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Final Report

# YELLOWSTONE NATIONAL PARK MAPPING FROM ERTS-1 COMPUTER-COMPATIBLE TAPES (MMC 077)

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10th and Dakota Avenue
Sioux Falls, SD 57198

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SEPTEMBER 1974

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16. Abstract

This report describes the computer-aided processing of data gathered by the ERTS-1 multispectral scanner (MSS) and used to prepare classifications of terrain comprising Yellowstone National Park. The data source was a single ERTS-MSS scene (frame 1015-17404) collected on 7 August 1972. The methodology, accuracy, and cost-benefits of this computer-aided terrain classification approach are discussed.

17. Key Words

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## PREFACE

The project described in the present report was a cooperative one between Dr. Harry Smedes of the U.S. Geological Survey, Denver, Colorado; Mr. Ralph Root, a Colorado State University student; and personnel of the Environmental Research Institute of Michigan (ERIM).

Dr. Smedes was very instrumental in bringing this project into being. He felt that a total resources map of the park area would greatly benefit the NPS in their management of the area, and that a computer-generated recognition map of Yellowstone would not only demonstrate the potential of multispectral remote sensing and associated data processing in mapping wildland areas but also potentially provide the NPS with a useful management tool. (Dr. Smedes and ERIM have previously collaborated in processing Yellowstone National Park remote sensing data. These previous efforts had to do with aircraft multispectral data collected over geologically interesting sites in both the Lamar River Valley and the Geyser Basins.)

Contributions to this report, particularly to Sections 2.2, 3.3, and 4, were made by Dr. Smedes and Mr. Root. This able assistance is gratefully acknowledged.

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# YELLOWSTONE NATIONAL PARK MAPPING FROM ERTS-1 COMPUTER-COMPATIBLE TAPES (MMC 077)

## 1

## INTRODUCTION AND SUMMARY

This is the final report on Task II, "Yellowstone National Park Mapping," under contract NAS5-21783. The Task II goal was to apply digital-computer-implemented pattern recognition techniques to ERTS multispectral scanner (MSS) data on computer-compatible tapes (CCT) in order to prepare vegetation and terrain maps of Yellowstone National Park. Creation of these maps is important to the management of the Park and implementation of the Master Plan for Yellowstone National Park [1] by the National Park Services (NPS) of the U.S. Department of the Interior. To our knowledge, vegetation and terrain maps of all of Yellowstone have never been prepared before.

### 1.1 COOPERATIVE WORKING ARRANGEMENTS

Our effort was a cooperative one between Dr. Don Despain of NPS; Dr. Harry Smedes of the U.S. Geological Survey in Denver, Colorado; Mr. Ralph Root, then a Colorado State University student assisting Dr. Smedes; and Messrs. Fred Thomson and Norman Roller of the Environmental Research Institute of Michigan (ERIM). Dr. Despain, by assisting in the definition of terrain units to be mapped and in qualitative evaluation of map accuracy, provided the guidance necessary to assure that a useful map product would be obtained. Dr. Smedes and Mr. Root defined the classification problem in greater detail, assisted ERIM in the selection of training sets for the various terrain units to be mapped, and both qualitatively and quantitatively evaluated the accuracy of the classification map. Messrs. Roller and Thomson implemented computer processing of the ERTS data, secured a resultant display of the classification map, assisted in verifying map accuracy, and consulted generally throughout the investigation on the procedures used to select training sets and evaluate accuracy.

This report details the procedures used for computer classification of the ERTS-MSS data and comments on the accuracy of the resultant maps. A report by Smedes and Root [2] details the approach used in selecting training sets, presents a more specific and detailed discussion of the natural resources management problems addressed by this study, and discusses cost-benefit analyses of some of the products generated by this study. The Smedes and Root report, together with this report, comprise a complete documentation of the project. Dual reports were written for this effort because the ERIM effort and that of the Smedes-Root team were funded by different contracts or agreements, with each having its own separate reporting requirements. Dr. Nicholas Short, NASA-GSFC Scientific Monitor, made contributions to the work on both contracts. The ERIM effort was monitored by Mr. Edmund F. Szajna, NASA-GSFC Technical Officer.

## 1.2 SUMMARY OF CONCLUSIONS

All investigators on this project felt that it was successful and worthwhile. In particular we concluded that:

(1) The ERTS-MSS data, with its four spectral bands, 80 m resolution, and 183 km swath width, when processed using supervised pattern recognition, yielded maps of 11 terrain units. These units were ones of particular usefulness to the wildland manager, and the 40-85% mapping accuracy of the various units is acceptable for a first-stage regional overview of the area to be managed.

(2) The investigators feel that the accuracy of the results, while adequate, could have been improved through the use of May-June data in combination with the early August data. By thus exploiting the temporal variations in the spectral signatures of some Yellowstone terrain units, more accurate and detailed classification maps could have been made from ERTS data.

(3) The approach of selecting training sets by photointerpretation of 1:120,000 scale color IR photography and transferring locations to "graymaps" of ERTS red band (MSS-5) data appears to be a good one for defining those training sets to be used in supervised pattern recognition. Because soil or rock, understory vegetation, and tree vegetation typically comprise a terrain unit to be mapped, a ground survey to establish the precise composition of each training set seems essential.

(4) Concise display of the processed results may be obtained by converting classification data in digital tape format to hard copy display by means of an "ink squirter" capable of generating pixels measuring about 0.25mm in recorded size. Because the ERTS pixel is effectively rectangular (57 m × 79 m on the ground), while the pixel the "ink squirter" produces is square, there is some distortion of the mapped product. This can be reduced by first converting the digital tape to an effectively square format by means of a "rotate and scale" geometric correction computer program.

(5) Although this project was carried out using ERIM-developed software on an IBM 7094 computer, considerable time and money could have been saved had the processing been implemented on a high-speed, parallel-pipeline, digital, maximum likelihood ratio processor such as MIDAS (Multivariate Interactive Digital Analysis System), currently under development at ERIM under NASA-AAFE funding. A time savings by a factor of 9 in implementing the classification of the Yellowstone National Park area (comprising about half an ERTS frame) could be achieved, and the human-interactive features of the MIDAS system could have reduced by an even greater factor the time spent selecting training sets.

(6) The procedures derived here seem applicable to other large, remote, wildland areas. The use of ERTS data for survey of such areas seems particularly promising since, where

inaccessibility is a problem, complete photographic or scanner coverage by aircraft may be both difficult and expensive, if not impossible. The above conclusions are discussed in greater detail in sections 4 and 5 of this report, and also in the Smedes and Root report [2].

## 1.3 LIST OF PUBLICATIONS

During the course of this investigation, several papers were presented at the ERTS significant Results Symposia, at the Ninth Symposium on Remote Sensing of Environment, and elsewhere. Two publications, in particular, relate specifically to this contract:

F. J. Thomson and N. Roller, "Terrain Classification Maps of Yellowstone National Park," given at the ERTS-1 Significant Results Symposium, NASA-GSFC, 5-9 March 1973.

H. Smedes, R. Root, and N. Roller, "Color Terrain Map of Yellowstone National Park, Computer-Derived from ERTS-MSS Data," given at the Ninth International Symposium on Remote Sensing of the Environment, held in Ann Arbor, 15-19 April 1974.

## 2

## THE YELLOWSTONE SITUATION—WHY A RESOURCES SURVEY IS REQUIRED

The National Park Service (NPS) of the Department of Interior has issued a Master Plan [1] detailing how the facilities of Yellowstone National Park are to be developed to accommodate a projected increase in the number of visiting tourists. This Master Plan, which guides development of Park facilities, requires a comprehensive survey of Park resources for at least two reasons: First, the resources of Yellowstone had never before been entirely mapped, to our knowledge. Second, some baseline resource information is necessary if NPS is to comply with the provisions of the National Environmental Protection Act (NEPA) in further developing facilities and fulfilling their charter of maintaining park areas in a state as nearly natural as possible.

The Yellowstone area is so vast that coverage of the area by even high-altitude aircraft sensors is impractical. An RB-57 photographic flight in 1969 produced 1:120,000 scale CIR (color-infrared) photography of about 75% of the park. ERTS data offered a good opportunity to obtain a synoptic view, but even so, the park area covered about half an ERTS frame.

### 2.1 BACKGROUND OF THIS PROJECT

Dr. Smedes and ERIM have previously collaborated in processing Yellowstone National Park remote sensing data. These previous efforts had to do with aircraft multispectral data collected over geologically interesting sites in both the Lamar River Valley and the Geyser Basins.

Perceiving that a total resources map of the park area would greatly benefit the NPS in their management of the area, Dr. Smedes was very instrumental in bringing this project into being. He felt that a computer-generated recognition map of Yellowstone would not only demonstrate the potential of multispectral remote sensing and associated data processing in mapping wildland areas but also potentially provide the NPS with a useful management tool.

### 2.2 POTENTIAL USES OF THE YELLOWSTONE PARK RECOGNITION MAP

The 11-category computer-generated map of Yellowstone Park has numerous applications which could aid park planning, management, and associated scientific research. These possible applications are discussed in detail below.

#### 2.2.1 COMPUTER GENERATION OF A PLANT-COMMUNITY-TYPE MAP

Many of the mapping categories initially selected for the Yellowstone Park recognition map were chosen to test the feasibility of mapping plant community types. Although some community types were found to be spectrally similar (and hence not discriminable) on the 7 August 1972

ERTS frame, use of imagery obtained during different seasons of the year should enable separate mapping of such vegetation. Community types so separable include: coniferous from deciduous tree species (using a winter ERTS frame); brush as opposed to mafic or shadowed rock outcrops (early summer frame); and grass/brush versus light rock 2 (open woodlands with nonvegetated understory) using a late spring or early summer frame when brush cover is verdant and grasses have not yet cured. [Later in the year, curing of grass in an open woodland with vegetated understory (grass 2) causes this mapping class to appear spectrally similar to an open woodland with nonvegetated understory (light rock 2)]. Delineation of insect-infested timber may also be possible by using ERTS data during winter or early spring when spectral contributions of understory vegetation are minimal.

The categories on the Yellowstone National Park recognition map we produced and the additional cover types that could be separated using winter, late spring, and/or early summer ERTS frames suggest the feasibility of producing plant community type maps for wildland areas like Yellowstone Park. Such maps would be a valuable contribution to the basic information which the National Park Service assembles on their many national parks as an essential in comprehensive planning, environmental impact analysis, or development.

### 2.2.2 EXAMINATION OF SURFACE COVER AS A FUNCTION OF TIME

A computer-generated recognition map, besides showing the location of individual mapping categories, also indicates the total area occupied by each vegetation or terrain class. Such information, obviously of great value in crop survey work over agricultural areas, is also potentially of use for inventory purposes in a national park. If recognition maps covering identical mapping classes are produced at given time intervals, areal changes in mapping classes as a function of time may permit valuable insights into such processes as (1) average surface area burned annually by naturally caused forest fires, (2) analysis of wildlife habitat via dynamic changes in vegetation types used for food and cover, (3) trends in snowpack accumulation and water levels in lakes and streams, (4) changes in hydrothermal geologic activity as reflected in changes of surface thermal deposits, and (5) changes in areas of insect-infested timber.

### 2.2.3 THE RECOGNITION MAP AS A DATA LAYER IN A RESOURCE-INFORMATION SYSTEM

A digitized multi-layered resource information grid prepared for purposes of land-use planning must contain data on the character of the surface cover. A computer-generated recognition map could provide this type of information in a form readily enterable into the grid storage system. Each resource information system grid point might contain, in addition to surface cover type, digitized information on topography, precipitation, geology, soils, and land use, among others. The National Park Service envisions the creation and use of such a multilayered information storage and retrieval system for major areas of the National Park System that require new or redirected planning, design, and development as well as concomitant analyses of projected environmental impacts.

## 3

## DIGITAL-COMPUTER-MAPPING APPROACH

Most of ERIM's effort was in accomplishing the digital-computer-implemented pattern recognition of Yellowstone National Park terrain units, using data from ERTS-MSS recorded on computer-compatible tape (CCT). In this section, the flow of operations is discussed in detail and key interaction points with Dr. Smedes and Mr. Root are identified. Preparation of the classification map and its display are described and an evaluation of its accuracy presented. Subsection 3.3, taken from Ref. [2] and addressing the evaluation of map accuracy, was written largely by Dr. Smedes and Mr. Root; the material is included in this report for completeness.

### 3.1 DIGITAL-CLASSIFICATION-MAP PREPARATION

The first step in the overall Yellowstone project was the preparation of classification maps of various terrain units. The maps were initially stored on digital tape, then printed out by means of either a computer page printer or special "ink squirter" display. Figure 1 shows the flow of operations for the entire Yellowstone Study. Operations taking place in all but the last two boxes ("concise display" and "accuracy evaluation") are the subject of this subsection. Succeeding subsections cover the display and accuracy analysis.

The first step in the analysis was to convert the ERTS-MSS CCTs into a format compatible with the ERIM software package. At the same time, we edited out some of the data from ERTS frame 1015-17404, collected on 7 August 1972, so that only data f[illegible] park would be converted in our subsequent processing. The MSS-5 (red-channel [illegible]rom this frame is shown in Figure 2. Some of the more prominent landmarks of Yellow[illegible]ational Park, such as Hayden Valley, the Lower Geyser Basin, and Yellowstone Lake, [illegible]e delineated. We determined from a joint comparison of topographic maps and imagery that data from the second, third and fourth tapes (of the four-tape set) completely covered the park. Further, to define the park more precisely, we were able to edit out the first 600 and the last 240 lines of the 2340-line ERTS tapes. The data we copied (and in so doing, converted from ERTS to ERIM format) consisted of lines 600 through 2100 of ERTS tapes 2, 3, and 4. (The eastern boundary of the park fell about halfway across the area covered by tape 4, but that entire tape had to be converted because the format conversion program could not copy portions of ERTS-CCT records.) By concurrent editing of the data copied, we ended up with about 3.6 million pixels for analysis, or about one-half the number comprising an entire ERTS frame.

The next stage in our processing effort was the preparation of digital "graymaps" of the red MSS-5 band data. Using the IBM-7094 program MAP, we prepared computer-paper displays of the data, using dark symbols to display low data values and light symbols to display high data values. After several iterations through small portions of the data, we finally obtained a set of symbols and a range of ERTS data values for each symbol that gave a good presentation of the data. Initially, we mapped every other pixel and line of ERTS MSS-5 data, primarily to

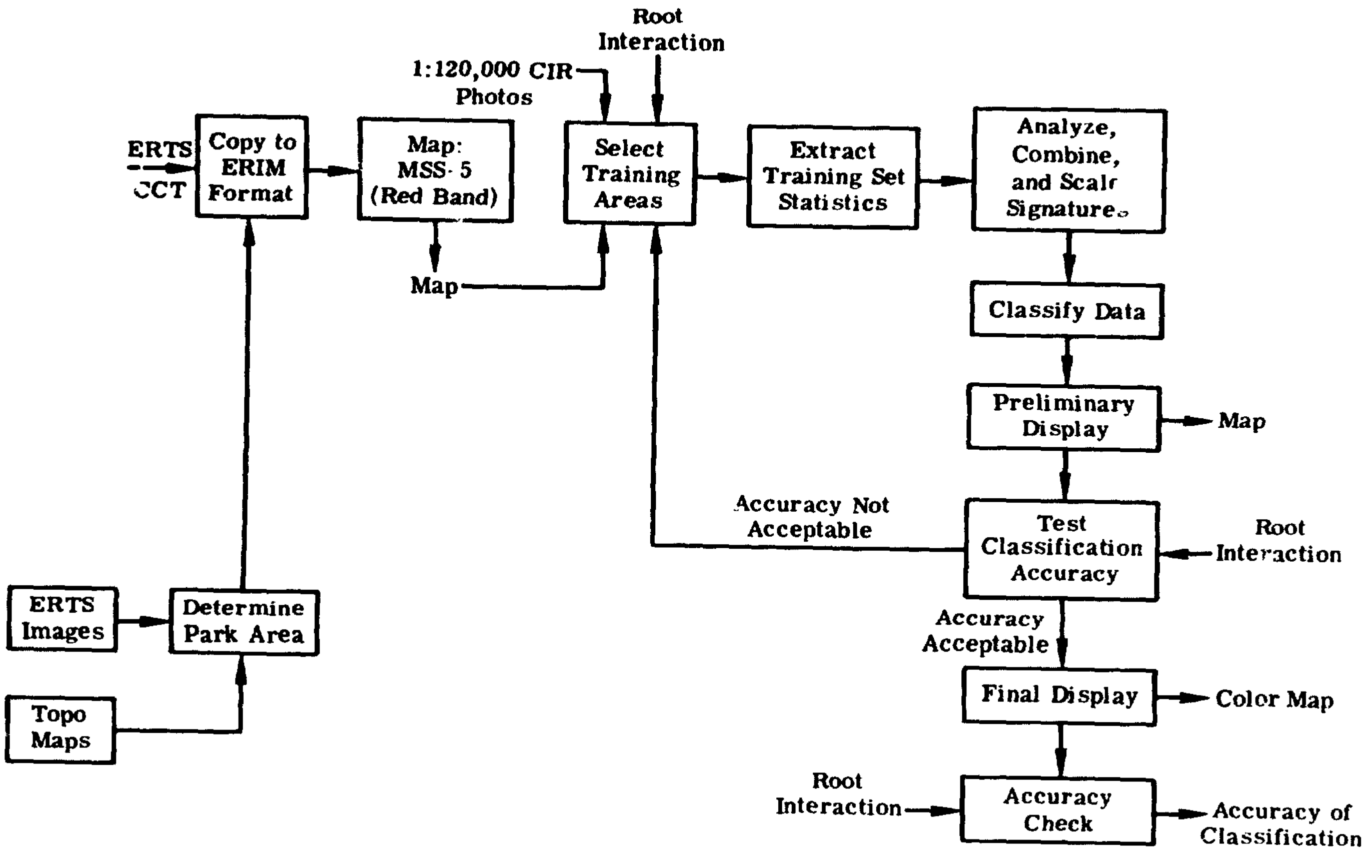

FIGURE 1. FLOW OF DIGITAL-PROCESSING OPERATIONS AND ANALYSIS FOR YELLOWSTONE PROJECT

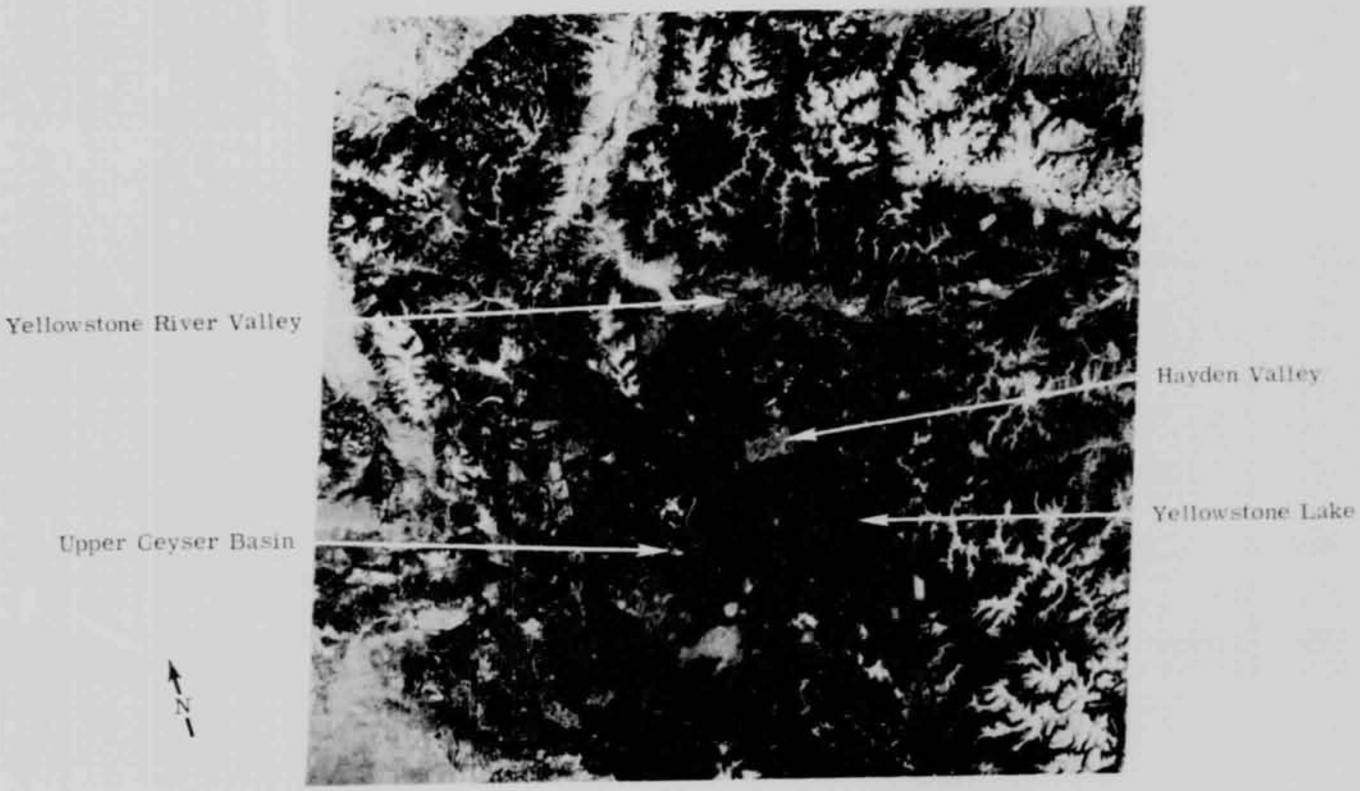

FIGURE 2. ERTS-1 IMAGERY OF YELLOWSTONE NATIONAL PARK
7 August 1972, Frame 1015-17404, Band MSS-5 (red-sensitive)

gain some conception of the data we were working with. This display, when printed on computer paper, was approximately 3 m square and covered nearly an entire wall of one of our workrooms. So rather than print a map of every ERTS pixel for the whole park, we instead chose and printed small (sample) areas of the data to guide us in our selection of training sets.

For a first attempt at selecting training set areas, the maps generated above were mailed to Ralph Root at Colorado State University (CSU), Ft. Collins. He had been analyzing 1:120,000 scale RB-57 color IR (CIR) photography collected in September 1969, and other photography, and had conducted extensive ground investigations within Yellowstone National Park in attempts to define training sets for the terrain units identified by Dr. Despain. Working without benefit of a zoom-transfer scope or other means of registering the digital map (at a scale of about 1:50,000) and the photography, he tried to transfer training set locations from the photography to the digital map. He then sent us line and pixel numbers for several training set areas for each class.

With the line and pixel information supplied by Mr. Root, we extracted the spectral signature for each area, using the IBM 7094 computer program STAT. The spectral signature is a statistical multivariate quantity, consisting of a set of means (or mean vector) (one for each spectral channel) and a covariance matrix. For the area defined, the means represent the average signal level in each band, while the covariance matrix defines the variation in signal in each channel (diagonal terms) and shows how one channel's signal variations are related to those in other channels (off-diagonal terms). Spectral signatures were extracted for all areas identified by Mr. Root. The program calculated the statistics and punched a card deck with the signature name, means, and covariances; it also prints histograms of the data values in each channel. Editing criteria imposed on the raw data values assure that if they lie so far from the means of the first 200 points as to make it unlikely that they came from the distribution (a $\chi^2$ test at the 0.0001 level is used), they will not be included in the calculation of the signature.

After securing the signatures for all initially identified training areas, we first sent a copy of the material to Mr. Root for analysis and then began our own signature analysis to determine inter- and intra-class separability. In analyzing signatures for the training areas defined by Mr. Root, we found five separable classes of materials in the scene—as shown in Table 1. The fact that a few of the signatures didn't seem to fit any of the classes was of some concern to us, because all signatures were supposed to be samples of only one terrain unit. Of further concern was the fact that there were only five apparently separable classes, since we felt we could distinguish about this number of classes from photointerpretation of the ERTS color-composite image.

To obtain an interim map product, as well as to learn something about terrain unit patterns in the park as a whole, we prepared a classification map of the entire park using the five classes

TABLE 1. THE FIVE SEPARABLE CLASSES OF THE PRELIMINARY YELLOWSTONE RECOGNITION MAP

1. Water
2. Light Rock and Soil
3. Coniferous Forest
4. Grasslands
5. Wet Meadow

identified from the signature analysis. The signatures for the five classes of Table 1 were obtained by combining the signatures of all the training set areas which we had assigned to the respective classes. Table 2 shows the mean values and standard deviations for each of the ERTS bands (in units of digital signal level) for each of the five signatures.

When our map of the 5-category recognition was completed, the procedure was then described [3] for the ERTS Significant Results Symposium in March 1973.

About the same time, Mr. Root commented that his analysis revealed an uncertainty in the location of several of the training sets —apparently from a lack of control in the process of transferring the areas on the 1:120,000 film to the ERTS graymap. Accordingly, we devised and implemented a new procedure for the location of these training sets. The revised procedure consisted of comparing enlarged 1:120,000 CIR photography (displayed on a VARISCAN projector) with digital graymaps of every ERTS pixel in both channels MSS-5 and MSS-7. The VARISCAN was able to enlarge the CIR photography to about the 1:22,000 scale of the graymaps. In one week at ERIM, Messrs. Roller and Root systematically reviewed the locations of all training sets, finding sizable location errors in some cases. (A more reliable method of checking and transfer would have been to register the photography and graymaps with a Zoom Transfer Scope, or to rectify the ERTS data by use of a geometric rectification computer program before comparison with photography. Although both capabilities are currently available at ERIM, they were not at hand when this work was done.)

After extracting new spectral signatures from the relocated training sets, we found that fifteen classes of materials, as enumerated in Table 3, stood a good chance of being discriminated. Signatures of different samples of each of the fifteen classes were combined to produce more representative spectral signatures. Table 4 shows the mean values and standard deviations (in units of digital signal counts) for each of the four ERTS bands for the fifteen signatures used in the preparation of the map. We then prepared a new recognition map using the fifteen classes and all four ERTS channels. From a preliminary map of the data, we became convinced that certain of the classes could, in fact, not be reliably discriminated. Most prominent among such classes were the different conifer species (spruce, fir, lodgepole pine), and dark rocks and brush. Consequently, the recognitions of these terrain units were combined yielding an 11-class final map.

Classification was performed using a modified maximum-likelihood ratio classification algorithm implemented on the IBM 7094 computer. Technical details of this algorithm have been discussed by Crane and Richardson [4]. Classification of all 3.6 million pixels, using fifteen signatures and all four ERTS bands, took about 100 minutes of 7094 computer time. All of the four ERTS channels were used for classification because previous experience with

### TABLE 2. MEANS AND STANDARD DEVIATIONS OF THE FIVE SIGNATURES USED FOR THE PRELIMINARY YELLOWSTONE RECOGNITION MAP

| Class | MSS-4 | MSS-5 | MSS-6 | MSS-7 |
|---|---|---|---|---|
| Water | 13.65 (0.79) | 5.85 (0.87) | 2.99 (0.70) | 0.27 (0.45) |
| Light Rock and Soil | 34.46 (6.90) | 36.17 (8.94) | 40.80 (8.74) | 18.59 (4.41) |
| Coniferous Forest | 17.93 (1.96) | 13.45 (2.67) | 23.54 (3.28) | 12.61 (1.98) |
| Grassland | 23.58 (2.20) | 20.86 (2.98) | 33.31 (5.58) | 18.18 (3.72) |
| Wet Meadow | 20.99 (1.76) | 16.35 (2.45) | 41.72 (6.39) | 26.17 (4.04) |

Note: Standard deviations appear in parentheses.

### TABLE 3. THE 15 SIGNATURES OF THE YELLOWSTONE RECOGNITION MAP

1. Lodgepole Pine (Density 1)
2. Lodgepole Pine (Density 2)
3. Spruce/Fir
4. Grass 3 (30-45% conifer cover)
5. Light Rock 3 (30-45% conifer cover)
6. Grass 2 (15-30% conifer cover)
7. Light Rock 2 (15-30% conifer cover)
8. Low Shrubs (wetland shrub)
9. Grasslands
10. Grass/Brush Mixture
11. Brush
12. Dark Rock
13. Light Rock
14. Thermal Deposits
15. Water

## TABLE 4. MEANS AND STANDARD DEVIATIONS OF THE 15 SIGNATURES OF THE YELLOWSTONE RECOGNITION MAP

| Class | MSS-4 | MSS-5 | MSS-6 | MSS-7 |
|---|---|---|---|---|
| L. Pine D1 | 17.23 (1.01) | 12.79 ( 0.98) | 22.07 ( 1.51) | 11.76 (0.94) |
| L. Pine D2 | 16.18 (0.88) | 11.01 ( 0.80) | 21.71 ( 1.37) | 11.46 (0.72) |
| Spruce/Fir | 15.58 (0.92) | 10.09 ( 1.12) | 20.01 ( 2.22) | 10.64 (1.42) |
| Grass 3 | 18.72 (1.33) | 13.50 ( 1.46) | 31.90 ( 6.26) | 18.36 (4.02) |
| Light Rock 3 | 19.15 (2.03) | 15.81 ( 2.74) | 27.11 ( 3.95) | 14.87 (2.30) |
| Grass 2 | 21.24 (2.18) | 16.93 ( 2.99) | 40.74 ( 6.05) | 23.74 (3.88) |
| Light Rock 2 | 25.68 (2.97) | 25.07 ( 4.09) | 37.07 ( 4.31) | 19.52 (2.15) |
| Low Shrub | 19.33 (1.05) | 13.38 ( 1.31) | 43.87 ( 3.61) | 26.35 (2.98) |
| Grassland | 22.64 (1.55) | 18.52 ( 2.63) | 47.62 ( 5.11) | 29.17 (3.83) |
| Grass/Brush | 24.17 (1.29) | 21.72 ( 2.30) | 37.97 ( 3.52) | 21.52 (2.59) |
| Brush | 26.32 (1.50) | 25.28 ( 1.88) | 31.30 ( 2.78) | 15.64 (1.79) |
| Dark Rock | 27.72 (4.42) | 26.41 ( 5.32) | 27.24 ( 3.80) | 12.51 (2.05) |
| Light Rock | 37.62 (8.29) | 40.40 (11.14) | 43.57 (10.83) | 19.78 (5.54) |
| Thermal Deposits | 65.48 (9.69) | 72.52 (11.23) | 71.00 ( 9.31) | 31.58 (3.60) |
| Water | 13.65 (0.79) | 5.85 ( 0.87) | 2.99 ( 0.70) | 0.27 (0.45) |

aircraft multispectral data had shown us that reducing the number of channels below four would significantly degrade probability of correct classification.

Initially, the classified data were stored in ERIM format on digital tape. Drawing from this data, we prepared preliminary maps of selected areas in order to qualitatively assess classification accuracy in areas of particularly good ground information. For these preliminary maps, all fifteen recognition classes were displayed by using as many different symbols to form blackand white graymaps. Both Mr. Root and Mr. Roller analyzed the preliminary maps to determine whether the classes which, from analysis of the signatures, appeared separable would in fact be separable throughout the park. We found that several classes could not be reliably discriminated; in particular, conifer species (spruce, fir, lodgepole pine) could not be. For example, recurrent fir recognition on the fringes of lodgepole pine stands led us to believe that the fir signature resembled a mixture of lodgepole pine and grassland. Hence, in pixels at the edge of lodgepole pine stands, mixtures of these two categories would be recognized as fir. Further, two categories—brush and dark rock—were poorly separated in the recognition maps. This latter confusion, we now feel, could be resolved by classification of May or June data, taken when the brush is at an earlier stage of growth.

After consulting with Messrs. Root and Roller, we decided to display conifer recognition as one symbol (or color) and to display the recognition of dark rock and brush as another symbol (or color). This reduced the number of categories from fifteen to the eleven classes shown in Table 5.

## 3.2 DISPLAY OF FINAL RECOGNITION RESULTS

Rather than prepare graymaps of every pixel of the final recognition product, we sought a more concise display. The typical graymap of ERTS data has a scale of about 1:22,000, which would have meant a Yellowstone National Park map 6 m square. Such a map is too large to be of practical use for the typical regional resource manager. We had had experience with an "ink squirter" display made by Mead Technology Labs, Dayton, Ohio. For this display medium, pixel size can be as small as 0.35mm square, or may be made larger in multiples of this size For our display, we chose to make the pixels 0.7mm square. This resulted in a 1 × 1.5 m map for Yellowstone National Park, at a scale of about 1:100,000. Because ERTS pixels are effectively rectangular (57 m along the scan line and 79 m along the orbital track) while display pixels are square, the resultant map appears stretched along the scan line. This elongation can be alleviated by geometric correction programs employing "nearest neighbor" interpolation, and by then correcting the recognition tapes.

To produce the color display of Figure 3, we first converted the recognition tapes we had prepared from ERTS tapes (viz., 2, 3, and part of 4) from ERIM format to a special 9-track

TABLE 5. DESCRIPTION OF MAPPING CLASSES FOR THE FINAL 11-CLASS RECOGNITION MAP

| Class Name | Code Name | Description |
|---|---|---|
| CONIFEROUS FOREST | CF | 40-95% coniferous tree canopy consisting of lodgepole pine, spruce-fir, douglas fir, white-bark pine, and other less common species |
| LIGHT ROCK 3 | LR-3 | 15-40% coniferous tree canopy cover with non-vegetated understory consisting of rock outcrops, rock rubble, talus, or coniferous litter mat |
| LIGHT ROCK 2 | LR-2 | 5-15% coniferous tree canopy with non-vegetated understory consisting of rock outcrops, rock rubble, talus, or cured grass |
| LIGHT ROCK | LR-1 | Light colored rock outcrops, rubble, or talus slopes with bare soil, and very sparse infrequent vegetation representing most life forms |
| GRASS 3 | G-3 | 15-40% coniferous tree canopy with grassy understory. Infrequent shrubs, bare soil, and rock exposures may be present. |
| GRASS 2 | G-2 | 5-15% coniferous tree canopy with grassy understory. Infrequent shrubs, bare soil, and rock exposures may be present. |
| GRASS | G-1 | Consists mostly of grass and other herbaceous forbs. Isolated trees, shrubs, brush, bare soil, and rock exposures may be present in insignificant amounts. |
| GRASS/BRUSH | GS | Consists of approximately equal amounts of grass and brush cover. Bare soil is present but less frequent. |
| BRUSH/DARK OR SHADOWED ROCK | B/DR | Consists of two classes that are similar spectrally but very different genetically:<br>(1) 70-90% brush cover, most commonly big sagebrush or bitterbrush. Grass and bare soil account for the remaining cover.<br>(2) Dark colored rock outcrops and related rubble, or lighter colored rocks or rock rubble darkened by shadow. Also may contain very sparse infrequent vegetation representing most life forms. |
| THERMAL DEPOSITS | TD | Consists mostly of siliceous sinter and associated weathering products. Lesser contributions come from sparse meadow grasses and occasional shrubs and coniferous trees. |
| WATER | W | Lakes, ponds, and streams with clear water more than 10 ft deep. The signature of shallow clear water is significantly affected by the bottom material, and turbid water is affected by the spectral signature of the suspended particles. |

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FIGURE 3. COLOR-CODED DIGITAL RECOGNITION MAP OF YELLOWSTONE NATIONAL PARK

800-bpi format required by Mead Corporation. At Mead, the data from the three ERTS tapes were merged so that a single ERTS scan line was written as a single record on tape. Further format conversion was then performed, and the 1 × 1.5 m display produced — the largest the Mead facility is presently capable of.

Figure 3 was obtained by simply photographing the display. The Mead Corp. charges for display of this data set were approximately $600.

### 3.3 QUANTITATIVE-ACCURACY EVALUATION OF THE 11-CLASS YELLOWSTONE MAP

Quantitative accuracy checks were applied to the digital recognition map. Here, rather than examine the classification accuracy of every pixel, we took a sample approach, taking selected samples throughout the park and then determining accuracies of recognition over the sample areas.

Ten test areas in which to perform a quantitative check on recognition map accuracy were selected throughout the park. These test areas are all approximately 0.5 km wide by 8 km long, each having an area of about 4 $km^2$. This size was chosen after examining overall patterns formed throughout the park by individual mapping units (i.e., terrain and vegetation classification categories). These patterns were worth checking in their entirety because they represent identifiable ecological units, such as alpine mountain ranges, subalpine montaine forests, extensive grasslands (e.g., Hayden Valley), large water bodies, areas of thermal activity, etc.

The rectangular test area shape was a trade-off between a long strip (which would have given the greatest amount of variation in ground cover types) and a square (offering the greatest sampling efficiency) [5]. Test areas were oriented with their long axis either parallel or perpendicular to the orbital path of the ERTS satellite, depending upon the extent and shape of the pattern of ground cover types being sampled. The ten locations were not randomly placed, but rather selectively situated throughout the park so they included representative examples of all eleven types of mapping units.

Recognition map data for each test area were obtained from the computer line printer, which arrays identification symbols for every other ERTS pixel in both rows and columns. Each test area printout thus contained approximately 2500 pixels. Test areas having orientations perpendicular to the satellite orbital path were 68 pixels long by 37 pixels wide. Those lying parallel to the orbital path were 49 pixels wide by 53 pixels long.

Prior to computer analysis of the ERTS results, using control information generated from photointerpretation of 1:110,000-scale color IR photography as the "ground truth," test area boundaries were carefully located on the ERTS and control data. Then the ERTS recognition data were coded on punched cards.

Two approaches were used to code the control data. First, the color-coded map data were sampled on a grid corresponding to the ERTS data, and results coded on punched cards. As a check on the accuracy with which this sampling technique represented the control data, the area of each class on the control map was determined by analysis using a high-resolution, color TV, level slicing system.

The recognition map and control data for each test area, with both types of data now coded on punched computer cards, were then analyzed by a computer program written to speed the chore of comparing recognition map data to corresponding control data. This program performs three types of data comparisons. First it compares, pixel for pixel, the recognition map data with the corresponding control data information and tallies correct and incorrect identifications. Second, it makes an area comparison, tallying percent area correctly identified for each mapping class. Third, it does a pairwise analysis using the point comparison data. This analysis reveals, for each test area, the amount and frequency of errors of commission as well as omission. Both indications are helpful in evaluating the overall accuracy of the recognition map.

Table 6 summarizes final results of the quantitative analysis. Overall mapping accuracies have been weighted in proportion to the areal extent of each mapping class known to be present within each test area. Also shown are the recognition accuracies, rank-ordered from best (1) to worst (11).

Point comparison results for all test areas are consistently lower than area comparison results. There were two reasons for this: First, it was difficult to assure that recognition map and control data were properly registered. Misregistration of ±1 pixel significantly compounded the effect of boundaries, as pixels located near boundaries were tallied as misclassifications when they were in fact correctly identified on the recognition map. Second, relief displacement in areas of rugged topography also caused local misregistration between the recognition map and control data. The area comparisons (Table 6b) show markedly higher identification accuracies because the effects of misregistration and relief displacement were minimized. However, the area comparison figures must be considered in the light of false alarm errors. In the area comparison we computed, in percent, the fractional area correctly identified by dividing the area of a given class on the recognition map by area of that class on the control map as determined from an actual point count of the sampled control data. If the percent correctly identified was greater than 100%, the excess over 100% was tallied as false alarm error.

In all the area comparison figures there exists the potential for offsetting errors to make results appear optimistically good. Area recognized may increase by errors of commission, where points not of a given class are recognized as that class. Similarly, area recognized may decrease by errors of omission, where points of a given class are recognized as points of

TABLE 6. SUMMARY OF MAPPING-ACCURACY RESULTS OBTAINED BY QUANTITATIVE POINT AND AREA COMPARISONS

a. Point Comparison Summary

| Mapping Class | Accuracy Tabulation (in %) by Test Area | | | | | | | | | | Weighted Mean (%) | Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | | |
| FOREST | 67 | 22 | 59 | 47 | 65 | 60 | 82 | 79 | 77 | 30 | 64 | 2 |
| LIGHT ROCK 3 | 21 | 17 | -- | 65 | -- | 40 | 38 | -- | 19 | 4 | 49 | 3 |
| LIGHT ROCK 2 | 12 | 22 | 0 | -- | -- | -- | -- | -- | 16 | 8 | 13 | 11 |
| LIGHT ROCK | -- | 3 | -- | -- | 18 | 33 | -- | -- | 38 | 0 | 32 | 7 |
| GRASS 3 | 17 | 12 | 50 | -- | 18 | 17 | -- | -- | 24 | 40 | 33 | 5 |
| GRASS 2 | -- | 17 | 24 | -- | 21 | 6 | -- | -- | 6 | 28 | 23 | 9 |
| GRASS | -- | 17 | 20 | 7 | 23 | 6 | -- | -- | 4 | 42 | 21 | 10 |
| GRASS/BRUSH | 6 | 23 | 29 | -- | 42 | 18 | -- | -- | -- | -- | 31 | 8 |
| BRUSH/DARK ROCK | 35 | -- | -- | 51 | -- | -- | -- | -- | 38 | 18 | 48 | 4 |
| THERMAL DEPOSITS | -- | -- | -- | -- | 50 | 31 | -- | -- | -- | -- | 33 | 6 |
| WATER | -- | -- | -- | -- | 16 | 13 | -- | 99 | -- | -- | 94 | 1 |

b. Area Comparison Summary

| Mapping Class | Accuracy Tabulation (in %) by Test Area | | | | | | | | | | Weighted Mean (%) | Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | | |
| FOREST | 91 | 64 | 67 | 70 | 100 | 66 | 83 | 93 | 100 | 44 | 77 | 5 |
| LIGHT ROCK 3 | 100 | 100 | -- | 100 | -- | 100 | 100 | -- | 100 | 100 | 100 | 3 |
| LIGHT ROCK 2 | 37 | 100 | 100 | -- | -- | -- | -- | -- | 100 | 100 | 62 | 7 |
| LIGHT ROCK | -- | 14 | -- | -- | 91 | 100 | -- | -- | 44 | 53 | 43 | 11 |
| GRASS 3 | 100 | 68 | 100 | -- | 100 | 100 | -- | -- | 56 | 79 | 82 | 4 |
| GRASS 2 | -- | 100 | 100 | -- | 100 | 100 | -- | -- | 98 | 100 | 99 | 2 |
| GRASS | -- | 39 | 35 | 8 | 74 | 10 | -- | -- | 27 | 98 | 52 | 9 |
| GRASS/BRUSH | 29 | 48 | 100 | -- | 55 | 100 | -- | -- | -- | -- | 54 | 8 |
| BRUSH/DARK ROCK | 100 | -- | -- | 70 | -- | -- | -- | -- | 100 | 68 | 77 | 6 |
| THERMAL DEPOSITS | -- | -- | -- | -- | 100 | 43 | -- | -- | -- | -- | 48 | 10 |
| WATER | -- | -- | -- | -- | 22 | 42 | -- | 100 | -- | -- | 96 | 1 |

another class. These two errors offset each other, and their effect becomes obvious when the commission errors so far exceed the omission errors that class area accuracies of greater than 100% occur.

All in all, the quantitative results presented in Table 6 closely substantiated judgmental (qualitative) examinations of the recognition map. Though there are some exceptions, the quantitative comparison yielded approximately the same order of identification accuracies. The order of decreasing recognition accuracy is not identical in point and area comparisons, primarily because where mapping classes had small areas and long, thin shapes, consequent registration problems often led these classes to be given a short count in the point comparison analysis. Especially affected were light rock, grass 2, thermal deposits, and coniferous forest.

Area comparison results yielded mapping accuracies ranging from 40 to 100%, with six mapping classes showing accuracies better than 70% —water, coniferous forest, light rock 3, grass 3, grass 2, and brush/dark or shadowed rock. The identification accuracy of brush/dark or shadowed rock fell off considerably in the qualitative analysis because of numerous false alarm errors, particularly along streams and shorelines. As expected, those mapping classes which are spectrally similar to one another, especially grass/brush and light rock 2, had lower recognition accuracies. Thermal deposits also had a low recognition accuracy since this class is spectrally similar to snow and highly reflective rock outcrops. The mapping accuracies obtained from the quantitative analysis are believed to be lower than the actual mapping accuracies because of misregistration of digital and control data, boundary effects, and local misregistration in areas of rugged topography.

The problem of boundary effects experienced in the first quantitative analysis procedure was addressed by sampling in test areas 1, 4, and 10, but this time directly from 1:110,000 NASA high-altitude color infrared imagery. Test areas 4 and 7 comprised virtually flat terrain, but test area 10 had approximately 305 m of relief. Table 7, part b, shows that area comparison accuracies for test areas 4 and 7 were higher using the photo as a source of control data rather than the control data reference map. Point comparison accuracies (Table 7a) were lower, however, because the photo effectively introduced additional boundaries since it supplied more detail than did the control data map This additional detail permitted a more accurate area estimate of control data mapping units, hence better area comparison results; but in the point comparison the introduction of more boundary effects resulted in even lower accuracy figures.

For test area 10, with 305 m of relief, the CIR photo did not produce any improvement in area comparison accuracies. The control data reference map was corrected for relief displacement, but the photo control data were not. Differences in the map versus photo point comparison results for this test area are probably due to relief displacement effects; differences in the area comparison results may well stem from relief displacement effects presen in the photo control

## TABLE 7. COMPARISON OF ACCURACY RESULTS OBTAINED FROM THE CONTROL-DATA REFERENCE MAP VERSUS THOSE FROM HIGH-ALTITUDE CIR AERIAL PHOTOGRAPHS

### a. Point Comparison Summary*

| Mapping Class | Test Area 4<br>Digital Map | <br>CIR Photo | Test Area 7<br>Digital Map | <br>CIR Photo | Test Area 1<br>Digital Map | <br>CIR Photo |
|---|---|---|---|---|---|---|
| FOREST | 47 | 37 | 82 | 83 | 30 | 33 |
| LIGHT ROCK 3 | 65 | 49 | 38 | 23 | 4 | 31 |
| LIGHT ROCK 2 | -- | -- | -- | -- | 8 | 7 |
| LIGHT ROCK | -- | -- | -- | -- | 0 | 2 |
| GRASS 3 | -- | -- | -- | 3 | 40 | 41 |
| GRASS 2 | -- | -- | -- | -- | 28 | 25 |
| GRASS | -- | -- | - | -- | 42 | 35 |
| GRASS BRUSH | -- | - | -- | -- | -- | -- |
| BRUSH DARK ROCK | 51 | 40 | -- | -- | 18 | -- |
| THERMAL DEPOSITS | -- | -- | -- | -- | -- | -- |
| WATER | -- | -- | -- | -- | -- | -- |

### b. Area Comparison Summary*

| Mapping Class | Test Area 4<br>Digital Map | <br>CIR Photo | Test Area 7<br>Digital Map | <br>CIR Photo | Test Area 10<br>Digital Map | <br>CIR Photo |
|---|---|---|---|---|---|---|
| FOREST | 70 | 76 | 83 | 97 | 44 | 87 |
| LIGHT ROCK 3 | 84 | 100 | 85 | 97 | 91 | 96 |
| LIGHT ROCK 2 | -- | -- | -- | -- | 99 | 36 |
| LIGHT ROCK | -- | -- | -- | -- | 53 | 18 |
| GRASS 3 | -- | -- | -- | 100 | 79 | 94 |
| GRASS 2 | -- | -- | -- | -- | 96 | 96 |
| GRASS | -- | -- | -- | -- | 98 | 73 |
| GRASS BRUSH | -- | -- | -- | -- | -- | -- |
| BRUSH/DARK ROCK | 70 | 99 | -- | -- | 68 | -- |
| THERMAL DEPOSITS | -- | -- | -- | -- | -- | -- |
| WATER | -- | -- | -- | -- | -- | -- |

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*Numerical results are expressed in percent accuracy of computer identification and include compensation for false alarm error.

data around the borders of the test area. Minor relief displacement within the ERTS imagery is undoubtedly contributing to misregistration problems in the point comparison analysis for test area 10 as well as for others containing rugged terrain. Orthophotos used as control data may solve this problem. Misregistration errors would still be likely to affect point comparison results, but more accurate area comparisons could be obtained if point counts were made directly from photos corrected for relief displacement. This would eliminate the need for producing the control data reference map—a costly and time-consuming step in the analysis process.

A further aid in obtaining better comparison results would be geometric correction (rectification) of the ERTS image before creation of the recognition map. The use of completely rectified ERTS data would help greatly in locating corresponding boundaries of the test areas, and would produce a product that could be used either as a precision map or as an overlay upon other maps of an identical scale. In areas of exceptionally high relief, however, a minor amount of relief displacement might still be evident on the rectified map.

## 4

## COMPARISON OF COSTS IN MAPPING FORESTED AREAS

The cost of producing a green forest overprint by conventional U.S. Geological Survey mapping techniques was compared with the cost of obtaining a computer-interpreted forest map using ERTS data. The forest mapping class was chosen for this cost comparison because of its importance as a land cover type and because of readily available and accurate data on the cost of conventional forest mapping. Table 8 summarizes photointerpretation, cartographic, and printing preparation costs for the conventional green forest overprint on the U.S. Geological Survey 1:125,000 topographic map of Yellowstone Park vis-a-vis the procurement, analysis, and printing preparation costs associated with a forest map obtained by computer analysis of ERTS data. Costs of the computer processing were ERIM estimates based on their experience with the ERTS-CCT data.

The cost comparison demonstrates that a map showing forested versus non-forested areas could be produced by computerized interpretation of ERTS data for less than one-fourth the cost of conventional forest mapping techniques. Should the U.S. Geological Survey widely adopt computer mapping of the green forest overlay, they could realize a potential cost savings of more than 75%. Production of topographic maps could then be increased (5% to 7% overall) by using this new mapping procedure.

The computer-interpreted forest map can be produced in a matter of days, and contains timely information which can be frequently updated to account for alterations of forest cover resulting from forest fires, avalanches, landslides, and (for application outside Yellowstone National Park) changes because of lumbering, road construction, or development. (These changes, covering less than 1 year of time, can be seen on ERTS imagery from the Yellowstone area). The computer forest map is produced by using a consistent statistical decision-making algorithm which assures the use of uniform identification criteria throughout the entire map. In contrast, the conventional forest mapping technique is subject to possible inconsistencies in human interpretation.

Another advantage of the computer-interpreted forest map is its ability to show many small clearings, down to the minimum resolution of the sensing system used (0.44 ha for ERTS data). A delicate mottling of forest and non-forest mapping classes can be mapped to reflect natural growth patterns of vegetation. To map this kind of detail by conventional means is presently too costly and time-consuming.

Further, the final 11-category recognition map of Yellowstone Park we produced for NASA-GSFC under the present program has demonstrated the ability of the computer mapping technique

TABLE 8. COST COMPARISON: THE U.S. GEOLOGICAL SURVEY GREEN-FOREST OVERPRINT VERSUS THE FOREST-MAPPING CLASS ON THE YELLOWSTONE PARK RECOGNITION MAP

a. U.S. Geological Survey Costs

| Man-hours | Cost per Man-hour | Total Cost per Unit Area | Cost of Forest Delineation (5% of Total Cost) | Park Area | Total Cost of Forest Interpretation |
|---|---|---|---|---|---|
| (1) Photogrammetry Costs: | | | | | |
| $4/\text{mi}^2$<br>$1.5/\text{km}^2$ | \$17 | \$68/$\text{mi}^2$<br>\$25/$\text{km}^2$ | \$3.40/$\text{mi}^2$<br>\$1.31/$\text{km}^2$ | 3300 $\text{mi}^2$<br>8540 $\text{km}^2$ | \$11,220 |
| (2) Cartography Costs: | | | | | |
| $4/\text{mi}^2$<br>$1.5/\text{km}^2$ | \$6.88 | \$27.52/$\text{mi}^2$<br>\$10.60/$\text{km}^2$ | \$1.93/$\text{mi}^2$<br>\$0.74/$\text{km}^2$ | 3300 $\text{mi}^2$<br>8540 $\text{km}^2$ | \$ 6,350 |
| (3) Preparation of Printing Plate: | | | | | \$ 20 |
| | | TOTAL USGS COST | | | \$17,590 |

b. Cost of Computer-Generated, Forest Overprint

| | |
|---|---|
| Procurement of ERTS digital input tape(s) | \$ 100 |
| Automatic image rectification (geometry correction) | 500 |
| Computerized recognition of forest mapping class | 3,500 |
| Preparation of printing plate | 20 |
| TOTAL COST OF COMPUTER MAP | \$4,120 |

to distinguish, and, with suitable display equipment, portray not only one, but now three levels of forest density. This indicates that it is possible to produce more than just a forest versus non-forest map, at a cost below or at most comparable to that of the conventional green forest overprint.

# 5
# CONCLUSIONS AND RECOMMENDATIONS

Several conclusions and some associated recommendations were presented in Section 1.0. These points are discussed in greater detail below.

We processed ERTS-MSS data using computer-implemented spectral pattern recognition techniques. The classes recognized were those defined by supervised pattern recognition — the analysts knew what classes they wanted mapped and trained the computer accordingly. The training and subsequent recognition resulted in accurate recognition of some categories and less accurate recognition of other categories. Accuracies ranged from 40 to 85% for the various classes, as discussed in Section 3.3. This level of performance is deemed acceptable for a first-stage overview of wildland areas such as Yellowstone. But more important than the accuracy figures, the map of the area convincingly portrays patterns of vegetation in true relation to terrain, and is thus extremely useful to a manager seeking an overview.

Although the August 1972 ERTS data produced acceptable results, these probably could be improved by broadening the data base to include ERTS data from the May-June time frame also. The temporal variation of spectral signatures defining certain terrain classes could then be exploited to separate classes which, because of their spectral similarity in the August data, had to be lumped together (e.g., dark rock and brush). Reluctantly, we feel that even the multitemporal approach will not allow us to separate the various conifer species. At ERIM we have shown [6] that separation of conifer species in controlled, well-managed stands can be accomplished using spectral information in channels narrower than the ERTS band and at different parts of the spectrum. The study in Ref. [6] was conducted with low-altitude aircraft data offering considerably better radiometric precision than ERTS. In view of the natural variability of stand density and the need for wider spectral bands to obtain adequate radiometric precision in satellite data, the problem of conifer species separation with a sensor carried by a space vehicle is felt to be a difficult one. If user interest is strong enough, the problem should be studied in greater detail.

The training procedure we used was to overlay high altitude photography, upon which training sets locations had been annotated, with ERTS digital graymaps. The high-altitude photography had a 1:120,000 scale, and the ERTS graymaps about a 1:22,000 scale. For supervised pattern recognition, some transfer technique of this sort seems essential. Alternatively, training set locations could be located by UTM coordinates, and the coordinates translated to ERTS pixel and line numbers. This approach, initially brought to our attention by Dr. F. P. Weber of the U.S. Forest Service, requires "precision" ERTS data. The maximum error in position must be less than one pixel, since one-pixel mislocations of training sets were found to materially alter some signatures in our study. While "geometric correction" programs developed for digital computers can, potentially, correct bulk ERTS data, the use of these programs is still experimental.

Concise display of processing outputs in a geometrically correct form is essential for user acceptance of map products derived from ERTS data. Provision by NASA of geometrically corrected bulk ERTS data on computer-compatible tapes will solve this problem. While "ink-squirter" devices are capable of generating concise 1:100,000 displays from ERTS data, several color video systems are capable of generating 1:1,000,000 displays. We used the facilities of Mead Corporation, Dayton, Ohio because they were available, convenient, reasonably priced, and produced an impressively colored product. Unfortunately, the color photo (Fig. 3) does not do justice to the original.

The present study was completed using digital computer software for the IBM 7094 computer. Processing was slowed by the frequent interaction required with the data, the batch-mode processing of the 7094 computer, and the need for hard-copy output. A rapid, parallel-pipeline, digital, pattern classifier, MIDAS, currently being implemented by ERIM under NASA-AAFE funding, potentially could cut the cost of processing these data through more rapid processing of data and improved operator interaction with the data (through real-time color CRT display). As a test case, Dr. Frank Kriegler processed tape 3 of Frame 1015-17404 on a prototype MIDAS. Using the same signatures as for the digital analysis, he processed the data in 5 minutes as compared to some 30 minutes required by our 7094 computer. A color display of recognition results, shown in Figure 4, was produced on an interim printer system. (The color CRT and color hard-copy printer are scheduled for development during the second year of the MIDAS program.) For details of the MIDAS system, see the report by Kriegler [7].

We feel the same approach taken in classifying Yellowstone National Park resources could be applied to other large and remote natural areas. The need for intermediate-scale photography could be obviated by the geometric correction of ERTS data and the location of training sets via reference to UTM coordinates. The advantages of ERTS for remote wildland area inventory are obvious. Further enhancing the likelihood of wider use are two prospects: the adoption of multi-temporal approaches (more feasible with geometrically corrected data than with bulk data), and the future probability that satellite sensors will offer a greater number and variety of spectral bands.

KEY

| | |
|---|---|
| Green | - Coniferous Forest |
| Orange | Light Rock 3<br>Light Rock 2<br>Light Rock |
| Brown | Grass 3<br>Grass 2<br>Grass<br>Grass/Brush |
| Magenta | - Dark Rock/Brush |
| Black | - Thermal Deposits |
| Blue | - Water |
| White | - Not Classified |

FIGURE 4. COLOR-CODED DIGITAL RECOGNITION MAP, PREPARED ON MIDAS, OF A PORTION OF YELLOWSTONE NATIONAL PARK

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