

Machine Processing of Remotely Sensed Data: Three Applications in Mexico

Abstract: In general, ground-data acquisition procedures in developing countries are not very efficient, and the resulting lack of reliable data produces significant delays in important management-planning decisions. This paper describes three studies involving different applications of machine processing of remotely sensed data, a recent technology that appears to have potential use for timely ground-information acquisition. The general methodology describes the use of a special software processing system. Finally, some conclusions are presented relating to the specific problems discussed and to the advantages of remote sensing in general.

Introduction

One of the more important factors delaying social and economic advancement in developing countries is the lack of accurate knowledge about natural resources and cultivated land. Although geographic data do exist, they are sometimes incomplete, inaccurate, or unsuitable for planning purposes. In addition, updating of available data is often not feasible because of the expensive and time-consuming methods conventionally used.

One common method for obtaining ground data in developing countries is visual interpretation of aerial photographs. Generally, the first step in this method is identification of classes of observable items, such as forests, bodies of water, crops, and bare soil. Once these classes have been established, the separation of each into more specific subclasses is performed. In photographic interpretation, the reliability of the data gathered depends on the photointerpreter's experience as well as on the quality of the photographic material. Other problems arise when an estimation of area is required, since the techniques used are highly subjective and can produce undetermined degrees of error.

Advantages of this technique are that the resolution is variable, depending on the flight altitude, the images are immediately available, and the image scale can be varied to match previous cartographic information.

Some disadvantages are the optic and geometric distortions, the cost of covering a large area due to the small coverage per aerial photograph, and the problem of mosaicking several photographs.

Another method used in ground-data acquisition involves surveys by a statistical sampling technique. This consists of making direct inquiries to randomly selected farmers; the information obtained is then statistically extrapolated. One of the principal advantages of this approach is the acquisition of otherwise unavailable information such as the use of fertilizer or crop yields per unit area. The main disadvantage is the decreased time for proper management planning that results from the extended time required for collecting and processing the data. In addition, these surveys can be effective only if they are made close to the harvesting season, since only at that time is the farmer able to make an accurate estimate of his production.

A new dimension to remote sensing of the environment has been added by sensing the earth from satellites. With the launching of Landsat vehicles it became possible to obtain sequential coverage of large areas in a short period of time at a relatively low cost per unit area. The large number of digital images produced by Landsat and Skylab, and all images produced by other digitizers, are useful only if a software system is available.

In this paper a remote sensing approach is treated by means of three studies involving land-use mapping, water resources monitoring, crop area evaluation, and erosion classification. The studies included Landsat and Skylab S192 images, aerial photographs, survey maps, and a software system called ER-MAN II (Earth Resources Management System) [See Refs. 1, 2, and Table 1].

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Table 1 ER-MAN II system capabilities

<i>Supervisor</i>	<i>Image creation</i>	<i>Contrast techniques</i>
system control system initial- ization terminal I/O input decoding image access error recovery reports resource alloca- tion check point/ restart	image composition image difference test image image subset	window Fourier filter correlation matrix general neighbor filter
<i>Image manipulation and display</i>	<i>Registration</i>	<i>Pattern recognition</i>
display color images display gray-level images up-down scroll line plot density slicing video look-up table modifi- cation	image registration to UTM image rotation left-right flip up-down flip specific polynomial modification	field selection statistics histograms probability of error divergence statistics modifi- cation goodness-of-fit classification pixel value clustering classification image creation classified character maps area mensuration

The ER-MAN II system is based on NASA's Earth Resources Interactive Processing System (ERIPS) [3] and consists of a set of software programs that perform a variety of functions related to digital image processing and a display system for user interaction. It runs on an IBM/360 or 370 computer with at least 512 Kbytes of real storage. Even when remotely sensed data analysis is a fairly complex task, ER-MAN II is relatively easy to use because it interactively guides the work of the analyst. The architecture of the system also permits the addition of new functions and features by the users.

The display system is a RAMTEK GX-100B with two screens. One black-and-white screen allows the user to interact with the computer by presenting "menus." The second screen is a color monitor used to display images with a resolution of 512 lines of data, each containing 510 picture elements. The user can input to the menus in one of three ways. He may use the keyboard to enter information, use a trackball (cursor) to point to a decision box on a menu, or point (with a cursor) at the image screen to denote areas for analysis.

General methodology

Once the geographic analysis problem is identified, there are several points that must be considered if a remote sensing approach is to be successful.

- Is a satellite image available?
- Are there photographs concurrent with the satellite image date that can be used to support the computer analysis?
- Does reliable ground information for the chosen season exist?

Other factors, especially in developing countries, are related to the time needed to collect the ground data and to actually obtain the satellite data, and include related postal and customs problems. The Mexican territory is *partially* covered by the Goldstone, California ground receiving station; thus only part of the images are available. Also, if a specific image date is desired, a previous contact with NASA must have been established.

• Data processing

The loading program for the ER-MAN II system has been modified in the IBM Mexico Scientific Center so that the system can now manipulate not only satellite images (Landsat and Skylab), but also images produced with a microdensitometer system.

The image can be displayed on a color screen by selecting three of the spectral data bands, one each for the red, green, and blue beams. Band 7 (0.8 to 1.1 μm) in the near-infrared portion of the electromagnetic spectrum is best suited for discriminating between land and water. Band 5 (0.6 to 0.7 μm) is generally best for determining topographic and cultural features such as drainage patterns, roads, and towns. Band 4 (0.5 to 0.6 μm) is sometimes used to qualitatively discriminate the depth and turbidity of standing bodies of water. Images from band 6 (0.7 to 0.8 μm) show certain tonal contrast and reflect various land-use practices. Most commonly, an image is formed from bands 7 (in red), 5 (in green), and 4 (in blue); the colors are analogous to those of infrared photography.

A set of programs designed to enhance or deblur an image has been added to the system. This "filter" package allows the user to enhance an image by applying approximations to the gradient (see Figs. 1 and 2) and Laplacian functions. It also permits the user to filter an image by first applying an FFT (fast Fourier transform [4]) algorithm and then multiplying the transformed image by a window function [5].

The two classification techniques available on the ER-MAN II system are now described.

Unsupervised

By using the interactive self-organizable clustering (ISOCLS) algorithm [6] all clusters with "similar" pixels



Figure 1 Landsat subimage from the Yaqui Valley. Band 7 appears in red, band 5 in green, and band 4 in blue. Areas planted with wheat are shown on the red squares while urban areas are shown in gray blue color.

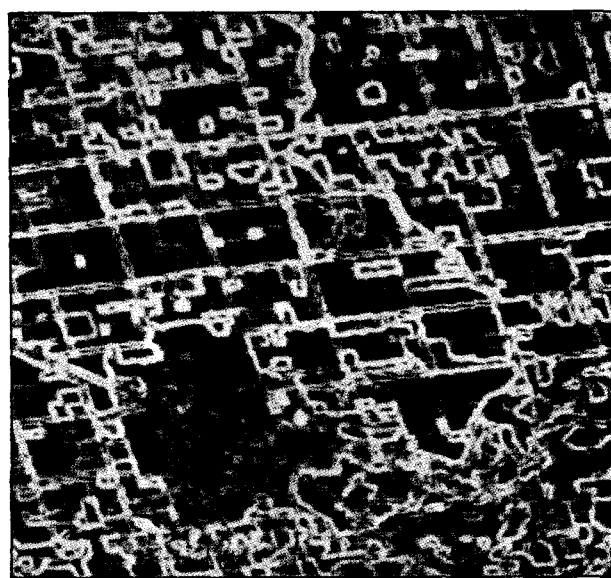


Figure 2 This picture shows Fig. 1 after a gradient has been applied to it. Notice that roads between the wheat fields are easily distinguishable. Differences among several urban uses are now detectable. Similar techniques were used on the satellite images to facilitate the process of training field definition.

(picture elements) are identified in an interactive process; the similarity is established by specifying parameters via the keyboard.

Supervised

1. Bayes classifier

The Bayes classifier [7] is used to find decision functions by assuming that the probability density functions are multivariate, normal (Gaussian) functions. To test the unimodality of the density function, the system provides a goodness-of-fit program. Two tests are available [8], the Pearson Chi-square and the Kolmogorov-Smirnov; each ascertains how well the data group approximates a normal distribution.

The areas of the image to be used as training and test fields are defined to the computer through the field selection option. The statistics processor computes the mean, the standard deviation, and the covariance for the selected training fields or defined classes. The Bayes program assigns each pixel to one of the candidate classes and computes the likelihood of the correct classification.

2. Look-up-table classifier

This processor, which was added to the system, classifies an image according to the spectral range of each class in each of the selected bands. A divergence processor reduces computer analysis time by determining the optimum set of channels to be used in classification.

The map processor can create a) an image that can be viewed on either color or gray-level terminal screens; or b) either a character map or a gray-level map on the line printer. Also developed was an area mensuration program that computes the number of pixels assigned to each class and converts the result to any desired unit of measurement. Many other processors can be used on specific problems.

The general methodology of our data processing and analysis is shown in Fig. 3.

Applications

• *Water bodies and land-use maps in the State of Durango*

Since water is a vital element for agriculture, it is necessary to monitor the quality and quantity of water bodies. Furthermore, knowledge of various land uses makes possible the proper distribution of available water resources. Therefore, a joint study involving a region in north central Mexico was made in collaboration with the Ministry of Water Resources [9]. The main objectives of this study were to monitor water quality in the selected area and to obtain, for the first time, land-use maps of the region.

The geographic conditions are as follows:

Site name:	Guadiana Valley
Geographical location:	N 25°00' - N 23°43'
	W 105°07' - W 104°53'

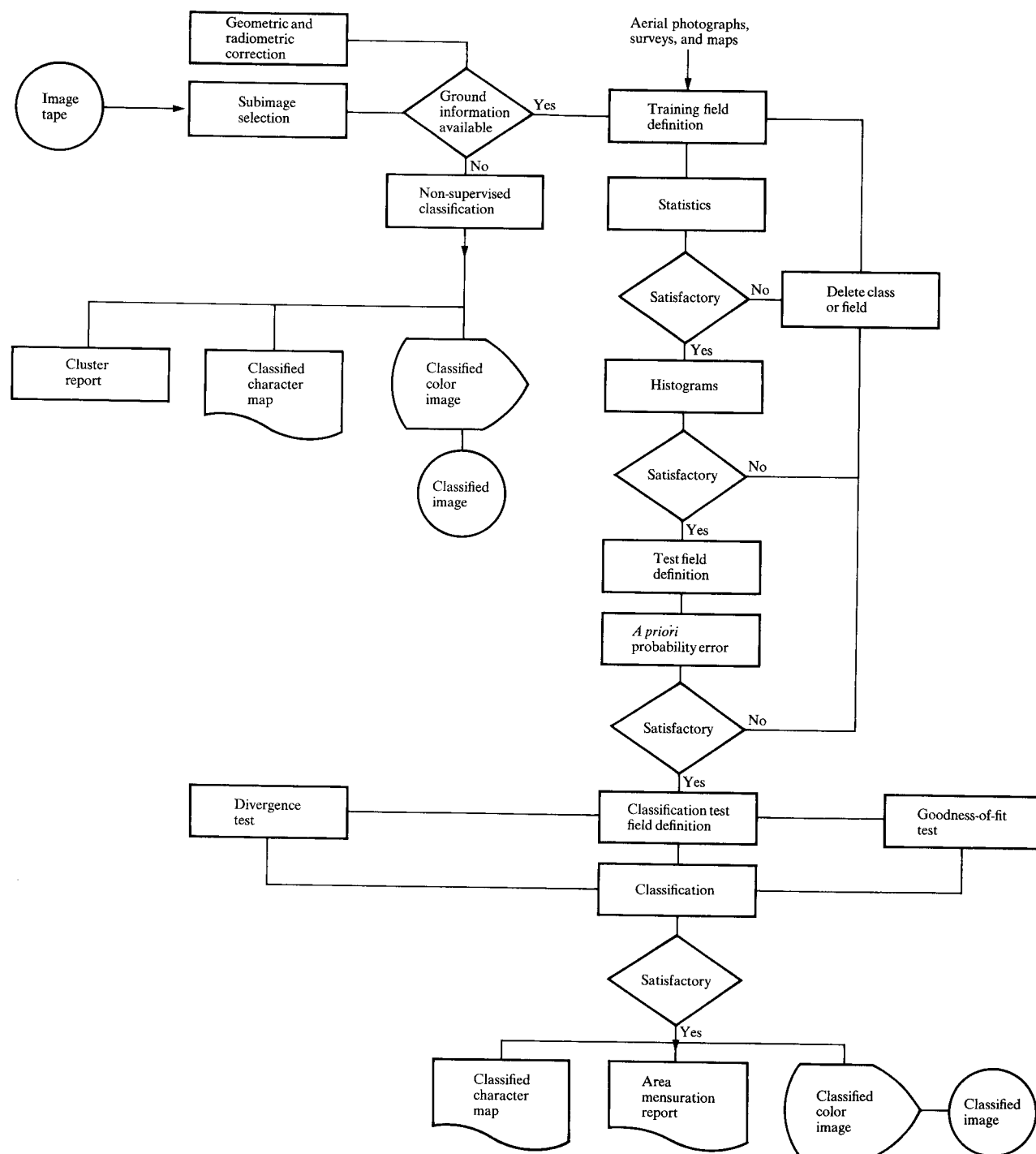


Figure 3 General methodology of data processing and analysis.

Area analyzed: 4150 km²
 Altitude: 2200–3100 m (relatively flat zone surrounded by mountains)
 Temperature: 25°C, annual average
 Precipitation: 450 mm annually

Three Landsat images covering the dry and rainy seasons were selected and a Skylab image was already available; cloud cover was zero in all four cases.

The Skylab S192 image has important properties which make it a useful tool in the analysis. There are 13 spectral

bands with wavelengths between 0.41 and 12.5 μm [10]. This variety of bands enhances interclass discrimination. Because of this, the Skylab image was specifically used in the water-bodies objective.

The S192 multispectral scanner is an optical-mechanical scanner coupled with a spectral dispersion system. It uses a rotating mirror to perform a conical scanning of the earth. The cone angle γ is $5^{\circ}32'$ about the instrument axis. Data are collected during the front $116^{\circ}15'$ of the 360° scanning cycle (see Fig. 4). Images produced by such conical scanners have unique geometric properties and require a different approach to correction. Therefore, a special software algorithm was designed [11] and the input data was reformatted so that the resulting digital image presented an undistorted geometric form.

Landsat data, like all data acquired by on-board-spacecraft sensors, are affected by a number of electronic, geometric, mechanical, and radiometric distortions. If these distortions are left uncorrected, the accuracy of the extracted information diminishes, and the utility of the data is severely reduced. The three Landsat images used were geometrically corrected by using a special software package; see also the discussion of corrections in [12].

The Landsat image from May 1976 was registered to a latitude-longitude Universal Transverse Mercator (UTM) grid by using the registration processor of the ER-MAN II system. The geographic coordinates from five ground control points, obtained from the National Territory Geographic Bank, were typed into the system and the image was transformed by a polynomial calculation. Unfortunately, the five control points were located in a relatively small area. A random distribution over the full image area would have been better; however, no other geodesic points were available.

Because of the lack of ground information, the Landsat October 1972 image was initially classified by using unsupervised techniques. Seven different classes were found. Later, after a trip to the zone, the correspondence between the computer classification and the actual ground components was made. Results were found to be satisfactory, but very rough for purposes of creating a map. To increase the accuracy, supervised classification methods were needed.

A set of aerial photographs (scale 1:50 000) was analyzed to obtain ground data, and the results were drawn on maps. This information was entered into the computer and an extrapolation to the whole selected region was made. The four satellite images were then classified by means of this information. The selection and boundary determinations of training fields were facilitated by using the filter processor and a technique whereby negative values of each satellite image were displayed [13].

The negative values were found by assigning to each pixel the value obtained by subtracting the original value

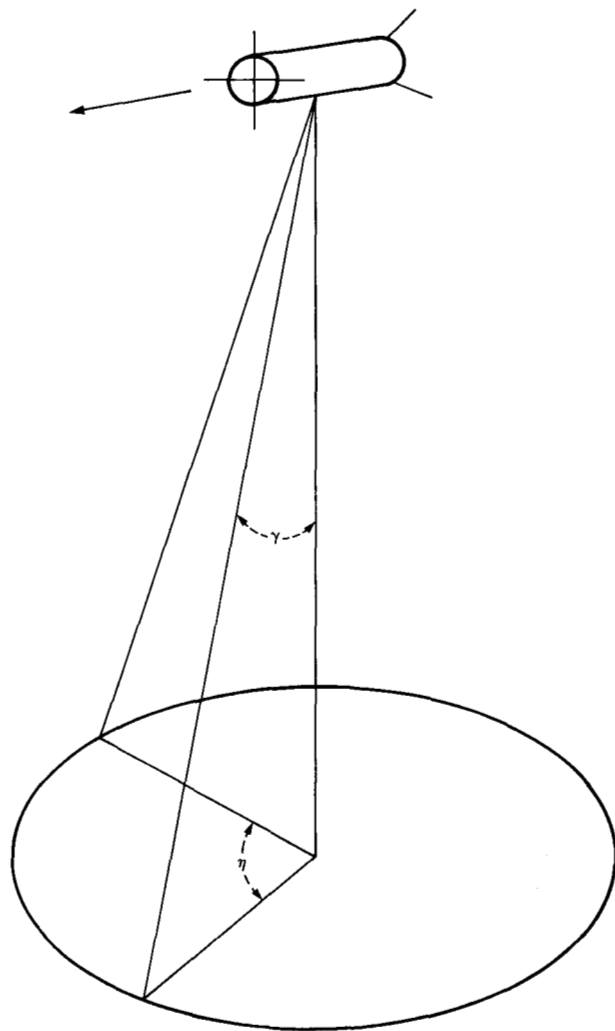


Figure 4 Skylab S-192 conical scan geometry. The cone angle γ is $5^{\circ}32'$ and the data are collected during the front $\eta = 116^{\circ}15'$ of the 360° scanning circle.

from a constant (in this case, 127 for bands 4, 5, and 6, and 63 for band 7). These negative bands were added to the original ones and the resulting compound image was displayed by selecting triplets of bands. Photointerpreters found with this technique that some classes and control points were more easily distinguishable than with the original image.

The results obtained included classification images, classification character maps, and the numerical estimation of areas (Table 2).

The water bodies were classified from the Skylab S192 image with high accuracy; a determining factor for their discrimination was the 13 spectral channels. Four different types of water were found, whereas only three were found from the Landsat data (Table 3).



Figure 5 Classified results of erosion over the entire State of Mexico. Color key: green (no apparent erosion), cyan (light erosion), violet (moderate erosion), red (serious erosion), orange (urban areas), yellow (crops), blue (clear water bodies), brown (turbid water bodies), and white (nonclassified areas).

Table 2 Classification according to land use and measurement of areas (km²) in the State of Durango.

Class	Landsat image date		
	October 1972	March 1973	May 1976
Water	43	22	31
Floodable zones	8	30	22
Irrigated crops	274	281	279
Nonirrigated crops	1245	1032	1129
Grass and bushes	982	1223	1095
Isolated trees and shrubs	515	532	523
Woods	23	17	13
Bare soil	321	342	330

Table 3 Classification of water bodies in the State of Durango.

Class of water	Average surface covered (km ²)	Extension during rainy season (%)	Decrease during dry season (%)
Clear, avg. depth 30 m	12.6	15	17
Covered with vegetation	3.8	21	9
With sedimentation, avg. depth 12 m	11.8	115	80
With suspended bodies, avg. depth 15 m	2.4	15	17

An interesting consequence of this study was the identification and measurement of potentially floodable zones. A yearly average of 30.6 km² is covered with water, while 35.2 km² represents floodable land. During the dry season, the water bodies decrease in area by 30 percent, while the potentially floodable zones increase by 45 percent. For the rainy season the pattern is quite different; floodable zones are completely covered by water and the total water area actually increases by 115 percent.

Another significant result of this project was the estimation of forest area. Wood-related products represent one of the principal sources of income for Durango State, where the Guadiana Valley is located. Information concerning the decreasing forest area is critically important to the government. In October 1972, forest area in the Guadiana Valley was 23.4 km²; in March 1973, it was 17.1 km²; and by May 1976, it had dropped to 12.9 km².

The final evaluation of the remote-sensed approach was difficult because there was no pattern against which a comparison of the data could be made. Forty points were selected from the classified images and a verification trip was made to the zone. It was found that 87 percent of those points had been accurately classified.

• Erosion in the State of Mexico

Erosion is an alarming problem in many countries [14]. In Mexico, because of the lack of technical resources for maintaining soil fertility, farmers move to forest areas, clear them, and use the land for crops on a temporary basis. The estimated land erosion in Mexico is astonishing: 80 percent of the territory shows some sign of erosion, and in a total of 50 km² of that area the soil degradation is so severe that organic life is virtually impossible. As a result, a joint study of the Toluca Valley with the National Forest Inventory Department was initiated [15]. The principal objective was to obtain an accurate map of five different degrees of erosion so that reforestation plans could be elaborated. The geographical data of this area are as follows:

Site name:	Toluca Valley (State of Mexico)
Geographical location:	N 28°32' - W 91°00'
Altitude:	2000 m average
Area analyzed:	23 000 km ²
Temperature:	13°C, annual average
Precipitation:	800 mm annually

The initial steps of this project included obtaining ground truth information by means of several trips to key areas; selection of training fields typical of five classes of erosion (see Table 4) using stereoscopic methods on aerial photographs; and acquiring satellite images covering the entire State of Mexico.

To fulfill the objective of the project, it was necessary to perform geometric and radiometric corrections so that true geographical coordinates could be associated with the images and the resulting maps matched with available maps of the region. The software package mentioned in the previous study was used for this purpose.

Training fields were defined and classification results obtained for the first image. Then the statistics modification option of ER-MAN II was used. That is, once the statistics obtained for the set of training fields from the first image were validated, dummy training fields were defined for the second image, and their "meaningless" statistics (mean vector and covariance matrix) were replaced with valid ones. See Fig. 5 for a classification image of erosion in the State of Mexico.

In addition to the five erosion classes, four other classes were defined for separating erosion-related from non-erosion-related areas. These classes were clear water, turbid water, crops, and urban areas (Table 4).

• Wheat cover in the Yaqui Valley

The objective of this study was a measurement of the land surface planted with wheat in a large irrigated region in northwestern Mexico, selected by the Agriculture Ministry [16]:

Site name:	Yaqui Valley (State of Sonora)
Geographical location:	N 27°10'–N 27°40' W 109°50'–W 110°40'
Altitude:	Sea level
Scene number:	85 307164555000
Analyzed area:	2520 km ²
Temperature:	23°C, annual average
Precipitation:	273 mm annually

The final result showed 1420 km² sown with wheat. This was significantly different from two official estimates of 1640 (water control office) and 1740 km² (statistical sampling technique). This difference exemplifies the main problem encountered, i.e., difficulty in estimating the accuracy of the results. Comparison of the computer results with ground data provided was not useful for accuracy evaluation because of detectable incoherencies, but the comparison was adequate for training field definition.

For determination of the accuracy of the crop identifications, we used aerial photographs of the zone taken on the same date as the satellite image. A zone of approximately 52 km², in which wheat was easily found by visual photointerpretation, was computer-classified and a comparison was made. The agreement in classification of crops between this photograph and the computer results was within ten percent.

Table 4 Classification of erosion and land use in the State of Mexico.

<i>Class</i>	<i>Area (km²)</i>
Very serious erosion	933
Serious erosion	1996
Moderate erosion	9375
Light erosion	1767
Nondetectable erosion	7691
Turbid water	118
Clear water	251
Crops	405
Urban areas	427

Table 5 Decomposition of ER-MAN II classified image into three basic color components.

<i>Color</i>	<i>ER-MAN II assigned number for color</i>	<i>Intensities</i>		
		<i>Red</i>	<i>Green</i>	<i>Blue</i>
Black	0	0	0	0
Red	8	15	0	0
Violet	9	9	0	11
Cyan	6	0	15	15
Green	4	0	15	0
Blue	2	0	0	15
Brown	7	6	4	3
Orange	3	15	8	0
Yellow	12	15	15	0

In fact, from our results, we were able to determine that one of the basic causes of the difference between official and computer results was that, on the average, 0.22 km² for every block of 4 km², representative of areas devoted to internal and external roads, houses, and barns, had been taken as wheat-sown in both official results.

Map production

Since the results of the previous studies were to be printed on cartographic maps, the digital classification images produced with the ER-MAN II system had to be transformed into photographic form. A problem arose because digital classified images from ER-MAN II were in color, whereas the microdensitometer system was limited to the production of monochromatic photographs because it has only one light-emitting diode (three are necessary for the

production of color photographs). To solve this problem, a software program was designed to decompose each pixel value of the classified color image into its three basic color components, red, green, and blue. Each classified image was decomposed into three basic color digital images. A transparency was obtained from each color component by using the microdensitometer; this was projected onto photographic paper with the respective color filter. The result was a high quality color photographic classified map (see Figs. 1, 2, and 5). Table 5 shows how the bands were decomposed.

An estimate of the time needed to analyze one square kilometer of a Landsat image was deduced from the three preceding studies. The results, estimated by using all the required capabilities of the ER-MAN II system running on an IBM 360/65, were 0.657 s/km² CPU time and 2.82 s/km² elapsed time.

Summary and conclusions

Remote sensing techniques appear to have a great potential in developing countries, especially in the inventory of natural resources and corresponding management planning. However, for optimal performance there is need for a well organized support system that can provide accurate ground data and make efficient use of the results obtained. In the developing countries, this organized support system often does not exist. Also, several agencies are often devoted to the same function, duplicating both cost and effort; the time response is severely affected by bureaucratic problems. One of the major advantages of remote sensing, when applied to developing countries, is that the need for an organized support system may bring additional benefits—the most important being the timely acquisition of reliable information to support intelligent management planning decisions. Once the whole system is working, the cost of the information is much less than when conventional acquisition techniques are used.

Although the application of remote sensing technology in developing countries brings important advantages to them, there are also disadvantages that should be considered: high initial investment; competition with other institutions or countries for the acquisition of images; and the implications of dependence upon another country either for information regarding agricultural planning or for equipment maintenance.

The general problem of estimating the accuracy of our results was always present because of the lack of reliable ground information. In the wheat study the accuracy was tested against aerial photographs (scale 1:50 000). In the other two studies several trips to the subject areas were made. Points from the classified images were randomly selected, and they were tested on the terrain. There re-

mains the unsolved question of how many points are sufficient for accuracy testing.

The methodology developed in the wheat evaluation study will be used for future planning. The study in Durango State produced land-use maps that are being used for hydraulic planning. The result concerning the decreasing wood area was brought to the attention of the government, and action is planned. The erosion study results will be used by the Mexico State government as a guide for a program of reforestation.

The machine processing of remotely sensed data has numerous potential applications, especially in developing countries. With future Landsat satellites important modifications to the software analyzing systems will be needed. Advances in the underlying computer technologies will very likely produce enormous advances in remote sensing technology; however, the principal advantage of remote sensing from satellites remains the providing of timely and accurate information on an extensive area at a cost that is justifiable.

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