus on the verification of these findings, using the TMS data acquired in May 1983, and also on use of band ratioing and other analytical techniques.

NMFS personnel have continued analyses to understand some of the relationships in their Estuarine Ecosystem Model. As reported in the previously cited IGARSS '83 paper, initial results indicate that salinity patterns and estuarine animal interactions affect the utilization of detritus.

Future efforts will concentrate on the calibration of the Productive Capacity Model. It will be calibrated by multiple regression analysis, using organic carbon export as the dependent response variable and primary productivity, shoreline den-

TABLE 7

Mapping Accuracy for Supervised TMS Classification*

GROUND-TRUTH CLASSES	UNCLAS-SIFIED 0	LOBLOLLY PINE 1	SLASH PINE 2	YOUNG REGEN. PINE 3	LONG LEAF PINE 4	ATLANTIC CEDAR 5
1	0.00	94.85	0.21	0.00	4.95	0.00
2	0.25	0.88	90.20	0.50	8.17	0.00
3	20.62	0.42	0.28	66.62	12.06	0.00
4	0.25	4.71	1.49	1.49	92.06	0.00
5	0.33	0.22	0.00	0.00	0.11	99.35

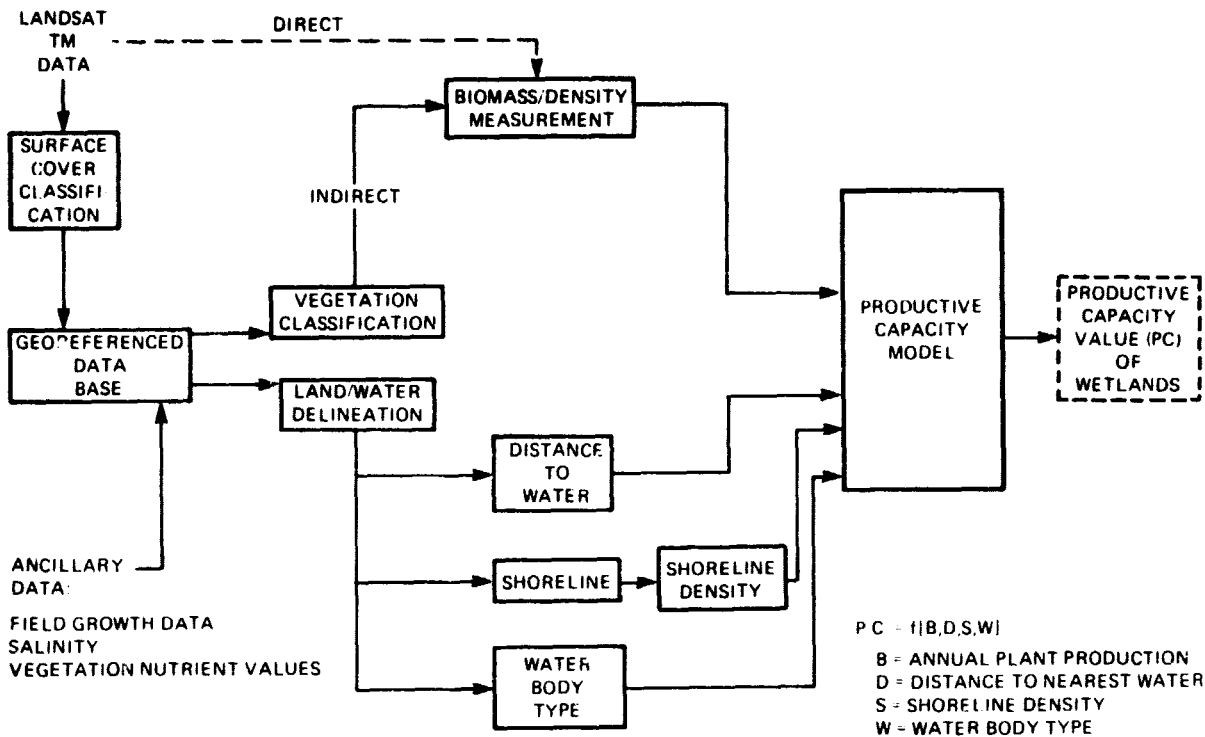*19 STATISTICS, THRESHOLD 99.9   PERCENT CORRECT OVERALL—88.57

　
Figure 6. Wetlands Productive Capacity Model

sity, distance to water, and water body type as the independent variables. Field collection for the response variable has been conducted in FY83 to obtain seasonal concentrations of organic carbon in the water column for both incoming and outgoing tides. The fractions of organic carbon sampled and measured included dissolved, particulate, and macroscopic detrital forms. Dissolved organic carbon (DOC) and particulate organic carbon (POC) were derived by automatic carbon analysis of water bottle samples. Detrital fragments were sampled with nets and dried and weighed for calculation of carbon content.

The carbon measurements will be defined as organic carbon export by adjusting for discharge from four hydrologically discrete locations in

the watershed. The organic carbon was sampled and water level and current velocity were continuously recorded at these four sites. The result of calibration, then, will provide predictive equations for organic carbon export from a typical Gulf Coast marsh for four seasons. Once the PC model is calibrated, the output data will be used as input data for developing the Estuarine Ecosystem Model by simulation methods.

CROP CONDITION ASSESSMENT AND MONITORING

Monsanto Agricultural Products Company and NASA/NSTL/ERL are participating in a joint research project to investigate the capacity of Landsat Thematic Mapper data to

provide agricultural information of utility to the agricultural chemicals industry. Specific objectives include the examination of TM data for detecting variations in weed infestation levels during the growing season and variations in crop residue levels in fields between growing seasons.

Work during FY83 focused on the examination of weed infestation levels in soybean fields in a Gentry County, Missouri, study area. Thematic Mapper Simulator data showed that spectral responses of all channels except Channel 4 decrease with increasing levels of observed weed infestation in soybean fields (Figure 7). Although, in general, fields with severe weed infestation have higher than average cover values (percentage of the field covered by crop or weeds), the same trends

exist in the data for fields of equal cover values over 40% cover (Table 8). It is hypothesized that differences in chlorophyll concentrations and plant water content between vigorously growing weeds and the soybean crop account for the changes in detector response as weed infestation increases.

Using simulated TM data, three classification methods were examined for their effectiveness in determining broad levels of weed infestation in soybean fields. The first method was a supervised classification scheme in which classification statistics were derived by merging statistics from fields of similar weed infestation levels. Through this method, three sets of statistics rep-

resenting severe, moderate-light, and no weed infestation were created. The statistics were then used to classify an independent set of verification fields of known infestation levels. The classification was 59.3% correct in identifying fields with the majority (greater than 50%) of their pixels in the correct weed infestation level according to ground truth data.

The second method consisted of developing three to four statistics per weed infestation level by searching each level with an unsupervised pixel clustering algorithm. The resulting statistics were used to classify the fields. Using this method, classification accuracy was increased to 66.7%. The increase in accuracy

was due to the use of classification statistics which better approximated the actual centers of variation found within the weed infestation levels. The statistics indicate a heterogeneity in soybean fields with light-moderate and severe weed infestation. Even within these fields, there are centers of variation which represent pixels of pure crop, as evidenced by the similarity to the statistics from fields with no weed infestation.

The third method consisted of assigning the statistics developed in the second method to one of three weed infestation levels based on their statistical similarity to mean signatures for each weed infestation level. The resulting statistics when
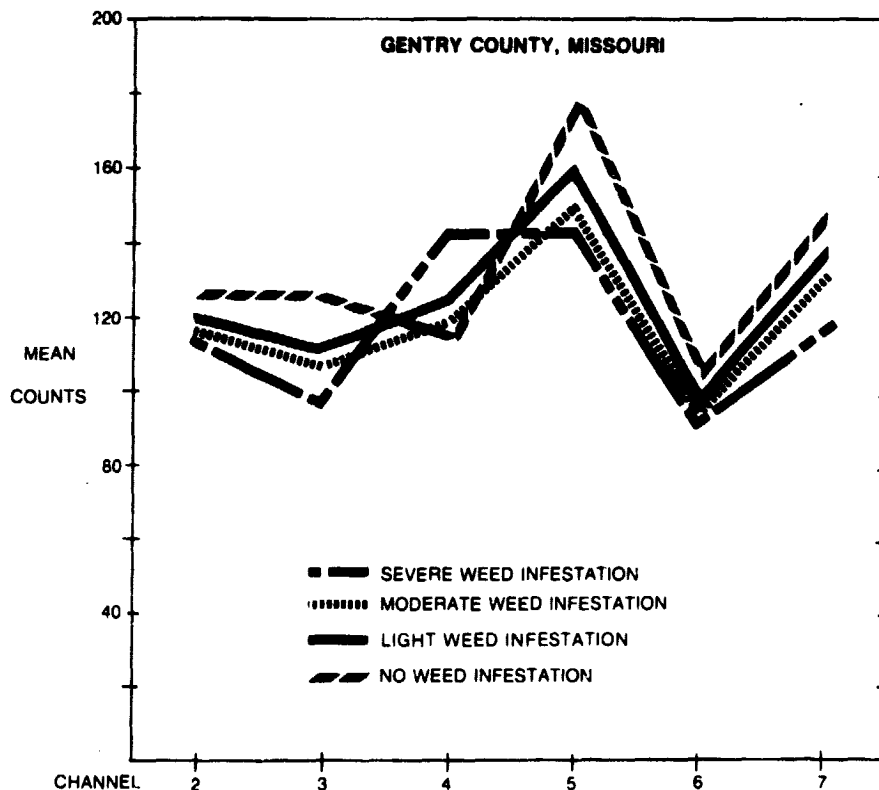

Figure 7. Spectral Signatures of Soybeans Within Four
Weed Infestation Levels

used to classify the verification fields yielded an accuracy of 70.3%. The increase in accuracy over the first two methods results from a decrease in the standard deviations of the statistics representing the weed infestation levels.

The Crop Condition Assessment and Monitoring joint research project will continue in FY84. Projected activities include continuation of the weed infestation work, using corn as the target crop, and an examination of the capability of simulated TM data to detect variations in crop residue levels with a late October data set.

TABLE 8

Mean Channel Response for Weed Infestation Levels within Four Coverage Levels in Soybean Fields

COVERAGE VALUE (%)	WEED INFESTATION LEVEL	TMS CHANNELS						
		1	2	3	4	5	6	7
80-100	SEV RE	102.81	113.50	91.57	147.35	142.21	90.77	106.08
	MODERATE	103.42	114.58	91.77	162.12	148.01	91.06	103.22
	LIGHT	105.61	112.11	98.17	147.11	157.07	93.95	117.29
60-80	SEVERE	103.18	111.55	101.18	110.43	144.64	93.62	117.34
	MODERATE	107.39	117.64	110.69	115.13	155.63	97.25	139.49
	LIGHT	107.02	116.30	105.74	124.66	155.19	96.11	137.60
	NONE	110.97	122.84	123.36	110.84	174.22	101.67	145.32
40-60	MODERATE	103.59	111.19	99.56	111.68	142.67	94.07	136.32
	LIGHT	109.37	120.50	112.26	124.66	158.82	97.42	128.34
	NONE	111.98	129.84	132.56	121.64	185.56	102.85	151.39
0-40	MODERATE	111.37	123.46	120.99	115.86	163.28	99.51	136.28
	LIGHT	113.87	128.02	129.02	123.07	171.56	101.45	146.62
	NONE	108 55	118.03	116.98	103.98	164.05	99.62	174.89

- TEST AND EVALUATION

    - Corridor Analysis
    - Urban Studies

TEST and EVALUATION

Four permanent test areas within the NSTL/ERL region have been identified for development under the Southern Test and Evaluation Program. The first area to be developed is the Gulf Coastal Plain (Figure 8), within which several project activities have been initiated.

The Gulf Coastal Plain is characterized by a wide variety of environmental and cultural conditions, which led to its selection as a testing ground for remote sensing technology. During Fiscal Years 1982 and 1983, work was conducted on a specific test site in Baldwin and Mobile Counties, Alabama, which is representative of the Gulf Coastal Plain physiographic region. Activities completed during this time included Landsat MSS-derived land cover inventories using unsupervised spectral signature development techniques for: (1) Mobile/Baldwin Counties, (2) Baldwin County, (3) Baldwin County Coastal Zone, and (4) the City of Mobile. In addition, a standardized data base for Baldwin County was constructed and, together with the MSS-derived land cover inventories, will be used to test and evaluate emerging sensor technology and new data analysis algorithms, including data base models.

CORRIDOR ANALYSIS

During FY83, the Baldwin County data base was used to test a weighted simulation model developed at NSTL/ERL from a software package developed by Environmental Systems Research Institute (ESRI). The model was composed of five data planes geographically referenced to the UTM coordinate system on a 50-meter grid cell size and used to determine relative levels of trafficability for each cell. Data planes used to model the area included:

- Landsat MSS-derived land cover
- U.S. Soil Conservation Service (SCS) detailed soils survey
- National Cartographic Information Center (NCIC) digital topographic data
- Digitized primary and secondary roadways
- Digitized urban centers

The original data comprising each data plane were very detailed and contained more information than was required for the application. In order to incorporate these data into the weighted simulation model, the variables within each data plane were aggregated into relevant categories based on hypothetical criteria for determining trafficability.

In some cases, this process entailed aggregating the detailed information contained in the original data plane. For example, 100 different soil types were combined into 6 load-bearing strength categories, and the 58 spectral classes derived from Landsat MSS data were combined into 9 land cover classes. In other cases, additional information was derived or computed from the original, as in the elevation data. From the NCIC digital terrain data, elevation is the original data plane variable from which aspect and slope can be derived. For the application, percent of slope was computed as a limiting factor for trafficability. The importance of trans-
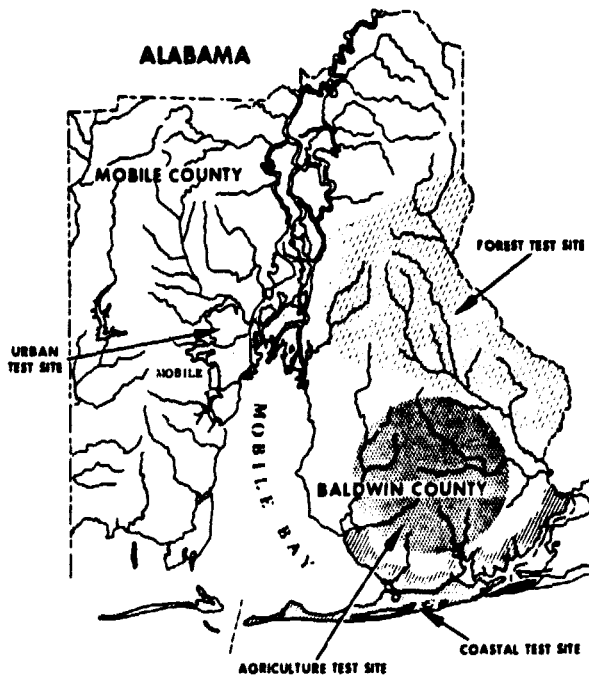

ALABAMA

MOBILE COUNTY

FOREST TEST SITE

URBAN TEST SITE

MOBILE

MOBILE BAY

BALDWIN COUNTY

COASTAL TEST SITE

AGRICULTURE TEST SITE

Figure 8. Gulf Coastal Plain Test Area

TEST AND EVALUATION

portation networks and urban centers was a function of distance, which was computed using an algorithm which determines the Euclidian distance between specified units.

In weighted simulation modeling, each cell representing the categories within each data plane was assigned a ranking value (X value) between a range from 0 to 10, with 0 representing the best condition and 10 representing the worst, as depicted in Figure 9. The conditions placed on corridor development in this exercise were assigned arbitrarily. For example, within the land cover data

plane, 58 spectral classes were combined to form 9 categories. These were ranked in terms of trafficability, with those categories offering the least resistance to corridor development (cultivated lands, pasture, etc.) assigned the lower values. In each case within the remaining data planes, the lower ranking values were assigned to the areas offering the least resistance to corridor development.

A significance value (N-weight) was then assigned to each data plane. The N-weight was multiplied by the X value for each cell (ex-

pressed as $X_i N_j$ = acceptability value) to determine the relative trafficability value within each data plane. The data planes were overlaid and the corresponding cell acceptability values within each data plane were then summed to determine a range of trafficability (Figure 9).

For the actual corridor selection, given Point A as the departure point and Point B as the target, the algorithm defines a minimum distance (path of least resistance) from Point A to Point B (Plate 9). In Plate 9, all data planes had differ-

(1) CATEGORIES AND CORRESPONDING 50-METER CELLS ARE ASSIGNED AN X VALUE

(2) X VALUE THEN MULTIPLIED BY WEIGHT (N VALUE) ASSIGNED TO CORRESPONDING DATA PLANE

$(X_1 N_1) + \cdots (X_N N_N)$ = ACCEPTABILITY VALUE

(3) RESULTS SUMMED TO DEFINE RANGE OF ACCEPTABILITY
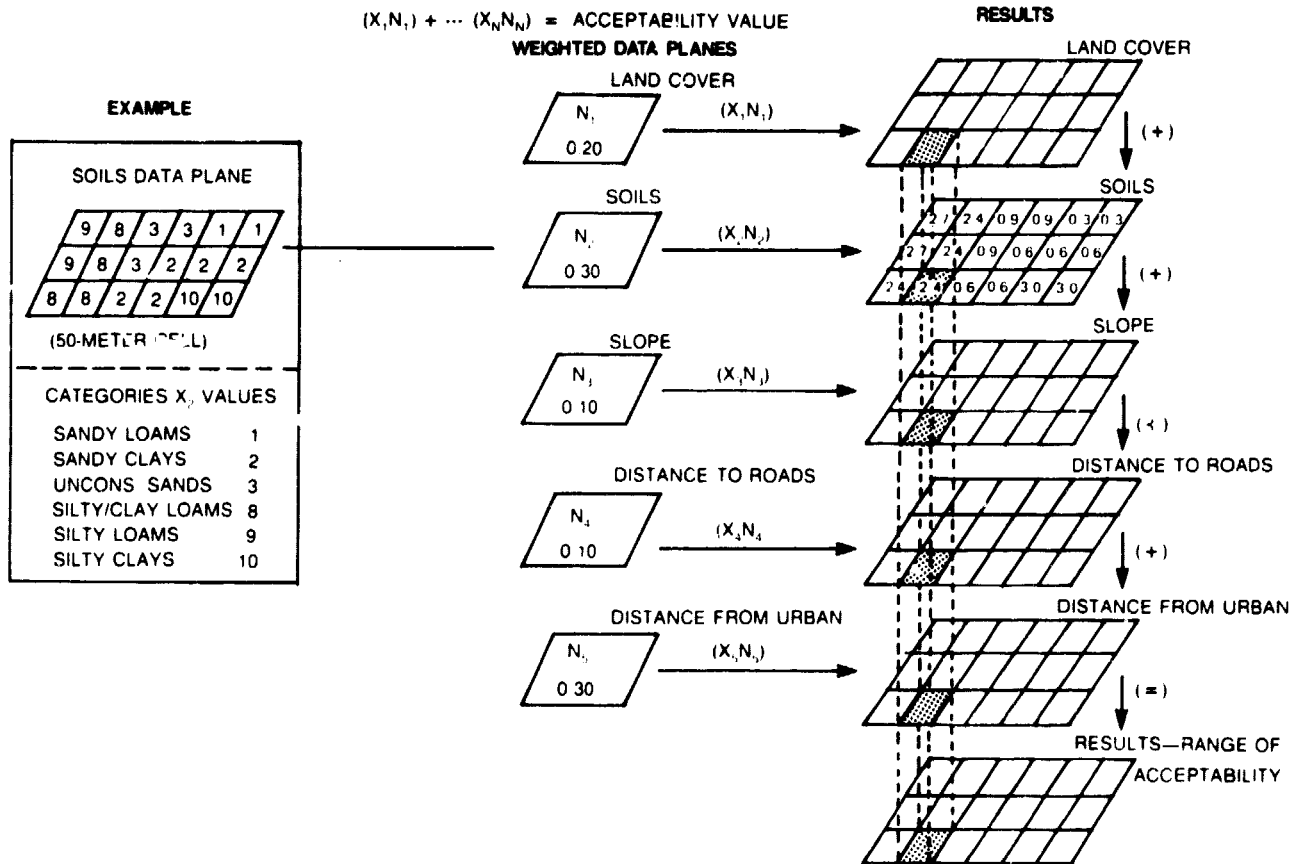
Figure 9. Weighted Simulation Model

SOUTHERN BALDWIN COUNTY
CORRIDOR ANALYSIS
RESULTS OF AUTOMATED
CORRIDOR SELECTION MODULE
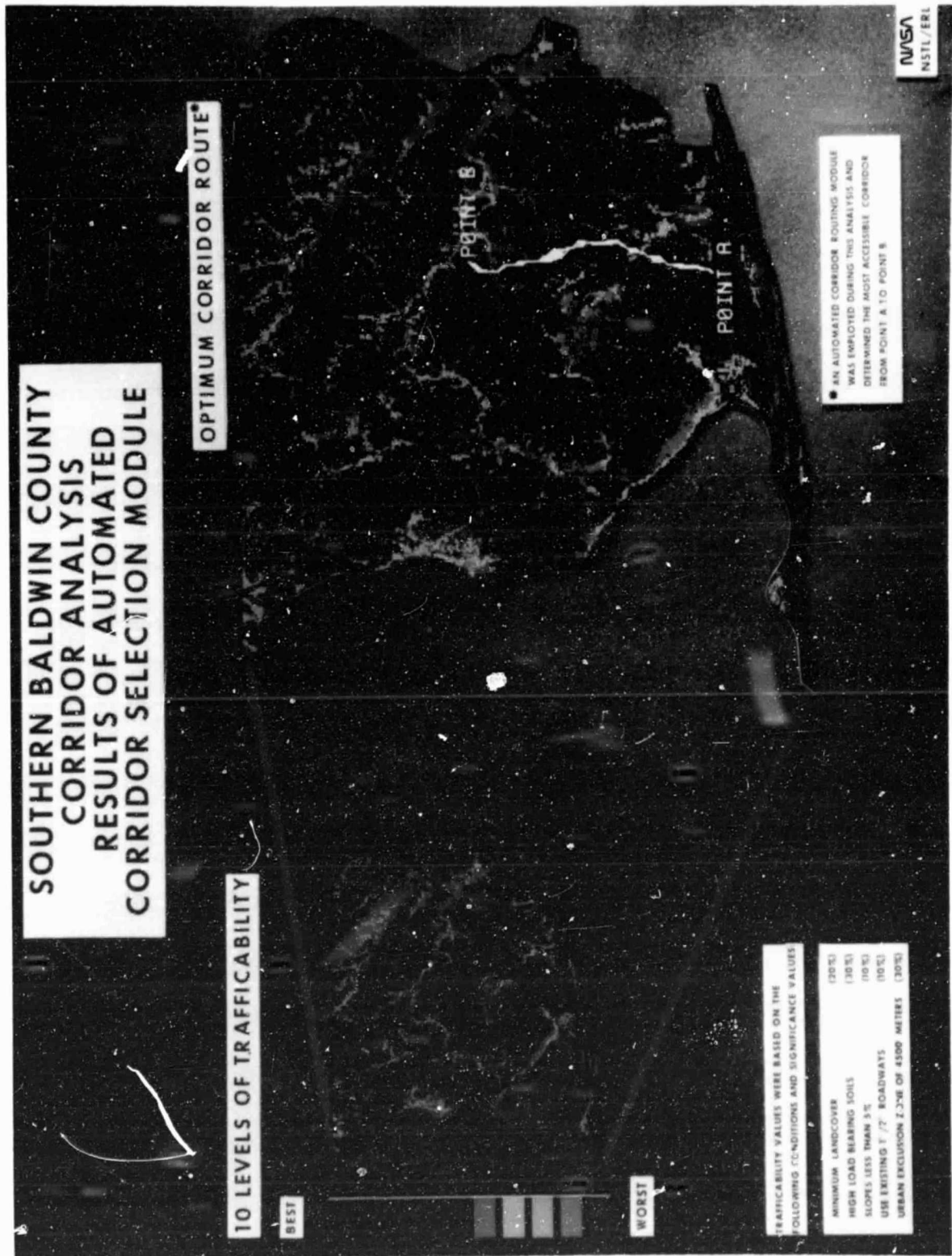
ent weights of importance assigned. Note that only when the urban exclusion zone (light blue) was assigned a 30% weight did the corridor selection algorithm avoid the urban center. A 10% weight did not result in avoidance of the urban area.

The purpose of this hypothetical example was to test weighted simulation modeling within the ELAS software package. The significance lies in the flexibility of ELAS: (1) to handle data from different sources available at different scales, (2) to standardize by geographically referencing each data set to the UTM coordinate system, and (3) to overlay each data plane for analysis. No restriction is placed on the number or type of data planes which can be used.

As decision-makers place increasing reliance on automated approaches for synthesizing more and more data, weighted simulation modeling represents a valuable tool for developing a range of options for consideration. Within the Gulf Coastal Plain test area, this model will be applied during FY84 to assessing coastal land capability by identifying areas for preservation, conservation, or utilization based on a number of variables ranging from environmental to political considerations.

URBAN STUDIES

Since the launch of the first Landsat satellite, geographers and land use planners have been interested in using space-acquired data for urban mapping. A diverse range of data analysis techniques has been applied to Landsat MSS data by researchers, ranging from tradition-

al photo interpretation to digital image processing algorithms, with varying degrees of accuracy. The limitations of MSS data content for delineation of urban morphology have been due to the rather coarse spatial and spectral resolutions of the data.

The advent of the Thematic Mapper, with its improved spectral, spatial, and radiometric resolution, holds promise for those concerned with mapping urban milieu, particularly with respect to understanding the impact of urban growth as it changes the character of the surrounding environment. To support the evaluation of TM data for urban area analysis, several studies were initiated during FY82 and FY83. Within the Gulf Coastal Plain test area in Alabama, Mobile is currently providing a permanent site to test advanced sensors. Complementary to the Gulf Coast work, NSTL/ERL has been cooperating with the University of Georgia and the University of New Orleans in an effort to quantify the capability of TM data for urban studies.

Under a research grant, the University of Georgia's Department of Geography has examined the utility of Thematic Mapper Simulator data for discriminating urban features in the Atlanta, Georgia, metropolitan area. TMS image data have been evaluated to assess the potential of 30-meter resolution multispectral data for mapping land cover. Visual photo interpretation of the data permitted 33 land covers to be mapped at Level II and Level III (urban classes only) from the Anderson, et al., USGS classification system. A point sample verification of the data, predicated on comparison with aerial photography, has indi-

cated that the TMS-derived land cover map has an overall accuracy of 80% correct classification.

Digital classifications were also produced from the TMS data using supervised techniques. An assessment of the optimal channels for classification of urban areas was determined by employing average transformed divergence and principal components analysis. Channels 2, 4, and 7 were determined to be the best three-channel data set for supervised classifications; the principal components approach produced a three-component set (principal components 1, 2, and 3) which gave accuracies comparable to those of the Channels 2, 4, and 7 raw data set.

Additionally, one of the first seven-channel TM data sets available to investigators from Landsat 4 was acquired over portions of Arkansas and Tennessee on August 22, 1982. In support of NASA's LIDQA program, researchers at NSTL/ERL conducted a preliminary evaluation of the TM data for discriminating and delineating urban features occurring within Union City, a small city in northwestern Tennessee which has a population of approximately 15,000 and encompasses about eight square miles (20.7 km^2) within its city limits.

A qualitative examination of the enhanced photo-interpretive qualities of TM data was conducted. In a false color composite image produced for the Union City area using TM Channels 2, 3, and 4, the 30-meter ground resolution of the data readily permits photo interpretation of individual structures and other urban features. This is a significant advancement over what has been available with MSS data, where the

TEST AND EVALUATION

80-meter spatial resolution allowed photo interpretation of only large urban phenomena.

The TM data were also evaluated for use in a digital classification of Union City. A pixel-to-pixel signature development algorithm was employed to derive statistics for a polygon of data delineated around the Union City urban area. Thirty-nine spectral signatures were derived using TM Channels 2 through 7 as input data.

These spectral responses were then classified and the classes were grouped, utilizing ground truth and ancillary data, into six specific land cover categories: (1) roads and inert materials, (2) commercial and industrial development, (3) residential development, (4) agricultural and bare soil, (5) transitional or grassland areas, and (6) forested areas.

Plate 10 shows the classification of Union City as delineated by the polygon that was used to define the urban area for signature development purposes.

An accuracy analysis was computed for the classification based on the evaluation of ground verification polygons with known land covers selected from the data. Because of the difficulty in defining precise ground truth polygons for the transitional/grassland and roads/inert materials classes, polygons for these categories were combined with the agricultural/bare soil, commercial/industrial, or residential categories. Table 9 gives the accuracies for the resulting four major land cover types used to estimate class ification accuracy.

A more in-depth discussion on the classification techniques used

and the results from analysis for Union City is presented in Quattrochi, et al., 1982, and Quattrochi, 1983a and 1983c. This preliminary evaluation was presented at the Early Results Workshop at Goddard Space Flight Center in February 1983, and at the URISA Conference held in Atlanta, Georgia, during August 1983.

The Union City investigation was an initial attempt at defining the utility of TM data for delineating discrete urban features. Present research at NSTL/ERL focuses on the analysis of TM data for discriminating urban morpholog with in a large metropolitan are obi has been established as one nent study area for urban i. es..ga-tions.

The TM data used for this research were collected on October

TABLE 9
Computed Classification Accuracies—Union City Study Area*

		COMPUTER CLASSES				
		AGRICULTURE	COMMERCIAL	RESIDENTIAL	FOREST	GROUND TRUTH PIXELS USED
T R U T H	**AGRICULTURE**	89.97*	8.37	1.66	0.00	
		1,570	146	29	0	1,745
H	**COMMERCIAL**	0.90	95.68	2.88	0 54	
		5	532	16	3	556
C L A S S E S	**RESIDENTIAL**	13.73	0.49	83.50	2.29	
		198	7	1,204	33	1,442
	FOREST	1.19	0.00	0.15	98.66	
		8	0	1	662	671
Percent Overall Correct = 89.90					Total	4,414

*Percent Correct and Number of Pixels Classified, by Class

ORIGINAL PAGE
COLOR PHOTOGRAPH
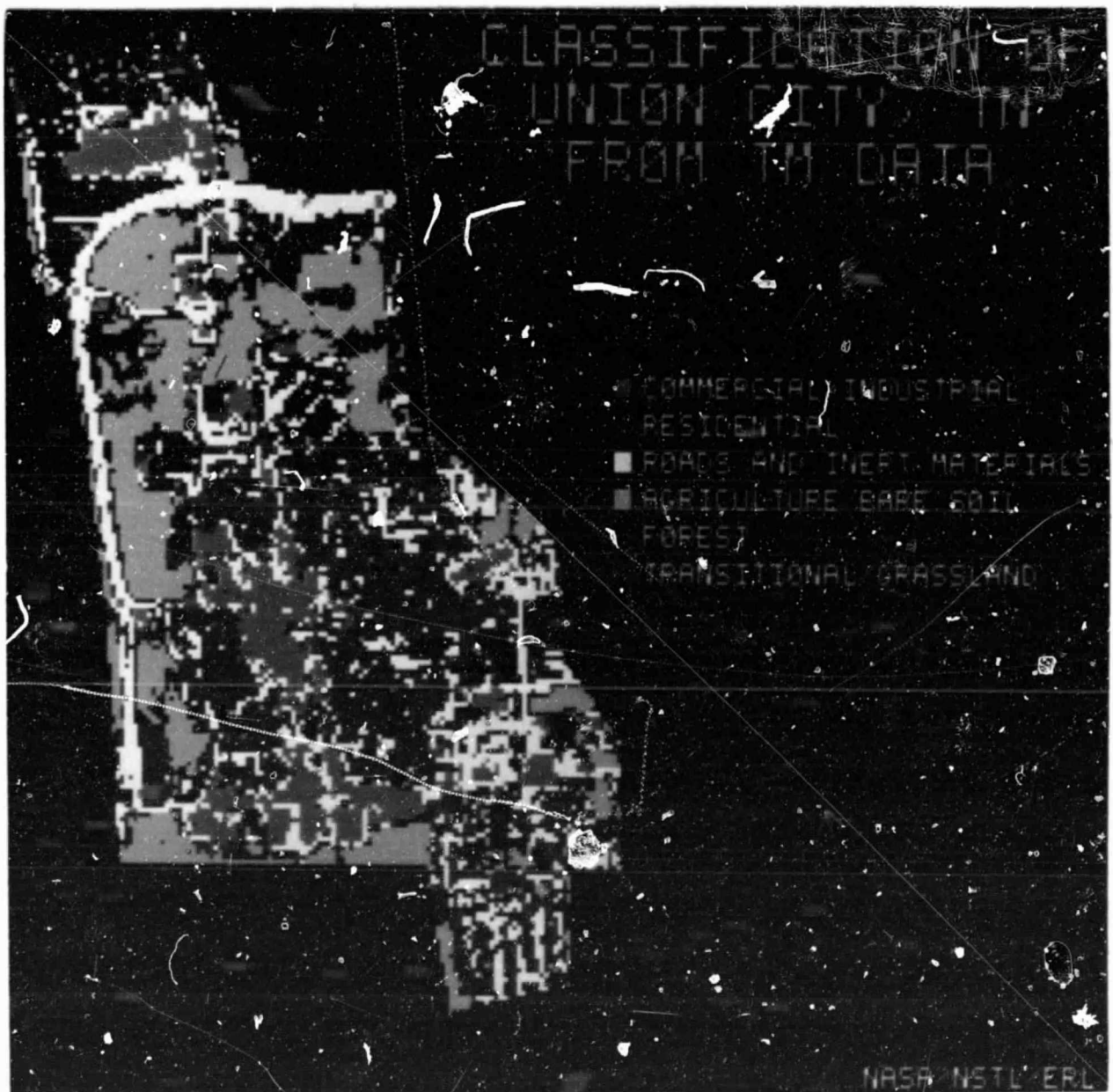
Computer-implemented land cover classification of Union City, Tennessee, derived from
Thematic Mapper data acquired on August 22, 1982

DISCRIMINATION OF URBAN FEATURES WITHIN A SMALL CITY

2⁷, 1982, and provide the basis of a joint investigation between NSTL/ERL and the Department of Geography at the University of New Orleans. To evaluate the digital classification products that could be derived from the data, a computer-implemented land cover classification was produced from TM Channels 1, 2, 3, 4, 5, and 7 for the Mobile area. Derivation of the classification proceeded in two phases. Spectral signatures were first developed by passing a 3- by 3-pixel moving window through the data. The six channels of raw data were then classified using the signatures produced from this technique. An analysis of the classification showed that 18.5% of the data were left unclassified. This unclassified class fell predominantly within the built-up areas of Mobile.

The second phase of data analysis employed a pixel-by-pixel signature development program to derive spectral statistics for only those pixels which fell within the unclassified area of the previous classification. These signatures were used to complete classification of the data. The result of this two-phased process was a composite classification of the Mobile area with 12 land cover classes (Plate 11). Although an analysis of the classification for Mobile is still in progress, an interim evaluation of the classification has been documented in Quattrochi, 1983b and 1983c; these initial results were presented at the ERIM Symposium at Ann Arbor, Michigan, in May 1983 and at the URISA Conference in Atlanta, Georgia, in August 1983.

Findings to date indicate there is more informational content in the TM data than can be extracted through existing spectral digital analysis techniques, and that the spatial attributes of the data have yet to be fully addressed. Furthermore, due to the combined increased spectral and spatial resolutions, there is more information in the resulting classification over Mobile, for instance, than can be adequately assessed by standard methods for computing classification accuracy.

Work at NSTL/ERL in cooperation with the University of Georgia and the University of New Orleans will continue during FY84 to evaluate TM data for urban studies and to develop new information extraction techniques which can capture both the spectral and spatial information content of the data.
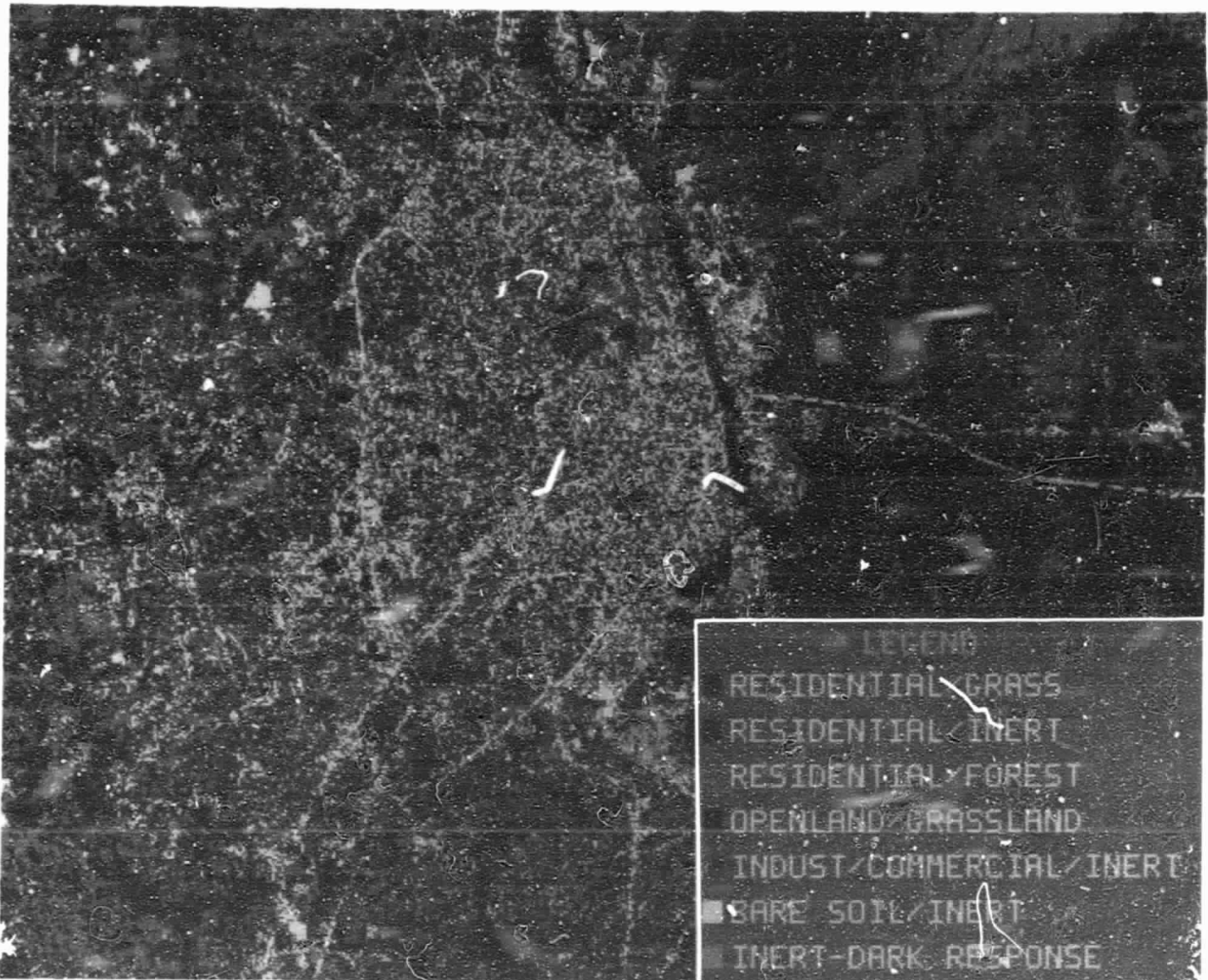
This classification of the Mobile metropolitan area, from TM data acquired October 27, 1982, was produced in two phases—first by using a 3- by 3-pixel moving window to develop signatures for "homogeneous" land covers and then by employing a pixel-by-pixel signature development algorithm which derived signatures for the residual, spectrally heterogeneous urban area.

LEGEND
RESIDENTIAL/GRASS
RESIDENTIAL/INERT
RESIDENTIAL/FOREST
OPENLAND/GRASSLAND
INDUST/COMMERCIAL/INERT
BARE SOIL/INERT
INERT-DARK RESPONSE
FOREST
BRUSHLAND/TRANSITIONAL
AGRICULTURE/GRASSLAND
MARSHLAND/WETLAND
WATER
OTHER LAND COVERS

TM LAND COVER CLASSIFICATION OF MOBILE, ALABAMA, AND ENVIRONS

SPACE STATION SUPPORT ACTIVITIES

SPACE STATION SUPPORT ACTIVITIES

NSTL has actively participated in the preliminary Space Station definition activities through working groups, short-term technology studies, and Program Operating Plan (POP) preparation, submission, and advocacy.

In FY83, significant contributions were made to the Space Station activities through the following working groups: Operations Working Group, Mission Requirements Working Group, Autonomy Working Group, Data Management Working Group, and Software Working Group.

NSTL/ERL was asked to participate in one of 14 short studies initiated by the Space Station Task Force Concept Development Group. The User Accommodation data system study was completed in four weeks by drawing from existing personnel experience. The primary purpose of the study, which was done in parallel with other NASA centers, was to determine if there were any significant cost drivers in the user interface portion of the Space Station Data Management System. A comparison of the individual centers' findings indicated no significant cost drivers.

The NSTL prepared and presented four Program Operating Plan proposals to the Space Station Task

Force Peer Review Group. The four studies were Data Management System Test Bed; Evolutionary Software Study; Expert System: Change Detection System; and Closed Ecological Life Support System Study. Although at this writing no final decision has been made on approval of any of the proposals, preliminary reports are encouraging and NSTL anticipates acceptance of one or more of the proposals.

NSTL will continue to actively support Space Station related activities and intends to undertake a significant role in Space Station development once it becomes an approved program.

NSTL/ERL has been selected to participate in the Data Management System Test Bed with Johnson Space Center, Marshall Space Flight Center, Kennedy Space Center, Jet Propulsion Laboratory, Goddard Space Flight Center, Ames Research Center, and Langley Research Center. NSTL's effort will be concentrated in the areas of user participation, sensor simulation, data and command, file protection, and software upgrade techniques. NSTL/ERL holds membership on the Space Station End-to-End Information System Test Bed Steering Committee.

A summary of NSTL's Space

Station involvement during FY83 is as follows:

- Committee Participation
  - Operations Working Group
  - Autonomy Working Group
  - Higher Order Language Working Group
  - Data Management Working Group
  - Mission Requirements Working Group
  - Software Working Group
  - Data Management System Test Bed Steering Committee
- Concept Development Group Short Study 12: User Accommodation Data Systems
  - Assigned to study team
  - Extracted data from personnel experience base
  - Documented study
  - Presented findings to combined group at NASA Headquarters
- Space Station Task Force POP Call
  - Data Management System Test Bed
  - Evolutionary Software Study Submittal
  - Expert System: Change Detection System
  - Closed Ecological Life Support System Study

APPENDIX

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Sources of Additional Information

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For additional information on the topics discussed, contact the principal authors listed below.

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