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Identifying Environmental Features for Land Management Decisions, Annual Report

United States, National Aeronautics and Space Administration

CENTER FOR REMOTE SENSING AND CARTOGRAPHY

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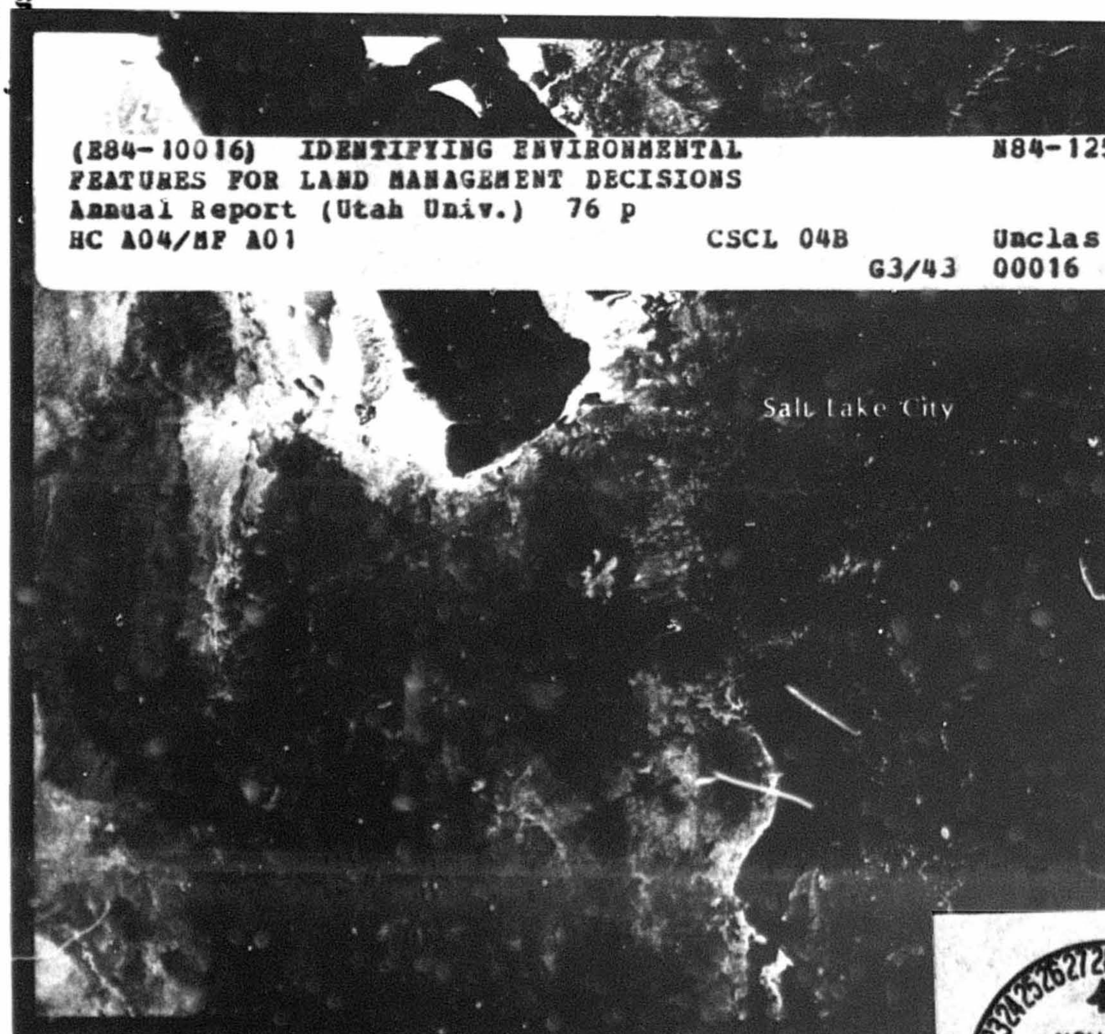

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UNIVERSITY OF UTAH RESEARCH INSTITUTE
Salt Lake City

ANNUAL REPORT

October 28, 1983

IDENTIFYING ENVIRONMENTAL FEATURES FOR LAND MANAGEMENT DECISIONS

National Aeronautics and Space Administration

Grant NAGW-95

Center for Remote Sensing and Cartography
University of Utah Research Institute
Salt Lake City, Utah

TABLE OF CONTENTS

INTRODUCTION

This annual report outlines the major accomplishments of the Center for Remote Sensing and Cartography (CRSC) since the annual report was submitted in October 1982, with reference to the semiannual report of March 1983. The past year has been characterized by important progress in the research of digital processing techniques, completion of projects involving integrated remote sensing and environmental analysis, and interesting developments for new and continuing projects. Our computing strength is stronger than ever; we continue to rely primarily on the University of Utah Research Institute's Prime computer and NASA's Earth Resources Laboratory Applications Software (ELAS). We continue to maintain and develop the software in-house, and through interaction with the newly formed ELAS Users Group.

The staff at CRSC has gone through some changes over the last year. John Merola has succeeded Richard Jaynes as manager, and continues to serve the vital role as leader of the digital processing section. Additions to the staff include two PhD candidates in Geography: Kevin Price, whose master's degree in Range Science adds substantially to our ecological studies, and Douglas Wheeler, who has a special interest in geographic information systems. Four work study students from the University of Utah have also been added; Steve Brower, from Mining Engineering; Jeanne Pearson, with a master's degree in Wildlife Science; Paul McDonald, a senior in Computer Science; and Gordon Douglass, with an interest in computer mapping. Saundra Buckley continues to serve as secretary of the center. We feel that we have a well-rounded staff with the ability to accomplish the goals we have set before us.

CRSC FOCUS

CRSC continues its applied research in dealing with an array of environmental and resource problems in the Intermountain Region. Our effort continues to focus on technical innovations, as guided by the specific needs defined in each project. More and more, we are conscious of the value of dealing with each project as a team effort between CRSC specialists and the resource specialists. In this way, we build a bridge between CRSC and the resource manager, which adds credibility and usefulness to our results.

At the root of each project, the driving force is the technical growth we can add through research developments. This approach leads to a continual CRSC concentration on alpine environments and arid/semiarid environments, the dominant landscapes of the region. This means that we must continue to be attuned to a variety of environmental systems, including vegetation, soil, hydrology, geomorphology, and agriculture. In every project, the interrelation of the various systems is not only evident, but significant in the problem-solving approach. This approach also leads to a continual stimulation to build strength in ancillary digital data, digital terrain data, and geographic information systems (GIS) developments, integrating them into remote sensing techniques in a variety of ways.

CRSC continues to pursue a course of merging remote sensing with GIS analysis. Ancillary data are vital in their own right as a decision-making tool, and also as a key to refinement in the classification of digital remote sensing data. Thus, we are moving toward an integrated procedure, invoking digital ancillary data and remote sensing data at appropriate levels, adding to the technical strength of CRSC.

Folded into this integrated procedure is the necessary field investigation, photo interpretation, map and archival data analysis to provide the resource manager with the comprehensive documentation necessary for sound decisions.

We do not intend to usurp, but to augment, the professional manager's role, filling those steps he is unable to fill otherwise. Our staff is well trained in field, laboratory, and library procedures in resource analysis as well as in remote sensing per se. Recently, we have been called on to perform such comprehensive evaluations, e.g., the Parker Mountain study for the Utah Division of State Lands and Forestry, and the Humboldt River study for Nevada Fish and Game. In these broad studies, as well as in projects more restricted to techniques of remote sensing, CRSC is ready to bring in the agency professional to the fullest extent. We wish to have agency personnel fully aware of the capabilities and limitations of the role of remote sensing and GIS analysis, so that their professional judgement is not abdicated to our laboratory or to the "machine." Meanwhile, CRSC adds another increment of basic as well as applied technical capability.

RECENT FUNDAMENTAL RESEARCH DEVELOPMENTS

The research developments presented here are those primarily developed, or concluded, over the last year. We begin with two research papers, produced out of project applications, and proceed to describe developments in use.

Identifying Ecological Range Sites Through Remote Sensing

This procedure was developed during the applied project on Parker Mountain. The project involved inventory and analysis of the rangeland. This procedure involves the use of map information derived from both high altitude color infrared photography and Landsat digital data. The maps are an integration of the two remote sensing sources along with soils, geology, and precipitation. Identification of the ecological range site for a given area requires an evaluation of all relevant environmental factors. These environmental factors combine to give a site the potential to produce characteristic types and amounts of vegetation. The utilization of the photography and Landsat digital data, coupled with digital ancillary data on soils geology and precipitation, is shown to be a means of achieving greater efficiency and accuracy in identifying ecological range sites. This paper is attached as Appendix A.

Contextual Analysis of Landsat Spectral Signatures

This paper (an abstract of which is included as Appendix B) is the conclusion of several years of development and testing. The procedure presented has proven itself in many projects and has become a "standard" approach to the classification of digital image data at CRSC.

The procedure consists of a sequence of three multivariate statistical routines to aid in detecting similarities and differences in spectral

signatures. A more precise computer classified land cover map is produced by using and understanding additional spectral classes that are represented by the signature. The sequence of statistical routines used are: principle components analysis, cluster analysis, and discriminant analysis.

Principle components analysis is used to transform the data set (signatures) into independent variables to remove collinearity. The variables now meet the assumptions of the statistical routines that follow. The output data are factor scores for two components representing the original data set. The factor scores are then used in a cluster analysis to group spectral signatures according to a similarity index. Finally, the factor scores and group clusters are used in a discriminant analysis. A two-dimensional scatter plot produced in the discriminant analysis allows one to obtain a graphical view of the spectral context in which a particular signature is found.

The use of discriminant analysis, in combination with examination of spectral signature plots and ground information, has been a key element in achieving good results from the unsupervised approach to Landsat data analysis.

Spectral and Spatial Contextual Analysis of Digital Imagery

At CRSC, we have developed and put into operation a technique for acquiring information about the context of a spectral signature. The procedure is analogous to analyzing a word in a sentence; take a word out of a sentence and it can be hard to understand the meaning of that word unless it is related to the other words in the sentence. Our procedure relates each spectral signature to all others acquired in a particular study area. The technique provides information about the interrelationships, specifically the spectral context of each signature in the set of signatures. Now that we are able to gather spectral contextual information about the signatures used to classify digital image data, we decided the next logical step was to include spatial contextual information for classification improvement. We believe this technique will be most useful for high resolution digital image data, such as Thematic Mapper (TM) data from the Landsat D series. Currently, the computer program has basically been developed and is operational. Testing has begun on a Thematic Mapper Simulated (TMS) data for Salt Lake County, 1982, but conclusive results are as yet unavailable.

Processing of Thematic Mapper Data

Several techniques have been evaluated to date on TMS data covering Salt Lake County. The purpose of this evaluation is first to prepare CRSC for the use of Landsat 4 TM data, and secondly, to compare TMS data to MSS in the urban environment of Salt Lake County. Our evaluation has focused on the spectral bands most useful for classification of land cover in the study area. The results show that bands 2, 3, and 4, in combination with band 7, are the most accurate for the broad application of general land cover mapping.

Evaluation of Change Detection Routines

We have committed much effort to the detection of agriculture-to-urban land use change using multitemporal MSS digital data. Although Landsat MSS data is a relatively coarse tool for discriminating categories of change in the urban size plots, its availability over the 11 years of the Landsat program prompts a thorough test of its power to detect change. A recently

presented research paper is attached as Appendix C. Many techniques have been tested and results are nearly completed. The results will be published in the upcoming paper: "Evaluating Landsat MSS Digital Data for Change Detection on the Urban Fringe."

Developments in Computer Programming

In the process of accomplishing our goals in the applied research projects we are involved in, new computer programs are being developed. They are being developed to augment and become part of our software package, ELAS. The following is a short list of programs developed at CRSC:

1. PLYI - polygon insert. This module allows the insert of polygons into an ELAS data file with no effect on the data outside the polygon.
2. PCHG - pixel change detection. This module is used to find changes in pixels from one date to another. It is used for continuous data and is specifically designed for use with albedo change detection.
3. PMIN - pixel minimum. Find the minimum pixel value for any or all channels in an ELAS data file.
4. CNTX - contextual reclassifier. This program reclassifies pixels based on spectral and spatial context information described previously.

Fully documented copies of these programs are, or will be, available to any ELAS user interested in them.

Another program, which is now part of ELAS, that has received some development but deserves special consideration is ACTB (Accuracy of Classification Table Builder). The reason ACTB deserves special consideration is that it has become the pivot of a "standardized procedure" for the calibration and verification of maps which result from the investigation into the processing of digital image data here at CRSC. As stated in the ELAS manual (Report No. 183) User's Guide, Section 5:

"5.16.5 ACTB - Accuracy of Classification Table

ACTB compares the results of a classification with 'ground truth' or verification data. ACTB outputs a table that shows class frequencies, percentages, percent correct, omission errors, and commission errors as a result of the comparison between the verification data and the classified data."

At CRSC, our "standardized procedure" for calibration begins by selecting, from air photos, ground verification plots. These plots are then digitized and are compared to the several digital image processing techniques being investigated. This is an iterating process in which the most accurate technique is selected.

ACTB is also used to verify the final map accuracy by adding to, or using separately, a set of new verification plots. These new plots are used to make a statement of the overall accuracy of the final maps. This has proved to be an important step in bridging the gap between CRSC and the resource manager. By using an accepted standard approach in stating map accuracy, we have found common ground in which to work together with the resource managers. This is as important to our research strategy as it is to users of our work.

APPLIED RESEARCH PROJECTS COMPLETED

Three projects have been completed since our annual report was prepared in October 1982. One of these projects has been completed since the semi-annual report in March 1983. Highlights of each project are presented below.

Salt Lake County Land Use

Because of rapid urban expansion along the Wasatch Front, many impacts are created, i.e., loss of farmland, changing water needs, transportation corridor demands, etc. Accurate update maps of urban expansion and land use change are needed by many agencies. This project is an attempt to answer to that need. It consists of two parts: (1) land use inventory, current to 1982, using color infrared (CIR) photography, establishing a sound baseline for change detection, and (2) an experiment to evaluate the effectiveness of Landsat MSS digital data to detect, measure, and map change in this complex environment. The CIR inventory is complete. Five copies of the report were forwarded to NASA Headquarters on October 5, 1983. Twenty-two quadrangle overlays at 1:24,000 have been presented to the Utah Division of Water Resources. The maps have been carefully checked, drafted, and turned over to the Division.

The new overlays are currently being used in their own right by the Division for Water Allocation Modeling. Other departments of state and local government are accessing them for their own purposes. For CRSC, the completed maps serve as the base for phase two of the study: evaluation of digital techniques for rural-urban change detection. Several technical innovations are being tested by CRSC in a project underway to detect change on the urban fringe.

Parker Mountain State Land Block

To test the effectiveness of Landsat data in detecting pasture quality and potential for grazing production, CRSC completed a comprehensive analysis of 39,292 acres of state land in south-central Utah. Five copies of the report were forwarded to NASA in March 1983.

This project established another milestone for CRSC, by integrating digitized ancillary geological data and elevation data with Landsat digital data, using ELAS program routines. Accuracies of classification of rangeland increased significantly. Using Landsat MSS data alone, accuracy of classification was 56%. By digitizing various basalt units taken from the state geologic map, and critical elevation lines as surrogates for precipitation variation, accuracy of classification increased to 77%, a substantial 21% over the best solution from spectral data alone.

The technical advancement to CRSC from this project was significant. In addition to adding ancillary digital capabilities, we developed improved sampling strategies for accuracy, verification, and gained further experience in principle components and other techniques.

Aspen-Conifer Succession Study

In a joint project with the Intermountain Forest and Range Experiment Station (U.S. Forest Service), a quantitative index was developed which correlates with apparently stable and seral aspen forests. Several classes of stable/seral aspen forests have been mapped in the Bear River Range of Utah and Idaho. Since aspen canopies tend to obscure understory conifers for early seral forests, a second date, using Landsat data taken when aspen trees are leafless, has been used. This study explored the extent to which

a two-date Landsat MSS analysis improves the detection of aspen/conifer forest mixes. By using two dates, our overall accuracy improved only by 4%, from 68% to 72%, but the accuracy of stable aspen improved from 79% to 90%; and late seral improved from 41% to 65%; conifer remained at 85%. As these are very important classes, from a forest manager's point of view, we feel our goals for this study were met, and then some.

APPLIED RESEARCH PROJECTS UNDERWAY

At this time, there are eight projects underway. These projects vary in their dimensions from small, specific investigation, fine tuning our recent developments, to the larger multifaceted investigation, encompassing many techniques and requiring the development of new capabilities. The importance of these applied research projects cannot be over-emphasized. CRSC could never have accomplished as much as we have in remote sensing research without the ability to work closely with, and provide results to, the user community, i.e., resource managers. Highlights of each project are presented below.

Evaluating Landsat MSS Digital Data for Change Detection on the Urban Fringe

This is a continuation of the Salt Lake County study in rural-urban change detection. The objective is to compare several digital procedures such as: band five differencing, data transformation using the Kauth transformation, and other algorithms for detecting land conversion patterns. Categories of land use change are selected on the basis of water consumption. The question is, how well can MSS data identify these categories and patterns of change? Several algorithms are being compared, utilizing both raw data and preprocessed data. Verification of results involve high quality color infrared (CIR) photography and field observation. The dates involved in the test are 1972, 1979, and 1981. "Change Maps" are produced at 1:24,000 scale. This digital analysis should help develop a procedure for wider area application and for subsequent updating without the necessity of repeated CIR photography.

Thematic Mapper Simulator Data Analysis

The thematic mapper simulator (TMS) is a multispectral scanner flown from an aircraft to simulate the TM data that will be available from Landsat 4. The goal in this analysis is to compare MSS data from earlier Landsat satellites and TMS data to identify the possible role of TM and its use in the future.

It has been stated by several authors that an improved spatial and spectral sensor, such as the TMS sensor, does not necessarily improve classification accuracies when processed the same as MSS data. The problem, as stated by Warton (1982), is as follows:

> "To illustrate the problem, consider the task of distinguishing between commercial and residential land-use classes in [spatially] high-resolution remotely sensed data. The straightforward per-pixel spectral classification of the data can identify only the spectrally dissimilar ground cover classes such as pavement, lawn, trees, roof. These components are common to both the commercial and residential land-use classes, making it difficult to distinguish between them on a per-pixel basis. It has been suggested by several authors that the solution to this problem is the use of contextual information (i.e., the local frequency distribution of components surrounding each pixel)."

A contextual reclassifier has been developed to address this problem. Spatial and spectral contextual information is applied in the procedure. The spectral contextual information is supplied by the statistical analysis of the signatures, as described previously. The two-dimensional scatter plot produced in the discriminant analysis is based on discriminant scores derived from the analysis. These discriminant scores supply the spectral contextual information. The spatial information is supplied by a moving window of specified dimensions, and a similarity matrix (derived from the discriminant scores) which evaluates the center pixel of the moving window. The center pixel is then reclassified if the specified parameters are met. This procedure will be tested on MSS as well as TMS data.

Humboldt River Riparian Habitat

The Nevada Department of Wildlife recently contacted CRSC regarding the need to obtain accurate, up-to-date maps of riparian habitat along a segment of the Humboldt River in north-central Nevada. Wildlife habitat is significantly affected by various activities along the river, i.e., channelization and spraying or burning of willow areas. The primary objective of the study is to prepare 1:24,000 scale topographic map overlays of riparian habitat and other significant features for a stretch of river which flows through portions of land represented on eight U.S.G.S. quadrangles. This mapping project will explore the extent to which environmental changes due to management activities may be monitored over time.

The primary purpose of the study is to provide a spatially-oriented information base for wildlife population and habitat management for this particular riparian zone. This information base will be a key element in the development of Department policies and public awareness regarding proposals and actions for river channelization and phreatophyte control. The study will also demonstrate the limits of using available aerial photography for obtaining necessary riparian habitat information.

Due to unusual amounts of precipitation last winter, the Humboldt River riparian area was flooded to a greater depth and for a longer than

usual period this spring. This caused somewhat of a delay in getting onto the ground and beginning preliminary field studies. This rare event provided the opportunity to record the water inundated areas along the river. On June 8, most of the Humboldt River was photographed, from Deeth to approximately 15 miles east of Battle Mountain. The photographs were taken from 3,000 feet above ground level using a panoramic camera (Enviropod) and color infrared film. Please refer to the semiannual report, March 1983, Exhibit D, for further detail about this study.

Agriculture and Wetlands Inventory in the Lower Sevier Basin

The objective of this study is to classify and map agriculture-related land cover and wetlands of the Lower Sevier River Basin (i.e., below Piute Reservoir). The mapping will be accomplished primarily by interpreting available high altitude color infrared (CIR) photography. Map overlays will be prepared to match existing U.S.G.S. topographic quadrangles. The acreage for agricultural lands and wetlands will also be tabulated.

This study will provide basic inventory information about water-related land use for application in basin-wide water budgeting by the Division of Water Resources. The coordinated mapping of wetlands and agricultural lands will also assist farmers and federal and state agency personnel in better understanding the relationship between wetlands and farms. Such information will promote more informed farm and ranch planning and assist agencies such as the S.C.S. in carrying out their responsibilities under legislation and regulations which protect wetlands. Finally, this study will provide a basis for documenting changes in agricultural land use since the last inventory, some 20 years ago, and will permit greater detail in future monitoring of resource uses in the Sevier River Basin.

EPA Enviropod

CRSC has signed an agreement with EPA and state agencies to test and evaluate the role of small format panoramic camera use in environmental monitoring and assessment. CRSC will serve as the technical advisor. Involvement in this program is ideal for CRSC since each Enviropod application could provide support information for our Landsat data and allow for evaluating the comparative utility of various stages of remote sensing data.

The Enviropod is a compact, self-contained, panoramic, two-camera reconnaissance system designed to be secured to widely available aircraft (Cessna 172 and 182). We have flown a total of 20 missions to date. The majority of applications have related to flooding, but land cover/land use inventories have also been flown. These land cover/land use inventories have given us the necessary experience to use the Enviropod to support projects investigating the use of digital Landsat data. The comparative rangeland study in Rush Valley, Utah will be our first investigation and application of this approach. Another investigation of this approach and of other techniques will be performed in a study of desertification in west-central Utah. A summary of these applied research projects follows.

Comparative Condition Study of Desert Rangelands in Rush Valley, Utah

One of the key issues in rangeland management is the uncertainity of stocking capacity on specific pastures. Closely related is the changing nature of that capacity through time. Range managers have attempted to resolve the problem by "measuring" condition and trend of the range. One of the difficulties is that the transect site (and the specific plants)

where measurements are taken may or may not be representative of the pasture. A sample size which is large enough to be considered representative is often not practical in terms of time and money. With recent budget cuts and fewer personnel, many range scientists are now looking for alternative methods for estimating rangeland condition and trend.

A two-phased approach is proposed: (1) to identify, map, and characterize rangeland ecological units within the study area and assess their relative condition, (2) to identify the relative trend of these units by comparison with a non-grazed area over a ten-year span (1972 to 1982).

The initial step of phase one will be to identify and map the various range units within the study area. As to statements of trend, it may be possible to identify a non-grazed area as a "control" area. Then by comparing grazed lands to the normalized data of the control area, it may be possible to make statements of increasing or decreasing forage through time. This is somewhat problematical, but theoretically feasible. As compared to trying to "measure" trend through selected indicator plants and transects, there is reason to believe the spatial remote sensing approach using a non-grazed area for control ought to be as valid, and perhaps more so.

Remote Sensing of Desertification Near Delta, Utah

An attractive method for dealing with the assessment and monitoring of degradation involves the combined employment of Landsat imagery, conventional aerial photography, field work, and digital processing of thematic map data.

The major objective in this study is to detect physical degradation from Landsat digital data and correlate the causal factors (salinization and erosion) to form a reliable working model. Previous research has indicated that salinization can be detected on Landsat based on an increase in brightness of spectral response due to the salt content in the upper crusts of the soils. Similarly, erosion should also exhibit a brighter spectral response due to lack of vegetation in eroded areas. This knowledge will aid understanding the dynamics of desertification and thereby improve resource management of the environment. A second objective is to improve the interpretation techniques of satellite digital image data as it relates to arid environment studies by combining raw data spectral signatures with ancillary field data to derive a workable approach for delineating areas of salization and erosion. The resource-oriented capabilities of remote sensing, applications in computer mapping, the use of information in a multi-disciplinary Geographic Information System, and interrelationships of the physical and biological landscape will combine to provide significant information to address the problems of desertification.

Mapping of Alpine Riparian Areas from Landsat MSS and Terrain Digital Data, Uinta Mountains, Utah

A significant amount of investigation into mapping alpine riparian areas using Landsat digital data exclusively has already been accomplished. In this investigation, it was discovered that stands of coniferous trees that are associated with water, i.e., standing in very wet soil and classified riparian, were separated consistently from dry conifer stands. During the verification of the maps, it was also discovered that shadowed slopes were consistently being confused with riparian conifer stands. To resolve this problem, it was proposed that digital terrain data be used in conjunction with Landsat digital data to resolve the confusion. Due to the interest

of the U.S. Forest Service in the use of digital terrain data, they agreed to reduce the size of the mapping project in order to include the analysis of digital terrain data.

At this time, we are still trying to implement the software that will allow us to use digital terrain data. We reported in our follow-on proposal and semiannual report that a modification to the Prime computer operating system had given us this capability. In testing the modification, it was discovered that it doesn't work. An alternative is to acquire from the Forest Service the software necessary to process the data on the University of Utah's Univac 1100/61 computer. This software has been received and will be implemented soon. The software called MULDEM will allow us to preprocess digital terrain data, on the less expensive Univac, and then bring the data (in a ready to use form) to the Prime. We will have to write a short program to allow ELAS to use this data. It is anticipated that we can finish this project by spring of 1984.

PROPOSED FUTURE RESEARCH

Fundamental Research

Software development is an area where a major effort will be made to improve our current capabilities. The improvement in software will become part of ELAS and will add to its already extensive capability.

On the topic of digital geographic information, which is vital to the future use of digital remote sensing data, we propose several areas of investigation such as the ability to produce polygons from the pixels of a classified digital image map. This is important in developing the capability to access the recent developments in polygon manipulation and analysis of digital geographic information. Specifically, we want to work closely with the state of Utah's Automated Geographic Reference (AGR) system which uses the Arc/Info software system of Environmental Sciences Research Institute's (ESRI) for polygon manipulation and analysis. At a recent meeting on October 21, 1983, of the Governor's Panel on Scientific Inputs to Land Use Planning, AGR Director, Riki Darling, disclosed the intent of the AGR to purchase a Prime computer and the ESRI Arc/Info software. Given our experience in the research and analysis of digital geographic and remote sensing information to produce land cover/land use maps, the capabilities of ELAS, and our use of a Prime computer put us in a very good position to provide technical support to AGR. Discussions to this end have already begun between CRSC and AGR.

Another area we intend to continue to investigate is the use of contextual information for the classification of land cover/land use from digital image data. We propose to develop the capability to create a

previously undefined class of land cover/land use based on the contextual information in a given window, or subscene, of a digital image.

Although CRSC and other facilities have been investigating the use of digital map data in GIS analyses, there is much still to be discovered. Once a map is in the digital form, the digital data are then used in various types of GIS analyses.

The ELAS program package allows us considerable flexibility in using the digitized maps for post-classification improvement of MSS digital data. For example, our analysis of rangeland in the Parker Mountain study was greatly improved using this technique. Polygons derived from soil and geology maps were digitized for stratification of the classification. Selected contour lines digitized from topographic maps also added significantly to the classification accuracy. Combined, the digitized entry of soil, geology, and elevation data produced a classification accuracy which was over 21% more accurate than the maps prepared from spectral data alone. A new computer program was written to insert the polygons back into the map after changes were made.

ELAS has also allowed us to use a very complicated GIS analysis for the combination of two dates of MSS data in the Aspen Succession study. The analysis was complicated in the sense that there were many possible changes that could have been made to any one pixel provided that it passed one or a combination of seven different tests. We are very pleased with the results obtained thus far. There are several other areas of fundamental research we intend to explore. For more information, please refer to our follow-on proposal submitted in April 1983.

PROPOSED PROJECTS FOR RESEARCH AND DEVELOPMENT

Land Use/Land Cover Inventories and Data Integration to GIS

In this project, it is proposed that we develop the technique of assessing land use/land cover in a digital format in order to integrate the data in the State of Utah's Automated Geographic Reference (AGR) system, i.e., GIS. A memo requesting proposals to accomplish this appears as Appendix D. Each of the three proposals is in a different geographic area within the northern part of the state. These areas have different land use/land cover types as well as various environments. We have chosen the North Cache study area for a first analysis and development of the techniques that will be used.

Soil Loss Evaluation in Pinyon-Juniper Using a GIS Format in Utah

We are exploring the possibilities of a project with the Soil Conservation Service to assess the capability of Landsat digital data, coupled with various GIS inputs, to detect variations in pinyon-juniper cover that correlate with erosion conditions. The experiment will be built around the Universal Soil Loss Equation.

PROFESSIONAL MEETINGS ATTENDED BY CRSC PERSONNEL

American Association of Geographers Rocky Mountain Regional Meetings, Boulder, Colorado, October 1983. The following papers were presented.

- Ridd, Merrill K., "Hazards to Development on the Wasatch Front. An Application of Geographic Information Systems Analysis "
- Merola, John A., "Aspen Succession"

ACSM-ASP Fall Convention, Salt Lake City, Utah, September 1983. The following papers were presented.

- Jaynes, Richard A., "An Integrated Remote Sensing Approach for Identifying Ecological Range Sites"
- Jaynes, Richard A., "Remote Sensing Evidence and Experts in the Courtroom"
- Merola, John A., Richard A. Jaynes, and Roy O. Harniss, "Detection of Aspen/Conifer Forest Mixes from Multitemporal Landsat Digital Data"
- Ridd, Merrill K., John A. Merola, and Richard A. Jaynes, "Detecting Agricultural to Urban Land Use Change from Multitemporal MSS Digital Data"
- Ridd, Merrill K., "Hazards to Development on the Wasatch Front: An Application of Geographic Information Systems Analysis"

ELAS Users Group Meeting, Bay St. Louis, Mississippi, NASA/NSTL/ERL, June 1983. John A. Merola made a presentation of research using ELAS. He was also appointed to chair the Documentation Committee.

International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, May 1983. The following paper was presented.

- Merola, John A., Richard A. Jaynes, and Roy O. Harniss, "Detection of Aspen/Conifer Forest Mixes from Multitemporal Landsat Digital Data"

RNRF Symposium on the Application of Remote Sensing to Resource Management, Seattle, Washington, May 1983, Richard A. Jaynes attended.

American Association of Geographers Annual Meeting, Denver, Colorado, April 1983. The following paper was presented.

- Ridd, Merrill K., "Color Stretching and Digital Analysis of Landsat Data: An Inventory of Guayule in Mexico"

ASCM-ASP Annual Meeting, Washington, D.C., March 1983. The following paper was presented.

Ridd, Merrill K., "Preliminary Digital Classification of Grazing Resources in the Southern Chihuahuan Arid Zone of Mexico"

Working session of Caribou National Forest, Idaho Fish and Game, etc., March 1983. John Merola presented the aspen succession study.

Meeting of Environmental Health Division, January 1983. Merrill Ridd was invited to present a summary of CRSC remote sensing activity.

International Symposium on Remote Sensing of Environment Second Thematic Conference: Remote Sensing for Exploration Geology, Fort Worth, Texas, December 1982. Merrill Ridd attended.

Utah meeting of ACSM-ASP. Richard Jaynes and Merrill Ridd presented a summary of CRSC projects. Held December 1982.

Bear River Resource and Conservation District meeting in Logan, Utah, December 1982. Merrill Ridd was appointed to a committee to create a pilot project for comprehensive soil and water management planning, based on remote sensing and GIS.

Utah Association of Geographers, November 1982. Merrill Ridd presented a paper on remote sensing studies of the Great Salt Lake.

Merrill Ridd was appointed to the Governor's Science Advisory Committee. Panel on Scientific Inputs to Land Use Planning

Following is an updated list of projects and reports by CRSC under NASA (or partial NASA) funding.

Table 1. CRSC Projects Supported in Whole or Part by NASA Grants NSG-7226 and NAGW-95

Project Short Title	CRSC Report	Agency/ies	Agency Support	Completed	Project Impact
PROJECTS COMPLETED					
North Ogden Hazards to Urban Development	78-1	Weber County, No. Ogden City, Pleasant View	Limited in Kind	May 1978	Adopted for Sensitive Area Overlay Zone Ordinance.
Irrigation Detection by Satellite, Iron Co.	79-1	Utah Div. of Water Rights	Limited in Kind	April 1978	Proven effective. Led to ground water study.
Price River Basin Rangeland Response to Summer Rain	79-2	U.S. Bureau of Land Management	Limited in Kind	May 1979	Proven effective but demands real-time data for application.
Korean Land Use II	79-3	Republic of Korea	$102,000	Aug. 1979	NASA funding helped develop software; technical development.
Snowpack/Runoff Correlation	Exper-imental	Utah Div. of Water Resources Soil Cons. Serv.	Limited	--	High correlations shown. Tabled until near real-time data is available.
Guayule Inventory I: Contrast Enhancement	80-1	Mexican Government	$90,000	Jan. 1980	NASA funding helped perfect computer enhancement.
Uinta Basin Wetland/Land Use	80-2	Utah Div. of Water Resources Soil Cons. Serv.	$10,000 $25,000	Dec. 1980	Wetland management, water allocation and management, agriculture resource planning.
Snow Cover/Mule Deer	80-3	Utah Div. of Wildlife Res.	Limited in Kind	July 1980	Landsat utility, tabled pending agency studies.
MX Draft EIS Review	81-1	Utah Governor's Office	ca. $2,000	April 1981	Used by Governor for MX policy and comment.
Guayule Inventory II: Statistical Classification Routines	81-2	Mexican Government	$100,000	Feb. 1981	NASA funding helped develop classification routines.
Farmington Bay Shoreline	81-3	Utah Div. of Wildlife Res. Great Salt Board	In Kind Minimal	April 1981	Deterred proposed project which would have damaged waterfowl habitat.
Irrigation Detection, Iron County II	81-4	Utah Div. of Water Rights	Minimal	May 1981	Proven effective; led to Bear River Study; leading to prosecution.
Davis County Foothill Development	81-5	Davis County Planning Comm. Four Corners Regional Comm. EPA 208 Weber-Davis Several State Agencies Seven municipalities	In Kind $63,000 $18,000 In Kind In Kind	May 1981	Being reviewed for adoption as the guideline for urban development control.

Table 1 (cont.)

CRSC Projects Supported in Whole or Part by NASA Grants NSG-7226 and NAGW-95.

Project Short Title	CRSC Report	Agency/ies	Agency Support	Completed/ Anticipated Completion	Project Impact
Sevier River Basin Wetland; Land Use	81-6	Soil Conservation Service	$23,000	Oct. 1981	Basic information for wetland mgt. and water allocation.
Farmington Bay Wildlife Habitat	82-1	Utah Division Wildlife Resources	In Kind	Mar. 1982	Likely to influence diking, revegetation, wetland permits.
Bear River Range Aspen Habitat	82-2	U.S. Forest Service, NSF	$11,000	Mar. 1982	Statistical signature refinement. Lead to riparian study.
Bear River Basin Irrigation Land Inventory	82-3	Bear River Commission	$ 9,000	Apr. 1982	Will be basis for water allocation between states.
Aspen/Aspen-Conifer Detection	82-4	Intermountain Forest & Range Experiment Station	$ 7,499	June 1982	Improve inventory techniques and habitat analysis.
San Luis Potosi Rangeland Inventory	82-5	Mexican Government	$52,000	Feb. 1982	NASA funding helped develop technical expertise for digital analysis.
Parker Mountain Rangeland	82-6	Utah Division of State Lands and Forestry	$ 4,541	Dec. 1982	Basic information and recommendations for revegetation and range management.
Multitemporal Aspen/Conifer Detection	83-1	Intermountain Forest & Range Experiment Station	In Kind	Mar. 1983	Refinement of techniques for forest inventories.
Land Use Inventory of Salt Lake Co.	83-2	Utah Division of Water Resources	$17,248	Apr. 1983	Data for hydrologic modeling and change detection.
Wasatch-Cache Riparian Vegetation	83-	U.S. Forest Service	$ 3,500	Sep. 1983	Basic information for wetland and wildlife management.
Humboldt River Riparian Habitat	83-	Nevada Dept. of Wildlife	$ 8,344	Oct. 1983	Information base for developing wildlife habitat policies and technique development for habitat monitoring.
EPA-Enviropod	84-	U.S. E.P.A. and various state agencies	In Kind	Apr. 1984	Planning and acquisition of Enviropod photography, and evaluation of results.
Middle Sevier	84-	Utah Division of Water Resources	$25,000	June 1984	Basic information for wetland management and water allocation.

AN INTEGRATED REMOTE SENSING APPROACH FOR IDENTIFYING ECOLOGICAL RANGE SITES*

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ABSTRACT

A model approach for identifying ecological range sites has been applied to high elevation sagebrush-dominated rangelands on Parker Mountain, in south-central Utah. The approach utilizes map information derived from both high altitude color infrared photography and Landsat digital data, integrated with soils, geological, and precipitation maps. Identification of the ecological range site for a given area requires an evaluation of all relevant environmental factors which combine to give that site the potential to produce characteristic types and amounts of vegetation. A table is presented which allows the user to determine ecological range site based upon an integrated use of the maps which were prepared in this study. The advantages of identifying ecological range sites through an integrated photo interpretation/Landsat analysis are discussed.

INTRODUCTION

The ecological range site concept has become the most widely used foundation for range management in recent years. An ecological range site (hereinafter "range site") is a "distinctive kind of rangeland that differs from other kinds of rangeland in its ability to produce a characteristic natural plant community" (S.C.S. 1976). The natural plant community or climax community is that assembledge of plants that would eventually occupy a site in the absence of abnormal disturbances and physical site deterioration. Range sites are derived from the analysis of vegetation composition (by dry weight) from relict sites with similar soil, climatic, topographic, and geologic characteristics. Plant association tables are prepared and analyzed for significant differences in the kind of dominant species and species groups, proportionate make up of dominant species and species groups, and total annual production. Thus, definition of range site and designation of an area as being that range site, provides a single expression of all environmental factors responsible for the development of that range site. The range site concept has, therefore, become a key component in the use, development, and rehabilitation of rangelands. Although a given range site model may oversimplify the inherent variability in nature, it is

* This study was supported by the Utah Division of State Lands and Forestry, and the National Aeronautics and Space Administration (Grant NAGW-95).

nevertheless a valuable and adaptable tool for developing rangeland management plans.

If rangelands were in relict condition, one would merely need to map vegetation types to identify range sites. Since many rangelands have received intensive use, range site identification is achieved through an integrated analysis of vegetation (considered a temporal attribute) and spatial attributes.

The traditional approach to mapping range sites is field labor intensive, with reliance on large scale black and white aerial photography for vegetation and geomorphic analysis. Spatial attributes are also obtained from available soils, geologic, topographic, and precipitation maps. The objective of this study was to explore the utilization of high altitude color infrared ("CIR") photography and Landsat digital data as a means of achieving greater efficiency and accuracy in the identification of ecological range sites. This study is part of a comprehensive study to analyze and map rangeland resources of the Parker Mountain study area (described below) for the Utah Division of State Lands and Forestry (Jaynes 1982).

STUDY AREA

Efforts to identify range sites in this study were carried out on the Parker Mountain State Land Block in south-central Utah. The study area occupies over 45,000 acres of high elevation (8,600-9,800 ft.) rangeland on the western edge of the Awapa Plateau, an eastward sloping plateau covered with various types of volcanic flows and deposits. The Parker Mountain study area is characterized by rolling hills covered with mountain big sagebrush and islands of aspen forests on its western half, and, on the eastern half, black sagebrush with mountain big sagebrush areas in swales and on north and east facing slopes. The climate is characterized by cold, snowy winters and warm summers. The predominant use of Parker Mountain is cattle and sheep summer grazing. Numerous antelope, sage grouse, Utah prairie dogs, and other wildlife are found in the area.

METHODS

Aerial Photo Interpretation

The primary medium for preparing a 1:24,000 scale topographic map overlay of vegetation was high altitude CIR photography flown on July 1-2, 1975. Film positive transparencies at 1:31,680 nominal scale were utilized. Mapping units were identified by examining the following: the color, texture, and patterns on the photographs; hydrologic features; topography (from topographic maps and stereoscopic viewing as needed); and ecological context. Scale adjustments and photographic displacement corrections were accomplished primarily by reference to U.S.G.S. orthophoto quadrangles, in addition to the use of a K&E Kargl cartographic projector. Interpretations were augmented by the use of a map from Landsat digital data (described below).

Three short trips to the study area in the summer and fall of 1982 were considered adequate for calibrating photo and Landsat interpretations with ground characteristics.

Landsat Digital Data Analysis

The Landsat multispectral scanner ("MSS") records light reflectance values for four spectral bands: green, red, and two bands of near infrared light. MSS data represents light reflecting characteristics for the combined land cover and terrain features within each picture element or "pixel," which covers approximately 1.1 acres of ground area. See U.S.G.S. (1979) for additional information regarding MSS data. Landsat data used in this study were recorded July 28, 1979.

Landsat MSS data are analyzed statistically to detect light reflectance patterns which are sufficiently unique to make different ground cover types of interest consistently distinguishable (Hutchinson 1982). The analytical approach used in this study, often referred to as an unsupervised classification method, began by examining the recorded MSS reflectance values for each pixel in the entire study area. From this search of individual pixels, statistics were generated which characterize pixel groups with similar spectral features. Next, a maximum likelihood classification routine was used to associate each pixel in the study area with one of the 46 spectral groups generated.

The analysis next focused on detecting similarities and differences between spectral groups. A simple means of evaluating spectral characteristics is to plot each spectral group's mean reflectance value for the four MSS bands to form a diagnostic curve or "spectral signature." Since evaluating spectral signatures is often quite subjective, a more objective technique was also applied. First, a principal components analysis of the mean values for each signature's four MSS bands reduced such data to factor scores for two components. Next, the factor scores were used in a cluster analysis which grouped spectral signatures according to a similarity index. Finally, the factor scores and group clusters were used in a discriminant analysis of the signatures. The two-dimensional scatter plot produced in the discriminant analysis allows one to receive a graphical view of signature relationships. (See Merola, et al. 1983 for an example.) The use of discriminant analysis, based on MSS principal components and cluster analyses, in combination with examination of spectral signature plots and field experience has been a key element in achieving good results from the unsupervised classification approach to Landsat data analysis.

An additional and most vital dimension to the process of digital data analysis is calibrating spectral signatures with "ground truth." This is accomplished by assigning print symbols to each signature or signature group and printing maps which may then be registered to standard base maps or referenced to photographs and field study sites. In this study, a digital print map overlay was prepared to match the U.S.G.S. 7½-minute quadrangles (scale 1:24,000) mosaic of the study area. Calibration of spectral signatures with actual land cover types was accomplished primarily by use of the vegetation map prepared from photo interpretation, high altitude CIR photography, and field observations. The above-described process of interpreting and combining spectral signatures based upon signature curve similarity, discriminant analysis of the signatures and calibration of signature print symbols with photograph and ground observations is outlined in Ridd, et al.(1983).

The correspondence between Landsat spectral signatures and unique ground cover characteristics may be weak in some instances (Todd, et al. 1980). Landsat and pixel-analyzing computer algorithms perform robot-like functions and it is often necessary to introduce ancillary information to improve ground cover maps which are based solely on MSS data (Tom and Miller 1980). In this study, for example, the digital map calibration process indicated substantial spectral similarity, and therefore confusion, between sites dominated by a relatively low growth form of big sagebrush and black sagebrush. This spectral similarity is not surprising considering that both shrubs occupy similar ecological sites: generally on south and west facing slopes which are rocky and relatively dry. Such differences are also not evident on CIR photography, but must be ascertained in the field. However, black sagebrush appears to occupy this ecological site only on the western rim of the plateau and in areas to the east of a generalized 8,250 feet elevation contour. To improve the digital classification, the zone occupied by the short growth form of big sagebrush was digitized and an algorithm constructed to allow the detection of differences between sagebrush species. Basically, the algorithm assigned each pixel with spectral signatures common to both species to different classes depending upon the location of the pixel with respect to the digitized zone.

Other areas of spectral similarity were also addressed by the introduction of ancillary data. The surface geology of eastern half of the study area is predominantly older volcanic material in the north, and very recent volcanic flows in the south. The topography in the north is characterized by a series of smooth ridges running in a southeast direction, whereas the southern area has more of a plateau character with various exposures. The combination of surface geology and topography differences between the areas has resulted in the confusion of big sagebrush, which grows in swales and northeast exposures in the north, with the black sagebrush signature of the south; since the black sagebrush areas which occur on southwest slopes in the north are spectrally different from black sagebrush on the recent volcanic flows in the south, there is little confusion between this spectral class and big sagebrush classes. The recent flows were digitized as separate units within the study area and new Landsat spectral class numbers were assigned to the signatures causing the confusion.

Spectral similarity was also encountered in areas which are primarily bottomland loamy soils with mountain silver sagebrush or wetland vegetation cover. The majority of bottomland soils were digitized from an available S.C.S. soils map and spectral signatures not normally associated

with mountain silver sagebrush and wetlands were reassigned class numbers to avoid confusion.

RESULTS AND DISCUSSION

CIR Photo Interpretation

High altitude CIR photography proved to be an ideal photographic medium for the task of mapping rangeland resources; it provides high resolution prints with more information and less displacement than low altitude photographs, and is relatively unaffected by atmospheric haze which significantly scatters blue light. In addition, contrasts between different vegetation types such as aspen and sagebrush are extremely vivid, whereas black and white photography often obscures such boundaries. CIR photography also generally produces greater discrimination between vegetation types than natural color photography because infrared light reflectance is highly sensitive to plant leaf shape and cell differences, as well as plant vigor.

Despite the advantages offered by the CIR photography in this study, field observations and ecological interpretations were vital in completing the mapping process. Generally, different ground cover types were found to be associated with distinct patterns of color, tone, and texture on the CIR photographs. A few circumstances led to confusion in interpreting the photos. For example, reddish-brown rocks on recent basalt flows often form a dominant feature which tends to produce similar CIR photo color-tone patterns, making black sagebrush areas indistinguishable from areas dominated by big sagebrush. Field observations and the map from Landsat digital data helped to sort out the confusion.

In a number of instances, the ability to reference the Landsat digital print map significantly aided in the task of mapping rangeland cover from CIR photographs; the digital print map often flagged areas which might otherwise have gone unnoticed because of subtle visual differences. Available geologic, soils, precipitation, and topographic maps were also quite helpful. The rangeland cover types delineated from these procedures follow: black sagebrush; mountain big sagebrush, short growth form (dry, rocky sites); mountain big sagebrush, tall growth form (mesic sites); mountain silver sagebrush; wetland (rush/sedge); aspen; Douglas fir; pinyon-juniper.

Landsat Digital Data Analysis

The methods applied in the analysis of Landsat data initially expanded the number of spectral signatures before reducing the number of classes mapped to 20. As noted above, a total of 46 signatures were developed from statistically searching the study area for representative signatures. Partitioning the study area based upon elevation, geology, and soils, as described previously, led to the creation of more than 10 additional classes. The final selection of 20 classes of rangeland cover represents a compromise between the goals of map simplification and preservation of meaningful (or potentially meaningful) detail. Further feedback from digital print map users will determine whether the number of classes mapped should be expanded or reduced. It is estimated that the Landsat map accuracy was increased by 25% through the efforts to partition the study area based upon ancillary information.

Landsat map accuracy was assessed by randomly placing a grid, with vertices at ten-pixel row and column intervals, over the Landsat map and photo interpreting the nearest group of 4-10 pixels of a given class. A total of 830 pixel groups (average group size was approximately 6) were examined, which represents a sample size of approximately 12% of all pixels. Table 1 presents an error matrix for six levels of vegetation cover interpretation. Overall map accuracy is 89%, with the greatest amount of confusion associated with short growth form big sagebrush. Map verification by examining pixel groups probably produces a positive bias over verification of individual pixels because it leads to the checking of areas on photos which are relatively homogeneous spectrally. However, simply looking at single pixels probably produces an opposite bias as a result of difficulty in achieving close registration between the Landsat map and photos. Sampling small groups of pixels is believed to be a good compromise, especially since pixels tend to occur as groups rather than as scattered individuals.

Table 1. Landsat map error matrix with verification for six levels of vegetation cover intrepretations.

Landsat Classes	VERIFIED CLASSES* Aspen	Big sage, tall form	Big sage, short form	Black sagebrush	Silver sagebrush	Wetland	Total	Percent Correct	Percent Commission
0,0,0,0,0,0	115	2					117	98	2
V,U,T		210	20				230	91	9
S,R,+,-		39	106	14			159	67	33
~,·,·,Blank		6	3	257			266	97	3
#,#		4	3		48		55	87	13
W						3	3	100	0
Total	115	261	132	271	48	3	830		
Percent Omission	0	20	20	5	0	0	Overall Accuracy: 89%		

*Verification of Landsat classes is based upon photo interpretation and field observation for regularly spaced pixel groups of 4-10 pixels each.

Table 2 illustrates that the Landsat map, based on available field information and photo interpretation, contains fair to good accuracy for most of the 20 spectral classes. The overall accuracy is 74%, with 21% average omission error and 23% average comission error. Table 2 also provides a brief description of the rangeland cover associated with the 20 classes.

Integration of Photo Interpretation and Landsat Maps

The availability of two different maps of rangeland cover could lead map users to feel obligated to select the

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more accurate of the two approaches. However, there is no need to make such a choice when the fundamental differences between both mapping procedures are examined. Both mapping techniques have trade-offs in terms of spatial and interpretive accuracies which makes direct comparison of maps difficult: relative map accuracies must be judged by reference to available ground truth and in light of the particular spatial and interpretive accuracy specifications of each mapping project.

Table 2. Landsat map error matrix with verification for twenty levels of vegetation cover interpretations.

Class No.	Landsat Symbol	VERIFIED CLASSES* 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Percent Correct	Percent Commission
1	0	19	4	1																		24	79	21
2	0	6	34	6																		46	74	26
3	0		4	14	1																	19	74	26
4	0		1	4	10					2												17	59	41
5	0					6																6	100	0
6	0						5															5	100	0
7	V							42	17	3	3											65	65	35
8	U							13	39	7	2											61	64	36
9	T							3	8	78	10	5										104	75	25
10	S							3	2	8	22	4										39	56	44
11	R							4	3	4	1	25	1	2		1	10	1				52	48	52
12	+									7			30									37	81	19
13	-									8		1		20			2					31	65	35
14	~									6		2			72	16						96	75	25
15	•														14	38	1					53	72	28
16	·											1					22	5				28	79	21
17	Blank																2	87				89	98	2
18	#																		20			20	100	0
19	#								4					3						28		35	80	20
20	W																				3	3	100	0
Total		25	43	25	11	6	5	65	73	123	38	38	31	25	86	56	37	93	20	28	3	830		
Percent Omission		24	21	44	9	0	0	35	47	37	42	34	3	20	16	31	41	6	0	0	0	Overall Accuracy: 74%		

*Verification of Landsat classes is based upon photo interpretation and field observations. Class interpretations corresponding to the numbers for verified classes (columns) and Landsat classes (rows) follow:

Aspen

1. closed canopy, good health
2. open canopy, good health
3. patchy or edges, fair-good health
4. patchy mix with big sage, fair-good health
5. open canopy/patchy, poor-fair health
6. mix with conifers, edges, north slopes

Mtn. big sagebrush: tall growth form

7. moist loamy bottoms, grassy understory
8. loamy north slopes, significant grass
9. rocky, north slopes in east, various aspects in west

Mtn. big sagebrush: short growth form

10. western half of area, south slopes
11. eastern half, mixes with black sagebrush
12. western half, south slopes
13. western half, south slopes

Black sagebrush

14. basalt flows
15. basalt flows, mixes with big sage
16. breccia areas, southwest slopes, mixes with big sage
17. breccia areas, southwest slopes

Mtn. silver sagebrush

18. very moist bottoms
19. drainage bottoms

Wetland

20. wet soil, rush/sodge

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Photo interpretation forces the mapper to generalize spatially to avoid creating map polygons which are too numerous and/or too small. Selecting minimum mapping unit sizes and simplifying the map legend are necessary in preparing a visually interpretable map where patterns may be detected. Landsat mapping includes numerous cells, which are equivalent to, but generally much smaller than, the photo interpreter's line-drawn polygons, thus offering the potential for increased spatial mapping detail. However, information obtained for each pixel by the Landsat scanner is already spatially generalized (ca. one acre pixel size), which offsets this advantage somewhat. Of course, the digital map format offers the advantages of automated area calculations, editing, updating, etc.

Interpretive generalizing and error occurs with photo interpretation since vegetation boundaries are not always distinct but, as a practical matter, lines must be drawn to complete map polygons. Generally speaking, the areal polygons mapped may be considered to have relatively homogeneous land cover. However, subtle but significant vegetation mixing may occur within some map polygons which is either undetected by the interpreter or overlooked to avoid additional lines and labeling of polygons which would clutter up the map. Landsat data is quantitative, and analysis of spectral signatures is generally more objective than photo interpretation. The Landsat spectral bands cover a narrower spectral range than most photographic emulsions and permit the analysis of single or multiple bands: aspects which often serve to simplify the process of associating light reflectance with ground cover. Error and generalizing in interpretation of classes occurs when the combinations of physical factors, which determine multispectral reflectance for different land cover types, produce similar spectral responses. Unless such situations can be corrected by the use of ancillary data to digitize boundaries which avoid the confusion, misclassification of pixels will occur.

Consequently, although Landsat analysis and CIR photo interpretations are both forms of remote sensing, comparing the products produced by both methods is similar to judging the difference between an apple and an orange. In addition, it can generally be assumed that ground truth is rarely available in such abundance as to permit good comparisons of the mapping approaches; Landsat maps are typically evaluated largely by reference to air photo interpretations, which leads to errors through misregistration or misinterpretation and bias that may inflate the apparent accuracy of maps from photo interpretation.

The vegetation map produced in this study from photo interpretation offers the advantages of allowing a user to easily detect general patterns and locate most vegetation boundaries with a high degree of accuracy. The main weakness of the photo interpreted map is that only six major vegetation classes were able to be mapped, and that environmental variations within map polygons are often generalized. The Landsat map overlay in large part compensates for these weaknesses in the hand-drawn map with its 20 cover classes and nearly one acre polygon size.

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Identification of Ecological Range Sites

The delineation of the vegetation cover types noted above provides an indication of present forage composition, but, more importantly, it provides a primary means of identifying range sites. The plant community occupying a given site is a "synthometer" of the total environment of that site. The biotic and abiotic components have, over time, led to the dominance of the existing vegetation. Since Parker Mountain has not recently had any widespread major disturbances, it may be assumed that the vegetation types mapped from CIR photography and Landsat data are the best single indicator of distinct sites for which management prescriptions may be developed. This is especially the case where available information regarding spatial environmental variables such as soils, geology, precipitation, and topography have been integrated in both land cover mapping approaches.

Range sites are mapped from an analysis of physical indicators which are associated with the range site. In this study, ecological conditions encountered on Parker Mountain suggest that twelve major range sites are present in the study area. These ecological sites have not been mapped per se, but may be identified for any portion of the study area by reference to Table 3, and available maps of vegetation, soils, and geology.

Table 3. Ecological range sites in study area, and associated photo interpreted land cover, geology, soils, and Landsat map symbols.

	Associated Map Characteristics			
Ecological Range Sites	Land Cover*	Geology	Soils	Landsat Map Symbol(s)
high mountain loam	"a" aspen, and "f/a" conifer/aspen	breccias (rarely basalt)	Faim	Various "O"
high mtn. stony loam	" " "	breccias & basalt	Parkay	Various "O"
high mtn. shallow loam	" " "	basalt flow	Parkay	Various "O"
semi-wet meadows	"c" mtn. silver sage	breccias	Foy	#, #
wet meadows	"w" wetland	breccias	Foy	W
mountain loam	"t" mtn. big sagebrush, tall growth form	breccias (rarely basalt)	Faim	V, U
mountain stony loam	" " " "	breccias (some basalt)	Parkay	T
mountain stony loam	"s" mtn. big sagebrush, short growth form	breccias & basalt	Parkay (some Forsey)	R, S, +, -
mountain shallow loam	" " " "	basalt flow	Parkay (some Forsey)	+, -
upland stony loam	"n" black sagebrush	basalt, breccias and sediments	Forsey (some Parkay)	Blank, ', ', ^
upland shallow loam	" " "	basalt flow	Forsey	^, '
upland stony loam (juniper)	"p" pinyon-juniper	landslide debris	Parkay (some Forsey)	Various

* Photo interpreted map.

CONCLUSION

This project has permitted a close evaluation of the relative merits of mapping rangeland resources from CIR photo interpretation and from MSS digital data. Best results are obtained when both approaches are used in tandem; each approach has certain inherent disadvantages which are to a large extent corrected by utilizing the other approach.

Combined with soils and geology maps, the vegetation maps permit an accurate means of identifying ecological range sites. At a cost of approximately $0.15/acre, this approach produces significant improvements in accuracy and efficiency over labor-intensive alternatives. The maps and other information generated as part of this study are presently being used by Parker Mountain range managers to select range condition/trend monitoring sites and plan range improvements.

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ABSTRACT

Contextual Analysis of Landsat Spectral Signatures

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A sequence of three multivariate statistical routines are presented to aid in detecting similarities and differences in spectral signatures. These signatures are derived from the picture elements (pixels) of Landsat MSS digital data. Several applications of this technique will be presented.

The technique presented in this paper assists in producing, from MSS data, a more precise computer classified land cover map. Using and understanding added spectral classes leads to improved precision of the classified land cover map. The sequence of statistical routines used are: principle components analysis, cluster analysis, and discriminant analysis. The signature, or mean light reflectance values for each spectral class, is used as the initial input data.

Principle components analysis is used to transform the data set (signatures) into independent variables to remove collinearity. The variables now meet the assumptions of the statistical routines that follow. The output data are factor scores for two components representing the original data set. The factor scores are then used in a cluster analysis to group spectral signatures according to a similarity index. Finally, the factor scores and group clusters are used in a discriminant analysis. A two-dimensional scatter plot produced in the discriminant analysis allows one to obtain a graphical view of the spectral context in which a particular signature is found.

The use of discriminant analysis, in combination with examination of spectral signature plots and ground information, has been a key element in achieving good results from the unsupervised approach to Landsat data analysis.

DETECTING AGRICULTURAL TO URBAN LAND USE CHANGE FROM MULTI-TEMPORAL MSS DIGITAL DATA*

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ABSTRACT

Conversion of agricultural land to a variety of urban uses is a major problem along the Wasatch Front, Utah. Loss of agricultural production is one problem; another is the changing water consumption patterns that result from the land use conversion. Although Landsat MSS data is a relatively coarse tool for discriminating categories of change in urban-size plots, its availability sometimes to the exclusion of other diagnostic data prompts a thorough test of its power to detect change.

This paper presents the procedures being applied to a test area in Salt Lake County, Utah, where the land conversion problem is acute. Results will be presented during the conference session. The objectives are to determine not only change but the identity of uses before and after conversion and to compare digital procedures for doing so. Class selections are predicated on water consumption categories. The question is, how well can MSS data be made to identify these class types, and at what minimum plot size? Several algorithms are being compared, utilizing both raw data and preprocessed data. Verification of results involves high quality color infrared (CIR) photography and field observation. Selection of Landsat dates was determined by available CIR data, in this case involving a two-year time span, from 1979 to 1981. The two data sets have been digitally registered, specific change categories are being internally identified in the software, results tabulated by computer, and "change maps" are to be printed at 1:24,000 scale. This digital analysis should help develop an automated procedure for wider area application and for subsequent updating without the necessity of repeated CIR photography.

INTRODUCTION

Salt Lake County, which represents Utah's major population center, continues to experience rapid urban growth. The impacts of urbanization on land use patterns and natural resources in the county are of particular interest to both state and local policy makers. The effects of urban development on a dwindling agricultural land base and water resources must be assessed to allow a rational basis for policy formulation.

There is a need to have the capability to monitor land use changes on an annual basis. Since it is impractical to expect that aerial photography may be obtained at such frequency, the logical choice is Landsat to provide repeated remote sensing data. Landsat data offers the additional advantage of being in digital form, thus obviating the need to perform the laborious process of repeated preparing and digitizing of line maps.

The objective of this study may be stated as follows: to utilize color infrared (CIR) photography and maps to calibrate a digital land use map from Landsat data, for the purpose of establishing a data base which may be updated in future years without the necessity of having repeated aerial photography coverage. Since this research project was underway at the time this paper was prepared, most of the results will be presented at the fall A.S.P. Conference. This paper focuses on the methods which have been and are being applied to accomplish the objectives noted above.

STRATEGY

The basic strategy is to establish 1979 as the baseline year, from which all subsequent change would be calibrated. For the baseline year, the most effective and accurate digital classification would be developed for the land cover types and sizes involved. The spatial/spectral data would remain on file for all future date comparisons. Updating might then be accomplished with simpler change detection algorithms.

The procedure for this research is to (a) experiment with a variety of classification algorithms and select the combination yielding the best results, using this to map the 1979 baseline stage, and (b) to experiment with various change detection algorithms to determine the most effective update procedure.

METHODS

The first step was to identify a representative test area within the county. A test block approximately 15 by 15 miles was found to contain all the major urban and agricultural types of interest. High quality CIR photography (1:30,000 scale), within one month of the Landsat digital data set, is being used to assist in identifying and calibrating cover features for that base year.

The digital procedures described below are being used to detect changes occurring between the base year (1979) and 1981. CIR photography (1:60,000 scale), within one month of the Landsat data set, is being used in the analysis of the 1981 Landsat data.

The analysis and mapping performed in this study are being carried out at the facilities of the Center for Remote Sensing and Cartography, using digital data

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obtained through NASA's Landsat satellite system from the EROS Data Center. For data processing, the Center is utilizing the "ELAS" package of computer software routines, developed by NASA's Earth Resources Laboratory, which is operational on the University of Utah Research Institute's PRIME computer.

The primary rationale for performing digital processing of MSS data begins with the assumption that different types of ground cover have different patterns of reflection. It is also assumed that these spectral patterns are sufficiently unique to make different ground cover types consistently distinguishable from one another using statistical classification techniques (Hutchinson 1982).

Standard Digital Data Analysis

Ground cover characteristics may be analyzed using digital image data from a variety of sources: Landsat multispectral scanner (MSS); Landsat thematic mapper (TM); airborne thematic mapper simulator (TMS); NOAA satellite sensor, advanced very high resolution radiometer (AVHRR); etc. The description of methods in this section applies to the analysis of digital image data from any such source.

Any digital image data must first be reformatted to make them compatible with processing hardware. Next, a grey level map is produced which encompasses the study area and some of the surrounding area. The size of the grey level map is determined by the number of features present to be used as ground control. As water bodies typically provide the sharpest and most spectrally distinctive features for control, a near infrared band is generally used to produce the map. (See Stage 1 of Figure 1.) These ground control points are used later to geographically reference the digital data to remove the effects of earth curvature, spin, etc. (See Stage 3 of Figure 1.) At this point of data processing, the raw data may be modified by other analytical steps such as filtering, principal components analysis, etc. Thereafter, a program called "SEARCH" is utilized to generate statistics which characterize pixel groups having similar spectral features across the bands. (See Stage 2 of Figure 1.) SEARCH is a routine which is used to provide training statistics for a program called "MAXL," which classifies individual pixels into a class based upon each pixel's highest statistical probability of belonging to a given class. The training statistics are derived from blocks or windows of data which correspond to areas on the ground containing the cover types of interest.

Once the study windows are selected, the SEARCH program examines each continguous six scan line (Landsat pixel matrix "row") by six element (pixel matrix "column") block; if the spectral data within the six by six block are too heterogeneous, the program will switch to the use of a three by three block of pixels. The statistics generated by SEARCH include mean pixel light reflectance values for each of the four bands, a covariance matrix, and *a priori* values.

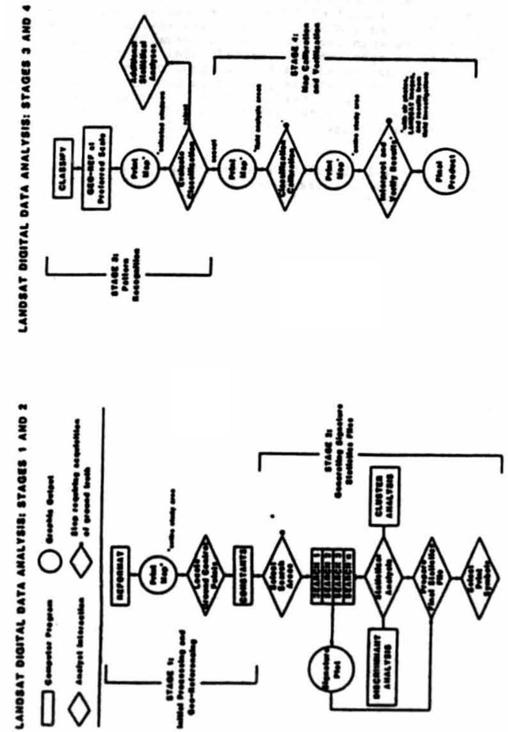

Figure 1. Summary of CRSC steps in Landsat digital data analysis.

A set of statistics is generated by SEARCH representing various classes of light reflectance patterns found in the study area "searched." The mean light reflectance values for each spectral band are plotted to form a signature which characterizes each class. SEARCH thus "trains" MAXL to recognize different ground cover patterns as it places individual pixels into classes. A knowledge of the manner in which different land cover features create spectral signatures, combined with the analysis of aerial photography and field checking of digital classifications, allow the researcher to provide an interpretation of Landsat-derived spectral classes, characterizing the various signatures according to ground information.

After light signatures are produced, further efforts are directed toward finding those signatures which would most likely reflect the major land cover types of interest. Stage 2 of Figure 1 illustrates several of the steps utilized in making detailed studies of signatures. A signature plot permits a substantial amount of interpretation; spectral signature shape and magnitude of reflectance are diagnostic of land cover types. Generally, similarly shaped signature curves indicate similar cover types while upward or downward shifts of similar curves indicate differences in topography, amount of ground cover, or the amount of mixing with other cover types, changing the overall "brightness."

At CRSC, there has evolved a somewhat "standard" set of statistical routines to deal with an often unmanageable number of spectral classes. The sequence involves principal components analysis, cluster analysis, and discriminant analysis, leading to a final classification. This sequence of routines may be applied to raw data or modified raw data (e.g., filtered, enhanced, etc.). The remainder of this section describes the application of these routines to Landsat MSS data, as performed for the Salt Lake County study area data. The analysis of signatures from other digital image data would be similar.

Spectral signatures are then studied statistically to detect similarities and differences, which are not always distinguishable from the signature plot. First, a principal components analysis of the mean values for each signature's four MSS bands reduces such data to factor scores for two components; typically bands 4 and 5 are combined into one component (visible light), and bands 6 and 7 combine to form the second (infrared light). Next, the factor scores are used in a cluster analysis which groups spectral signatures according to a similarity index. Finally, the factor scores and group clusters are used in a discriminant analysis of the signatures. A two-dimensional scatter plot produced in the discriminant analysis allows one to obtain a graphical view of the spectral context in which a particular signature is found. (See Figure 2.) The discriminant analysis scatter plot, with the two axes representing visible and infrared light components, may be divided into regions or groups of signatures that correspond to similar ground cover types. This process is a vital link in allowing an often

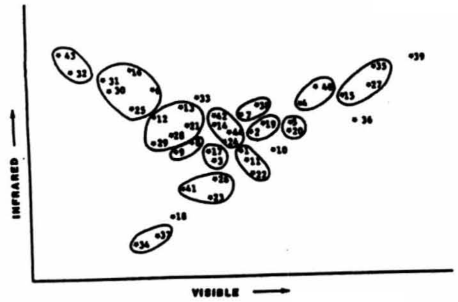

Figure 2. Scatter plot generated from discriminant analysis of filtered Landsat data in the Salt Lake County test area.

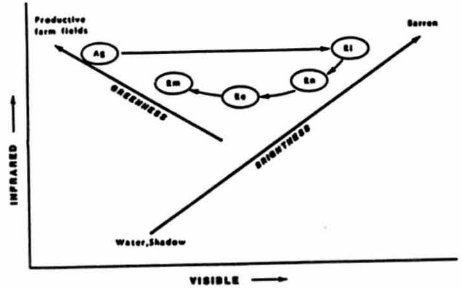

Figure 3. A theoretical model of agriculture-to-urban land use conversion.

unmanageable number of signatures to be combined into groups of similar signatures. This procedure allows the researcher a great deal of flexibility in performing Landsat digital analysis; a large number of signatures are available and one may concentrate on the signatures of particular interest, while signatures of lesser interest may be grouped together or omitted.

A vital dimension to the process of digital data analysis is calibrating spectral signatures with ground information. By assigning a print symbol to each signature or signature group, a print map may be prepared and registered to standard base maps (e.g., U.S.G.S. 7½ minute quadrangles) and referrenced to photographs and field study sites. In this way, signatures are calibrated with actual land cover types. The use of discriminant analysis, based on MSS principal components and cluster analyses, in combination with examination of spectral signature plots and field experience (as outlined in Stages 2, 3, and 4 of Figure 1), has been a key element in achieving good results from the unsupervised approach to Landsat data analysis (e.g., Merola, et al. 1983; Ridd, et al. 1983).

Modified Raw MSS Data Analyses

The procedures described above have been applied to both raw and modified Landsat data.

Filtered Data. Reformatted Landsat data were spatially "filtered" to increase homogeneity of pixel spectral values within a given cover type. The filter routine uses an unweighted moving average, or low pass filter. (See Jensen and Toll 1982.) In general, data filtering involves adjusting raw spectral values for a given pixel to reflect the average spectral reflectance of a three by three pixel matrix around that pixel. This process tends to smooth out subtle spectral differences within an area which often results in the enhancement of edges between areas that have significant spectral differences (Haralick 1979).

Principal Components. As part of the ELAS program package, there is a program which derives principal components from raw data. The program then outputs, on a pixel-by-pixel basis, the component score for the pixel based on the principal component being used. This program does not rotate the components. If it did rotate the components, one would be able to derive two components in a single analysis, one for the two visible bands and one for the two infrared bands; the two components would then be orthogonal or uncorrelated to one another (Johnston 1978). Since this is not currently possible, we derived our components in two separate analyses, one to derive the visible component and one to derive the infrared component (Walker and Shu 1982). Although these components are not orthogonal to one another, they are very close to being so, and should provide information about the use of this technique.

Other differencing routines are being examined as well. A band 7/band 5 ratio was performed to combine the attributes of those two bands to detect change. Another technique being evaluated is a ratio of principal components. The ratio of visible/infrared was done on the two dates separately, then the two dates were differenced to form a differenced image. Another differencing technique utilizes a Multi-Temporal Vegetation Index (MTVI), presented by Derenyi, et al. (1982). A Vegetation Index (VI) was computed for each date as follows:

$$VI = \frac{\text{band 7} - \text{band 5}}{\text{band 7} + \text{band 5}} \cdot K$$

then, the VI for one date is differenced from the other:

$$MTVI = VI(T2) - VI(T1)$$

Each of these techniques has shown some promise in various parts of the study area. Some are more effective for conversion of dry farm, others for rangeland, and others for irrigated land.

Postclassification Improvement

Following spectral classification, selected ancillary terrain features are digitized to stratify cover types otherwise confused by spectral analysis. In addition, certain masks are created for "fixed" cover types, such as parks, golf courses, and public spaces that are spectrally confused with desired classes. These stratified and masked data files remain in the operating system for use in subsequent date change detection.

Verification

The accuracies of the several methods being explored are assessed using 247 ground verification plots. These plots have been digitized and can be compared to any map produces. The comparison is performed by a program in ELAS (ACTB) Accuracy of Classification Table. The table which is produced is an error matrix that shows class frequencies, percentages, percent correct, omission errors, and comission errors as a result of the comparison between the verification data and the classified data.

A Model of Land Use Conversion

The scatter plot in Figure 2 shows the 44 signatures derived from filtered data in the Salt Lake County test area. Signature groupings have been determined by analysis of the scatter plot, coupled with a signature plot from SEARCH, a classified print map, and field and photo observation. Each group is associated with a particular land cover type, relevant to the land conversion process.

Figure 3 presents a graphic illustration of a theoretical model of agriculture-to-urban land conversion in Salt Lake County. Irrigated farm lands occupy the upper left

Thematic Mapper Simulator Data Analysis

The thematic mapper simulator (TMS) is a multispectral scanner flown from an aircraft to simulate the TM data that will be available from Landsat 4. The goal in this analysis is to compare MSS data from earlier Landsat satellites and TMS data to identify the possible role of TM and its use in the future.

It has been stated by several authors that an improved spatial and spectral sensor, such as the TMS sensor, does not necessarily improve classification accuracies when processed the same as MSS data. The problem, as stated by Wharton (1982), is as follows: "To illustrate the problem, consider the task of distinguishing between commercial and residential land-use classes in [spatially] high-resolution remotely sensed data. A straightforward per-pixel spectral classification of the data can identify only the spectrally dissimilar ground cover classes such as pavement, lawn, trees, roof. These components are common to both the commercial and residential land-use classes, making it difficult to distinguish between them on a per-pixel basis. It has been suggested by several authors that the solution to this problem is the use of contextual information (i.e., the local frequency distribution of components surrounding each pixel." A contextual reclassifier is being developed, at this writing, to address this problem. Spatial and spectral contextual information are applied in the procedure. The spectral contextual information is supplied by the statistical analysis of the signatures, as described previously. The two-dimensional scatter plot produced in the discriminant analysis is based on discriminant scores produced in the analysis. These discriminant scores supply the spectral contextual information. The spatial information is supplied by a moving window, of specified dimensions, and a similarity matrix, derived from the discriminant scores, to evaluate the center pixel of the moving window. The center pixel is then reclassified if the specified parameters are met. This procedure will be tested on MSS as well as TMS data.

Change Detection Data Analysis: Image Differencing

Image differencing involves subtracting the digital values of one image date from another, on a pixel-by-pixel basis. The first step in image differencing is to register each image to UTM coordinates using ground control points. The results of the differencing are transformed into positive values by adding a constant, and a histogram is produced from the differenced image. As Jensen and Toll (1982) have stated: "A critical element of the image differencing method is deciding where to place the threshold boundaries between change and no change pixels displayed in the histogram." Jensen and Toll found that image differencing with band 5 produced the best definition of agricultural-to-urban change for fall data in the Denver area. The present study has, tentatively, shown greater promise using band 7 data from mid-summer.

region of the scatter plot. From this point, a field cleared for urban use dramatically shifts to the upper right region of the plot. Incipient residential (Ri) initially responds as barren land. New residential areas (Rn) have had some homes and streets constructed, which reduces brightness but have little effect on greenness. Initial landscaping established residential (Re) areas, and eventual maturing of residential vegetation (Rm) draw spectral characteristics toward the agriculture region of the plot.

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