COMPUTER-AIDED CLASSIFICATION OF THE FIRST FRAME
OF DIGITAL ERTS-1 (i.e., LANDSAT-1) DATA

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ABSTRACT
ERTS-A was successfully launched to become ERTS-1 (later renamed Landsat-1) on July 23, 1972. At that time, the Laboratory for Applications of Remote Sensing at Purdue University had some unique data analysis capabilities, so NASA asked LARS/Purdue to conduct a digital analysis of the very first frame of digital Landsat-1 data collected. This data set was obtained on July 25, and was of the Red River Valley area on the border between Oklahoma and Texas.

The data tapes arrived at LARS by courier in the evening of July 26 and preliminary classifications were completed by July 28, using clustering pattern recognition techniques. A team of two LARS staffers flew to the study area on July 30 on a “field observation” mission, obtaining valuable aerial photography of the area as well as ground observation data. Some forested areas that had been sprayed with 2,4,5-T as a rangeland improvement project were very distinctive on the infrared bands of the ERTS data, but not on the visible bands, nor could they be located from the air during the field observation mission. Additional analysis of the data resulted in detailed classifications of three study areas, using 17 - 20 spectral classes that were based on combinations of clustering and supervised training data. The final classifications were judged to be quite good, and did an effective job of mapping forestlands, agricultural areas, reservoirs, major roads, and even a powerline right-of-way. The results of this analysis work were presented at the NASA Earth Resources Technology Satellite-1 Symposium on September 29, 1972, and also at the 23rd International Astronautical Congress, Vienna, Austria, October 8 - 15, 1972.

INTRODUCTION
A new era for resource managers in all disciplines was initiated with the launch of the first Earth Resources Technology Satellite (ERTS-1) or Landsat-1. For the first time ever, good-quality data could be obtained from satellite altitudes for most of the earth’s surface and at reasonably frequent intervals. At that time, LARS (the Laboratory for Applications of Remote Sensing at Purdue University) was either the only lab or one of a very few facilities in the U.S. that had the capability to analyze digital multispectral data, especially for an area the size of a full frame (185 x 185 km) of ERTS data. Therefore, NASA requested LARS to conduct an analysis of the first frame of digital data obtained from the satellite. The purpose of this analysis was to obtain preliminary indications of the potential value of such satellite data and to evaluate the quality of the data obtained.

To achieve the most rapid analysis possible, we were asked to send someone to Goddard Space Flight Center to obtain the data as soon as it had been collected. Bill Simmons, one of the computer technicians at LARS, went to Goddard and in the afternoon of July 26 he was given the digital tapes of the multispectral scanner for the first full frame of data obtained by the satellite, along with a printed black and white image from Band 5 (0.6-0.7μm). He took a flight back to Indiana that evening, arriving at LARS at about 11:00 p.m., and by the next morning he had the data properly formatted and displayed on the LARS digital display unit, ready for analysis. The analysis was conducted by David Landgrebe, Roger Hoffer, Forrest (Bud) Goodrick, and other members of the LARS staff.

INITIAL ANALYSIS
This first frame of digital ERTS-1 data covered an area of the Red River Valley area along the border between Texas and Oklahoma. Preliminary examination of the image revealed an interesting array of forest, rangeland and...
agricultural areas, as well as some interesting geologic, cultural and water resource features. (See Figures 1 and 2.) However, none of us involved in analyzing the data had ever been to this area, and we had no ground observation data available. This situation had been somewhat anticipated since we did not know exactly when or where the satellite would first be activated to start collecting data. We had therefore decided to do the analysis in two phases – first, a preliminary analysis to become somewhat familiar with the area and to define various features of potential interest, followed by a field trip to the region. Phase 2 would involve a more complete, detailed analysis of the data.

![Figure 1. A color infrared composite image of the first data obtained by ERTS-1.](https://example.com/image1.png) (from *Proceedings of the NASA Symposium on Preliminary Results of ERTS Data Analysis*)

We started the analysis effort by simply comparing the imagery to existing maps. Through this process, we were able to define water bodies, rivers, major highways and some urban areas with a great degree of certainty. Some forested areas, large geological features and some agricultural areas could be at least tentatively identified through interpretation of the multispectral scanner data. Color infrared composite imagery was prepared and proved to be especially helpful for this preliminary familiarization activity. In Figure 1, for example, the large black feature in the lower left is Lake Texoma. The Red River can be seen to the east of Lake Texoma. Atoka Reservoir is the small blue feature near the center of this image, and a portion of Eufaula Lake is at the very top center. The blue

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color of Atoka Reservoir and Eufaula Lake is apparently due to high levels of sediment, as compared to the relatively clear water of Lake Texoma. (Clear water shows up as black on color infrared composite imagery whereas turbid water is bright blue.) The rather distinctive wiggly white line near the upper left portion of the image defines the Canadian River valley. The Ouachita Mountains are in the upper right portion of this image. The relatively bright red color is indicative of forest cover in this area.

We used a "non-supervised" approach for the initial classification of the full frame of data, largely because of our general lack of familiarity with the region from which this data had been obtained. Every nth pixel of every mth line was sampled to obtain a data set that could then be clustered to develop the training classes. We used a large sampling interval and allowed the program to automatically group the pixels into a defined number of spectral classes. We started with 15 spectral classes. However, because of the large sampling interval, several of these classes contained very few pixels and were therefore either deleted from the training data set or combined with what appeared to be similar classes. The complete frame of data was then classified, using a Maximum Likelihood classification algorithm. A tentative identification of the cover types represented by the various spectral classes used in the classification was achieved by examination and comparison of the ratios and spectral groupings of the training data, along with a detailed comparison between the classification results and the color infrared composite imagery. The cover type classes identified in this manner were necessarily broad and included: 1) rangeland and pasture; 2) agricultural areas with sparse canopy and bare soil; 3) forestland and woodlots; 4) relatively clear water; and 5) relatively turbid water. In general, each of these broad cover type groups consisted of several spectral classes.

In addition to the analysis of the entire frame of ERTS-1 data, we decided to do a very detailed analysis of two sub-sets of the data, one involving the area around Lake Texoma and the other focused on the Ouachita Mountain area. Figure 2 shows the four wavelength bands of imagery for the Ouachita Mountain sub-set area, and Figure 3 is a color infrared composite image of the same area. Note the distinct straight line going from northwest to southeast on the two visible wavelength band images (i.e., 0.5 - 0.6μm and 0.6 - 0.7μm). This feature is also very distinct on the color infrared composite image. During the field trip to the area, this straight line was found to be a powerline right-of-way, with a grass ground cover. In Figures 2 and 3, note also the very straight east - west line in the 0.8 - 1.1μm image and on the color infrared composite. Examination of the digital data revealed that this was a bad scan line of data in the 0.8 - 1.1μm band, but not any of the other bands.

Figure 2. The four wavelength bands of ERTS-1 data for the Ouachita Mountain study area.
Figure 3. A color infrared composite image of the Ouachita Mountain study area. Note the unusual straight lines and square corners of the L-shaped, very light toned feature in the upper center of the image. By comparing Figure 3 with Figure 2, it is evident that this feature has very high reflectance in all four wavelength bands. Also note another L-shaped feature near the center of the image, just below the power line right-of-way (but with the bottom of the L going in the opposite direction from the feature at the top center). This area is rather black on this image and is surrounded by red forestland. A comparison between Figure 3 and Figure 2 reveals that this feature cannot be seen on the two visible bands but is dark toned on the two near infrared bands. (See the results section for an explanation.)

After examining the initial analysis results, several areas were identified for the field team to check out during a two-day field trip being planned. Several points of interest were designated in the Ouachita Mountains and Lake Texoma areas. The two L-shaped areas mentioned in the caption for Figure 3 were of particular interest. We suspected that both of these areas had been subjected to some sort of forest management practice or treatment activity, but wanted to find out why these areas were so different from the surrounding forestlands. We were also very interested in learning why there was such a distinct banding appearance present in the Ouachita Mountains. Two lakes south of the Red River were also of interest because they had very different spectral characteristics that we thought might be associated with possible differences in turbidity and/or water depth. We requested the field team to make note of any other areas of interest or possible significance that might be observed during the field trip.

FIELD WORK

On July 30 and 31, two members of the LARS team – Chris Johannsen and Bud Goodrick – traveled to the study area to obtain field observation data. One of the more humorous aspects of this entire analysis effort occurred in conjunction with this field trip, in that Purdue University required approval prior to any out-of-state travel. Such travel requests had to be submitted at least two weeks prior to the travel, so we had dutifully submitted the required paperwork. However, since we did not know exactly when or even where the first frame of ERTS-1 data was to be
acquired, the travel request submitted had been rather vague. Consequently, we received a phone call from the Provost’s office inquiring about this strange travel request that indicated that we wanted two people to travel somewhere between the Canadian border and the Mexican border, sometime within the next two or three weeks, by either commercial aircraft or rented car (or some combination thereof) to do “field work”! What on earth was this travel request all about? It sounded as though we didn’t know where or when we wanted to go or what we wanted to do! We had to admit that we really did not know when or where we were wanting to go, but we thought that we did have a reasonably good idea of what we wanted to do once we got there. The travel request was approved.

Chris Johanssen and Bud Goodrick flew to Oklahoma City on July 30. They were met by an Oklahoma State Soils Extension Specialist and an Oklahoma Extension Forester who were intimately familiar with the agricultural and forestry practices of this area. A small plane had been reserved to fly the team over areas of interest. Thus, the field observation team was airborne over the site on the fifth day after the ERTS-1 data had been acquired! They had with them the Channel 5 image (the visible red, 0.6-0.7\(\mu\)m band) of the entire scene provided by NASA, color infrared composite images of selected areas that had been made at LARS, black and white photographs of the initial classification results, a sectional air navigation chart with many of the points of interest designated, two 35mm cameras and black & white panchromatic, color negative and color positive films, and a portable tape recorder to be used for verbal comments.

The flight over the study site proved to be very informative and beneficial for interpreting the spectral classes that had been generated by the computer during the unsupervised classification analysis. From the air, the field team could see that the banding that was so evident on the ERTS-1 imagery of the Ouachita Mountain area was caused by some ridges with rock out-croppings and geologic stratification. There was also a difference in the density of forest cover and in shadow effects on the east facing ridges as compared to the west facing ridges. As previously noted, on the red wavelength band image (0.6 - 0.7\(\mu\)m) in Figure 2, there is a very distinct, straight line running from the upper left to the right center part of this image. The same line is not as distinct on the green wavelength band (0.5 - 0.6\(\mu\)m) but could not be discerned at all on the infrared wavelength bands. From the air, the field team verified that this is a grass covered powerline right-of-way. Considerable time was spent flying around Lake Texoma and observing visual differences in water quality as well as agricultural uses of the land, particularly along the north shore of the lake. Several small bright areas were determined to be recently harvested hayfields. The highly reflective area in the upper center of Figure 3 was found to be pasture that had been converted from forestland. Examples were found of areas that were in the process of being converted from forest into pastureland. The L-shaped area surrounded by red forestland just below the powerline and to the right of center in Figure 3 proved to be a most interesting situation. By comparing Figures 2 and 3, it can be seen that this area has a relatively low reflectance in the two reflective infrared wavelength bands (0.7 - 0.8\(\mu\)m and 0.8 - 1.1\(\mu\)m), but cannot be distinguished from the surrounding forest cover in either of the visible wavelength bands (0.5 - 0.6\(\mu\)m or 0.6 - 0.7\(\mu\)m). From the air, even though the field team flew around this area for some time, no visible difference could be discerned between this area and the surrounding forest cover. This was somewhat surprising and very interesting, so they asked the Extension Forester to try to obtain any information available concerning forest management practices in this area.

The team spent the following day on the ground, checking agricultural conditions and practices and becoming familiar with the soil characteristics of the area. Agricultural crops were primarily cotton, grain sorghum and peanuts, growing in quite sandy, high reflecting soils. Much of the area in this part of Oklahoma was rangeland and forest. Several stops were made along the north shore of Lake Texoma to examine the water quality, width of beaches, and other features near the lake. The team returned to Oklahoma City late in afternoon and flew back to Lafayette, Indiana that same evening.

**DETAILED CLASSIFICATION RESULTS**

Based on the knowledge gained from the ground and low altitude aircraft observations, as well as the wealth of information obtained from the Oklahoma Extension Agents, a second series of classification analyses were initiated. For the full frame analysis, eleven spectral classes that had been previously defined were retained and, based on the field information, additional classes were added in order to improve the separation of classes and to correct errors that had become apparent. Training samples were taken from the Atoka Reservoir, Lakes Texoma and Tishomingo, and several pasture areas that had been visited by the field team. A new set of twenty spectral classes was therefore
a combination of classes defined by the clustering algorithm and classes from selected areas defined by the analysts.

The cover types that were effectively differentiated in this second analysis sequence included six categories of
land use/land cover including: (1) rangelands; (2) agricultural fields [most of which had only a thin vegetative
canopy]; (3) mostly bare soil, generally rather sandy; (4) forested areas [five different spectral categories]; (5)
highways and highly reflecting rock outcrops; and (6) water [four different spectral classes]. The second
classification results contained more informational classes and detail than had been defined during the first phase of
the analysis, clearly reinforcing the importance of “ground truth” data and effective knowledge of the characteristics
of the area being studied. The classification of the full frame of ERTS-1 data is shown in Figure 4. On the right
side of this image one can discern several straight horizontal lines that were caused by bad scan lines in the data (one
of which goes all the way across the center of the image).

![Classification results for the entire first frame of digital ERTS-1 data.](image)

Figure 4. Classification results for the entire first frame of digital ERTS-1 data.

Figure 5 shows the classification results for a portion of the Ouachita Mountain area. The light blue area in the
upper center was the pasture that had been converted from forest. The L-shaped area near the right center of the
image and below the power line right-of-way is seen on this classification image as black. This was the area of
forest cover that had low reflectance in the near infrared bands but that could not be visibly distinguished from the
surrounding forest cover from the air when the field team flew over that region. It was clearly classified as a
distinctly different spectral class as compared to the surrounding forest cover. Correspondence with the local
Extension Forester later indicated that this area had been subjected to aerial spraying as part of a rangeland
improvement program. The procedure involved aerial spraying of the area with 2,4,5-T to kill the deciduous forest
overstory and allow the grass underneath to develop into a better quality rangeland. According to the information
obtained, this block of forest cover had been sprayed the previous year but the spray application had not been
adequate to completely kill the trees. Consequently, in 1972, the vegetation had developed its normal green
appearance (to the eye), but was believed to still have a serious stress condition, resulting in a distinct decrease in
infrared reflectance. This information provided by the Extension Forester explained the difficulty that the field team had experienced in locating this particular area from the air. This situation is thought to be one of a relatively few well documented cases of what has sometimes been referred to as “pre-visual stress detection” using remote sensing techniques. It is particularly interesting that such a situation was found on the very first frame of ERTS-1 data obtained! It could be noted that there have been many cases in which vegetative stress has been enhanced through the use of color infrared photography or imagery obtained in the reflective infrared wavelengths. In these situations, photo interpreters may see an area that is under stress on B & W infrared or color infrared photos first, but then when color or panchromatic photos are examined, the area does show up but just not as distinctly as on the infrared photos. That was not the case in this situation; the areas that had been sprayed were distinctly different on the infrared bands of ERTS-1 imagery, but could not be discerned either on the visible bands of ERTS-1 imagery or visually from the air when flying around the area.*

* An interesting possible explanation for these results came several years later when the author of this paper was talking with Dr. Charles Olson, Jr., Professor Emeritus from the University of Michigan. Dr. Olson had learned about a herbicide spraying study over a forested area in Virginia in which black-and-white IR photos had been taken before, a day after, and several days after the area had been sprayed. The sprayed trees were very dark on the infrared photos taken the day after the spraying, but on the photos taken several days after the spraying, the trees were the same light-tone that they had been in the photos taken before the spraying. Herbicide application is known to result in the generation of ethylene that fills the foliar air space. The researchers therefore hypothesized that on the photos taken the day after the spraying, the ethylene was absorbing the IR radiation, causing the trees to appear dark-toned. They further hypothesized that a few days later, the ethylene had diffused out of the leaves. Therefore, the trees were dead, but they still had green leaves that reflected “normally” in both the visible and in the photographic infrared portion of the spectrum. Frank Sadowski, who was involved in the study, told Dr. Olson about this study. Dr. Olson then went to the library and confirmed that ethylene has strong absorption bands in the photographic infrared portion of the spectrum. It would seem at least somewhat possible that a similar situation might have been what we had encountered with this first frame of ERTS-1 data, given the fact that the field work had been conducted about a week after the ERTS-1 data had been obtained, although the date of the spraying of the scrub oak had not been documented.
The classification results clearly showed the powerline right-of-way and a highway (white linear feature that is most evident in the upper right portion of Figure 5). The reddish brown areas on the far left and far right sides of Figure 5 were other areas that had been sprayed with 2,4,5-T, but in these cases the oak overstory vegetation had died and appeared brown to the eye.

The classification results for the Lake Texoma sub-set are shown in Figure 5. This image displays an example of spatial detail that surprised the analysts – the highway bridge crossing Lake Texoma in the lower right portion of this figure. (Figure 4 also had some examples of fairly narrow features such as roads and the powerline right-of-way.) These features were not as wide as the 79-meter resolution of the scanner, yet they were clearly visible, at least in places, on the imagery and the classification map. The reason such features could be seen on enlargements of the imagery and the classification results was due to the high contrast in spectral response between the feature and the surrounding background (e.g., a white, highly reflecting road surrounded by water having a very low near infrared reflectance, or a highly reflecting road surrounded by forest having a low visible red reflectance). The high reflectance of something in a fairly large portion of the pixel will cause the average reflectance for the entire pixel to be much higher than the low reflectance of the surrounding pixels. Therefore, features that are much smaller than the resolution of the scanner can sometimes be found on the imagery or digital data. Figure 5 also shows that there were at least three different spectral classes of water present. Differences in water quality were cited by local contact personnel as the cause for the spectral differences observed in the reservoirs in this area. These water quality differences were not particularly obvious from the airplane, but did show up distinctly on the ERTS-1 imagery.
SUMMARY

The analysis of this first frame of ERTS-1 data resulted in detailed and, as nearly as could be determined, reasonably accurate sets of classifications of the various cover types present. We were also able to verify that the quality of the MSS (multi-spectral) scanner data was, for the most part, very good. The full frame of ERTS-1 data was classified and two sub-sets of the data were also classified. The preliminary classifications were followed by a field trip to obtain detailed information about the area, both on the ground and from the air. The field data thus obtained, along with information provided by Oklahoma agricultural and forest extension personnel, proved to be crucial for the final classifications. A combination of “unsupervised” (i.e., clustering) and “supervised” training statistics resulted in a final classification based on twenty spectral classes. This approach for the final classification was believed to be very effective. Less than two weeks elapsed between the time this first frame of digital ERTS-1 satellite data was obtained until the analysis, including the field trip, had been completed for the entire 12,000+ square mile area. This clearly demonstrated the potential for a rapid turn-around using such satellite data to obtain maps of large geographic areas.

REFERENCES
