DELINEATION OF IRRIGATED LAND USING LANDSAT IMAGERY[1]

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I. INTRODUCTION

The High Plains test site (fig. 1) is one of five areas selected in the State of Texas as part of the Applications System Verification and Transfer (ASVT) Project of the Texas Natural Resources Information System (TNRIS). This test site was chosen because the Texas Department of Water Resources (TDWR) needed timely information regarding water usage for irrigation in northwest Texas. The Test Plan for this project (Finley and Baumgardner, 1981) identified three objectives for the study of this test site: (1) identification of irrigated cropland, (2) definition of the spectral signature of drought-stressed vegetation, and (3) identification of broad crop categories. This report presents the results of work on the first objective, identification of irrigated cropland.

As set forth in the Data Collection Plan for this study (Finley and Baumgardner, 1980), Landsat imagery, aerial photographs, and ground truth data collected during the summer of 1980 are the data sources for this investigation. Initial efforts at delineating irrigated cropland focused on Swisher County, Texas, and applied a band ratio technique to Landsat data. The difference between Bands 7 and 5 was divided by the sum of the two bands: (B7 - B5)/(B7 + B5). This ratio was named the "vegetation index" (VI) by Rouse and others (1973, 1974). However, the use of the VI in this study was frustrated by software problems. Personnel from the U.S. Geological Survey, who

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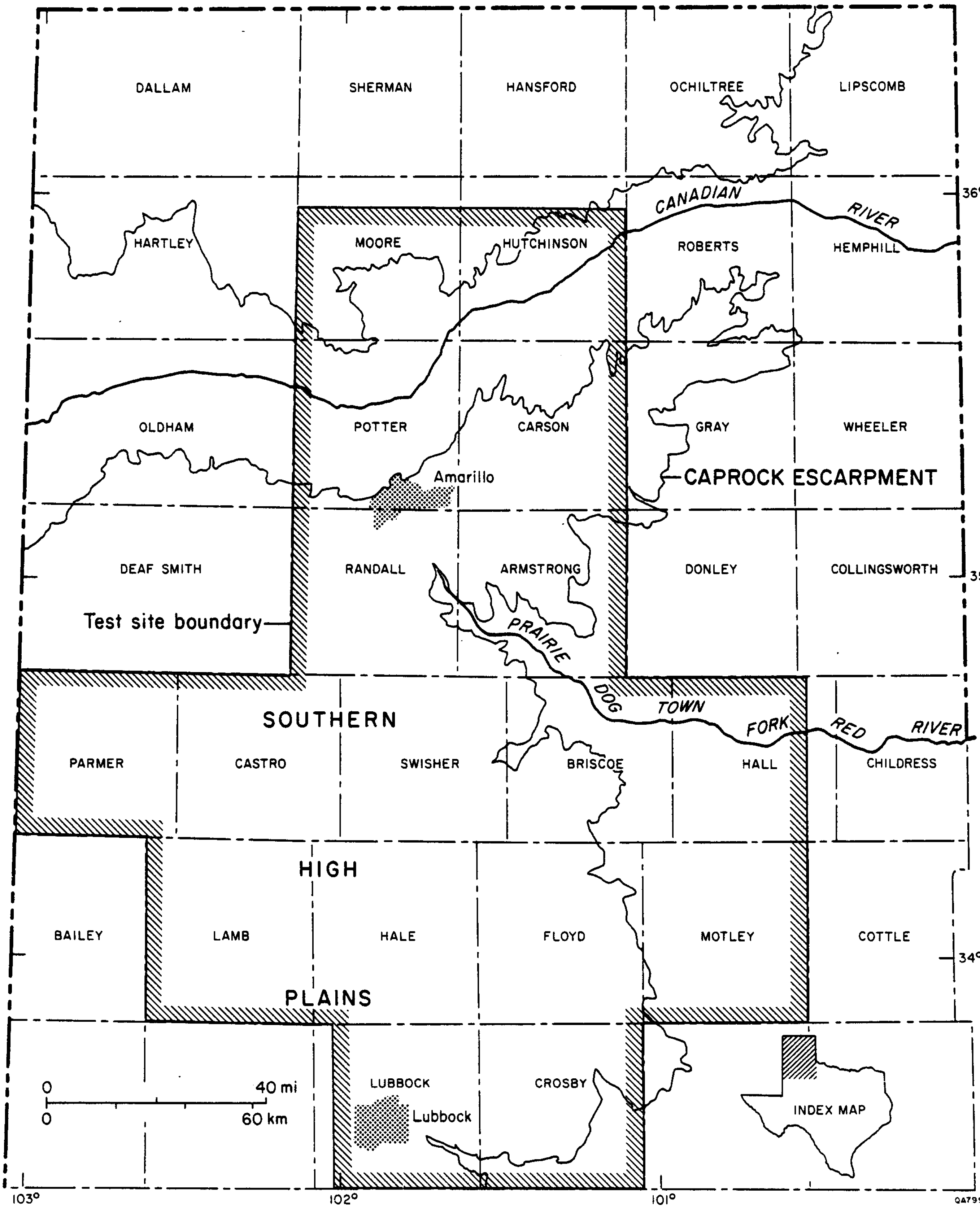

Figure 1. Location of study area in the Texas Panhandle. Aerial photographs of Parmer County were used during this study.

had been conducting a similar study for the entire High Plains region of the United States, suggested that a simpler band ratio might be more useful and that Parmer County might be a more suitable study area (Gail Thelin, Ames Research Center, personal communication, 1982). As a result, the study area was changed to Parmer County on the Texas-New Mexico border (fig. 1).

II. IRRIGATED CROPLAND, NEED FOR STUDY

In the High Plains of Texas (fig. 1), irrigation is an important part of the economic base of the region. Irrigated cropland in the High Plains accounted for 67 percent of the total irrigated land area in the State in 1979 (Texas Department of Water Resources, 1981). Most of the 5.2 million acres (2.1 million ha) were irrigated with 5.4 million acre-ft (6.7 km^3) of ground water pumped from the Ogallala aquifer. Depletion of the aquifer has already occurred where the saturated thickness is insufficient to sustain historical pumping rates (Texas Department of Water Resources, 1981).

Since 1958, inventories of irrigated land in Texas have been conducted about every 5 years by the Texas Department of Water Resources. In addition, as part of their annual county surveys, the Texas and U.S. Departments of Agriculture report irrigated acreage for selected crops (Texas Crop and Livestock Reporting Service, 1980, 1982). A more frequent inventory of irrigation would be useful for monitoring annual or even monthly irrigation patterns. Landsat data provide an opportunity for such monitoring. At present, the Landsat 4 satellite obtains data for a given location in the United States every 16 days. This repetitive coverage potentially enables an investigator to monitor the growth cycle of crops and, when used in conjunction with information on rainfall and cropping practices, to identify areas of irrigated land. In addition, the digital format of the Landsat data facilitates computation of areal extent of irrigated lands or other selected types of land cover or land use.

A remote sensing survey based on Landsat data should not be expected to replace ground surveys conducted on a farm-by-farm basis. Rather, the Landsat data can be used to supplement surveys conducted by mail (such as the Texas Crop and Livestock Survey) and to provide more frequent (perhaps annual) estimates than the detailed inventories now conducted every 5 years by the Texas Department of Water Resources.

III. METHOD OF STUDY

A. Multidate Landsat Survey

Landsat imagery data for three dates were used to identify irrigated lands (fig. 2). The images were chosen on the basis of digital data quality and on date of overpass to monitor the spring-summer irrigation period (table 1). The data used in this study were obtained by the Landsat 2 and Landsat 3 satellites on May 13, July 15, and August 29, 1980. A more complete survey could have included a winter scene showing irrigation of winter wheat.

Before analysis, the data were registered to U.S. Geological Survey topographic maps at 1:24,000 scale. The control network for each scene had about 10 control points. The satellite coordinates (line/sample) and Earth coordinates (latitude/longitude) were determined for each control point. This map registration made it possible to determine the Earth coordinates of any point in the study area.

B. Band Ratio

A simple band ratio technique was used to identify lands having dense vegetation cover. Spectral data from Landsat 2 and Landsat 3 satellites are collected in four bands, or parts of the electromagnetic spectrum (fig. 3). In this study, data from two of these bands, Band 5 (wavelength = 0.6-0.7 μm) and Band 7 (wavelength = 0.8-1.1 μm) were used in the following ratio: B7/B5. This ratio, termed the IR/red ratio, is sensitive to the amount of photosynthetically active vegetation present in the plant canopy (Tucker, 1979). Because green leaves have high reflectance values in Band

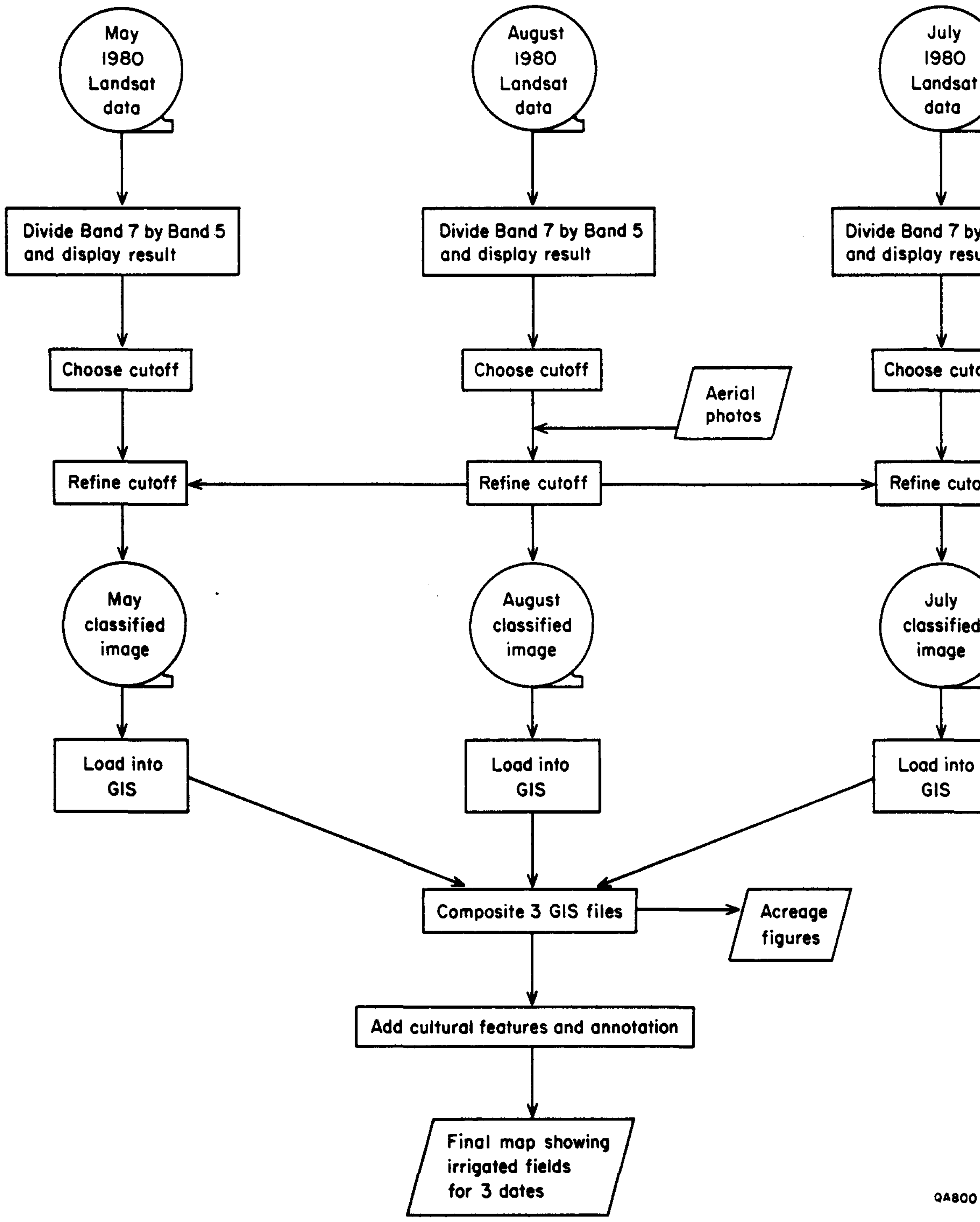

Figure 2. Data analysis procedure for delineation of irrigated lands. Before band ratioing, data were registered to U.S. Geological Survey topographic maps. Concurrent aerial photographs were available only for August scene. Acreage figures were derived for three separate dates and for the composite map.

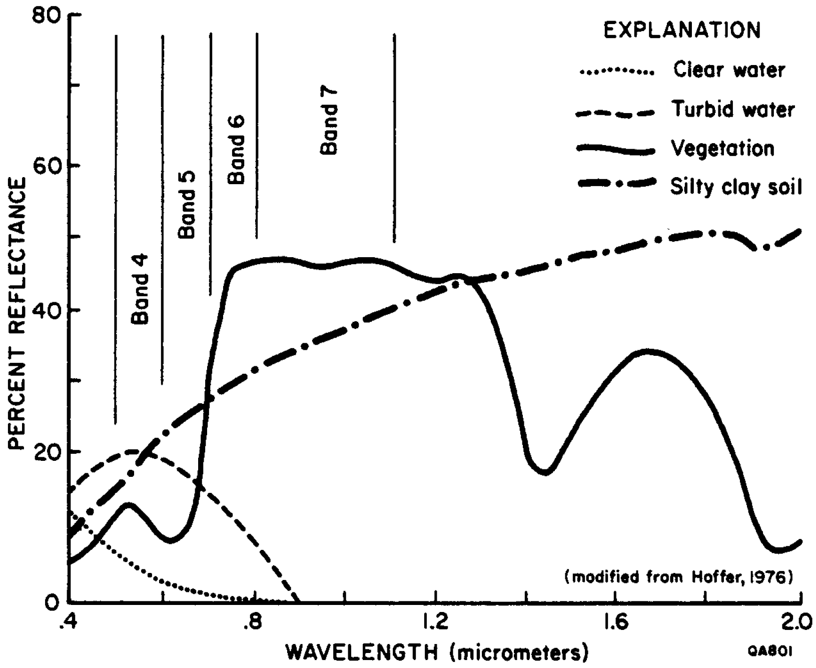

Figure 3. Spectral response of various land cover types. The four bands of the Landsat Multispectral Scanner (MSS) cover wavelengths from 0.5 to 1.1 micrometers. Note that vegetation has low reflectance in Band 5 and high reflectance in Band 7.

7 and low values in Band 5 (fig. 3), areas having dense leaf canopies will have high ratio values. Other land cover types will have lower ratio values, including wet, irrigated fields having very sparse leaf canopies.

The band ratio technique assigns each picture element (pixel) of the Landsat data a separate value. That part of the Landsat image covering just Parmer County has 707,138 pixels. The ratio values of these pixels were divided into 91 data value groups (fig. 4). The highest values corresponded to high band ratio values (B7/B5) and thick vegetation canopies. Low data values corresponded to low band ratio values and water or bare soil.

The next step in the data analysis was to choose the data value above which all pixels represented irrigated land. This value was named the cutoff value (fig. 2). This is discussed in the following section.

C. Define Irrigated Land

Irrigated land is defined, in this study, on the basis of a Landsat False Color Composite (FCC) image for each date. A visual comparison was made of the colors on the FCC, and the areas of brightest red color (and thickest vegetation cover) were designated irrigated land. This definition assumes that the thickest leaf canopies developed as a result of irrigation rather than rainfall. This assumption is partly supported by the sharp rectilinear boundaries between most red and non-red areas, which would not result from randomly distributed rainfall over similar types of crops. Similar techniques have been described by Gaydos (1979) and Keene and Conley (1980).

This definition of irrigated cropland differs markedly from that used by the Texas Department of Water Resources and the Texas Department of Agriculture. Those agencies consider land to be irrigated if water is applied to it by artificial means at anytime during the year. A field that received water only once before planting would be categorized as irrigated. In addition, if a field is irrigated during the production of two crops during the year, it is counted twice, once for each crop. Double-cropping

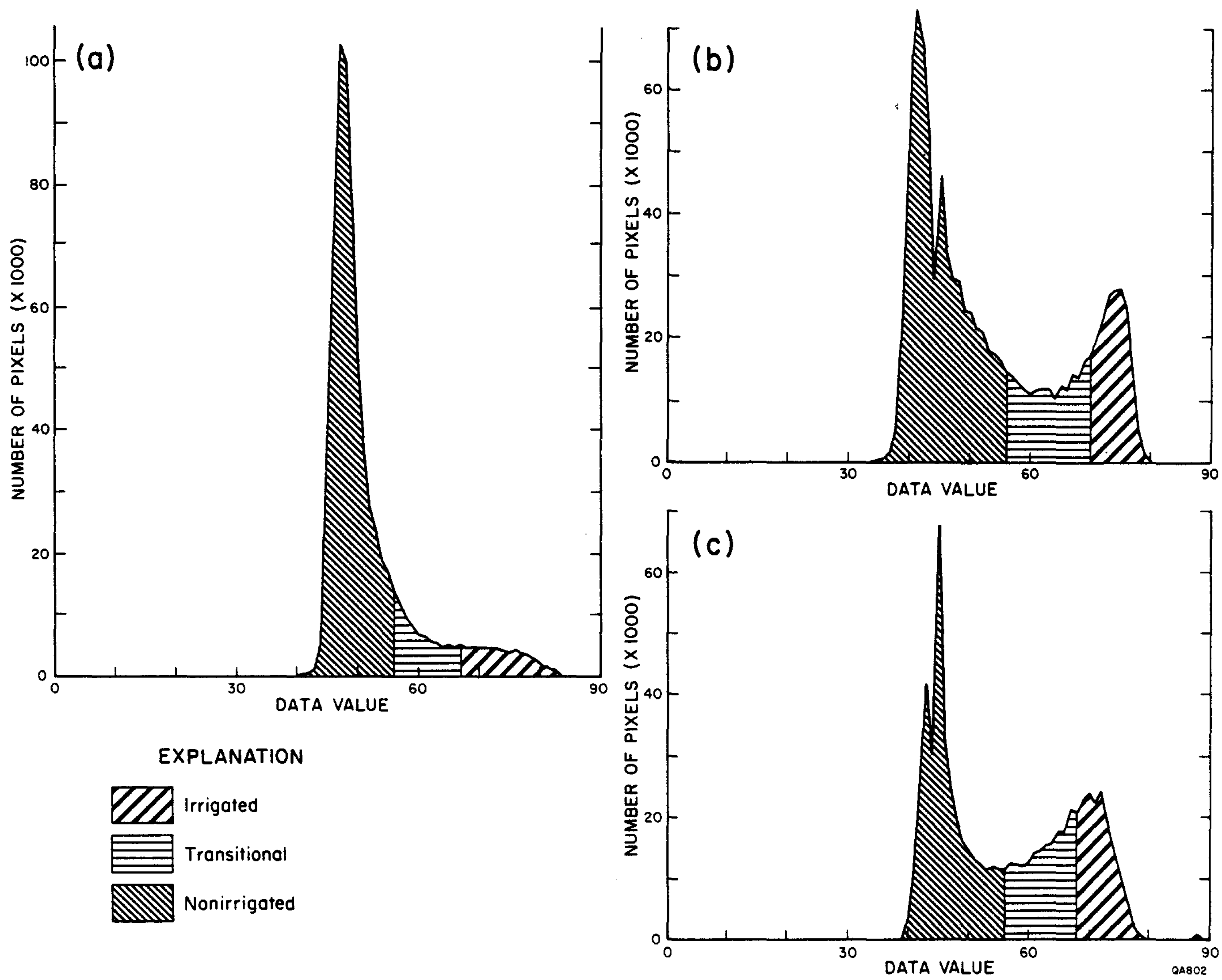

Figure 4. Histograms of band ratio data values from Landsat data for (a) May 13, 1980, (b) July 15, 1980, and (c) August 29, 1980. Band ratio is (B7/B5). Initial image analysis divided data values into three categories, as shown. Final image analysis reclassified transitional data values as nonirrigated.

amounted to 3,000 acres (1,214 ha) in Parmer County in 1979 (Texas Department of Water Resources, 1981). On the other hand, the Texas Department of Water Resources converts skip-row-planted crop acreages to equivalent solid-planted acreages if only the skip-row is irrigated. For example, a 100-acre (40-ha) irrigated field planted 2-in and 2-out would be recorded as 50 acres (20 ha) of irrigated cropland. This latter procedure, however, probably does not have a significant effect on total acreage for an entire county because most skip-row fields are not irrigated.

These differences in definition result in different estimates of irrigated acreage for Parmer County (table 2). This is not surprising because the band ratio technique (described previously) used on the Landsat data to delineate irrigated crops will not detect fields that are irrigated but do not have a well-developed leaf canopy, such as during pre-plant irrigation. Furthermore, we have used data for only three dates during the entire year, and irrigated crops grown in the fall and winter, such as wheat, are not included in the Landsat-derived figures.

Even when similar definitions of irrigated cropland are used, different results are obtained by different estimation methods. For example, the Texas Department of Water Resources relies on Soil Conservation Service personnel (of the USDA) based in each county to provide data about irrigated lands. In contrast, the Texas Crop and Livestock Reporting Service, of the U.S. and Texas Departments of Agriculture, mails questionnaires to a stratified sample of all the farmers in a county. The responses are extrapolated to the rest of the total (Archie Olson, U.S. Department of Agriculture, personal communication, 1983). Results from these two methods can be quite different. For example, for 1979 the estimates of irrigated acreage of cotton, grain sorghum, and wheat differ by as much as 88 percent (table 2).

D. Delineate Irrigated Land

After the Landsat data were divided into 91 data value categories, they were assigned various levels of gray and were displayed on a color television display

Table 1. Landsat imagery used in this study. Path/row coordinates for all images are 33/36. Highest value of digital data quality is 9. On the basis of a comparison with data for July 15, the missing data for August 29 are probably not significant (figs. 6 and 7). Data values refer to band ratio results (fig. 4).

Date (1980)	Image ID No.	Cloud Cover	Digital Data Quality				Data Values		Comments
			B4	B5	B6	B7	Nonirrigated	Irrigated	
May 13	E-30800-16395	0%	9	9	9	9	1-66	67-90	
July 15	E-22001-16453	10%	9	9	9	9	1-69	70-90	
Aug. 29	E-30908-16355	10%	9	9	9	9	1-67	68-90	Landsat line-start problem. 19 mi^2 in NW. corner lost

Table 2. Estimates of irrigated cropland in Parmer County, Texas. Data from 1979, the most recent year for which detailed data are available from both agencies, are included. The USDA figures are for acres harvested, which are slightly less than acres planted for the same year. Percent difference is expressed in terms of USDA figures.

Crop	1979 Irrigated Area (acres)			1980 Irrigated Area (acres)		
	USDA	TDWR	Percent Difference	USDA	TDWR	This Study
Corn	+	238,100		135,000	+	+
Cotton	50,000	43,500	14	67,300	+	+
Grain sorghum	22,800	27,300	20	21,600	+	+
Sugar beets	+	2,100		4,300	+	+
Wheat	43,400	81,535	88	53,000	+	+
Other grain	+	11,197		+	+	+
Miscellaneous	+	17,254		+	+	+
Total	+	420,986		325,000*	325,747*	129,220

*Includes acreage for crops not listed in table or in source.

+Data not available.

screen (fig. 2). The analyst then sequentially changed the colors for each data value from gray to yellow-green for non-irrigated land and from gray to red for irrigated land. Color assignments were made by comparing the data on the screen with the Landsat FCC for the same date. Areas that showed up as bright red on the FCC were changed to red on the screen.

The analyst approached the cutoff between nonirrigated and irrigated land from opposite ends of the histogram (fig. 4). As the cutoff point was approached, data values were temporarily assigned a third color, defined as transitional, between the irrigated and nonirrigated classes. Final determination of the cutoff point for the August 29 image was made by enlarging parts of the image on the display screen and comparing them with aerial photographs made on August 31, 1980, approximately concurrently with the Landsat overpass on August 29 (fig. 2). The transitional data values were then reclassified as either irrigated or nonirrigated (table 1).

Only selected areas of the entire area were checked because the same cutoff value applied to the entire county. Using the same criterion to define irrigated land over the whole county ensured that the data were interpreted uniformly.

The color scheme that was determined by this method was used on images from the other two dates of Landsat data. The cutoff was then changed, if required, by comparing the image on the screen with the Landsat FCC for the same date. No aerial photographs were made concurrently with the Landsat overpasses in May and July.

Comparison with aerial photographs helped the analyst to refine his/her decision regarding field boundary positions made on the smaller scale images. At this stage, most large (>20 pixels) fields were already classified as irrigated or nonirrigated, and all that remained to be done was to smooth boundaries by classifying transitional pixels along the borders between irrigated and nonirrigated fields.

In short, this procedure created a larger scale FCC image that had only two categories (table 1). In this study, there was no independent confirmation that red fields were irrigated. However, the sharp boundaries between red fields and adjacent fields of other colors on the FCC image supports the assumption that the leaf canopy, which the red color represents, is a product of irrigation, not precipitation.

E. Smoothing

After the cutoff values were determined for each of the three dates, the resulting data were "smoothed" to remove small anomalous areas. For example, small areas classified as nonirrigated because of local water stress or retarded canopy growth were removed from the middle of an irrigated field. Conversely, local water conditions may have fostered leaf canopy development in a nonirrigated field, giving a response that resembled that of irrigated crops. A minimum value for the size of a field was chosen, and all fields that size or smaller were reclassified to the surrounding color. The minimum size in this study was 20 pixels, which approximates 20 acres (8 ha). Very few, if any, fields of 20 acres or less are irrigated.

F. Compositing

The data for each date that resulted from smoothing were stored in the Geographic Information System (GIS), then plotted on a previously stored cultural base map of Parmer County. Data for each date were displayed separately (figs. 5-7), then were combined to produce a single map that showed the total irrigated area for all three dates (fig. 8). Any field that was irrigated on more than one date was counted only once in the final total.

III. RESULTS

The amount of irrigated land increased from 39,156 acres (15,853 ha) on May 13 to 101,913 acres (41,260 ha) on July 15, and the amount increased again to 116,745 acres (47,265 ha) on August 29. Because some of the fields irrigated on one date were also irrigated on the other dates, the sum of the separate amounts for each date does not represent the total amount of irrigated land for all three dates.

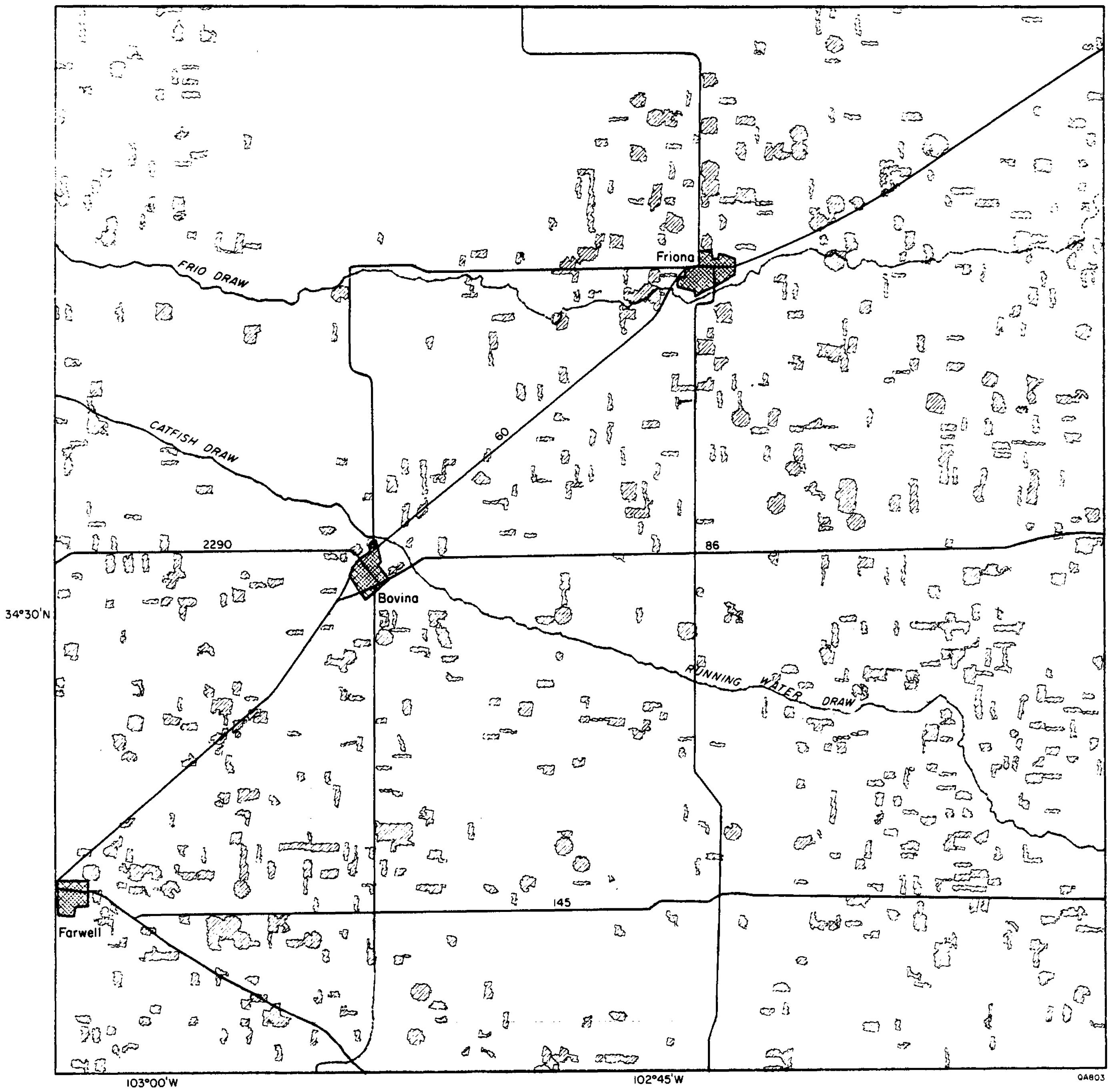

Figure 5. Irrigated land in Parmer County, Texas, May 13, 1980. Sum of irrigated fields larger than 20 acres (8.1 ha) is 39,156 acres (15,853 ha).

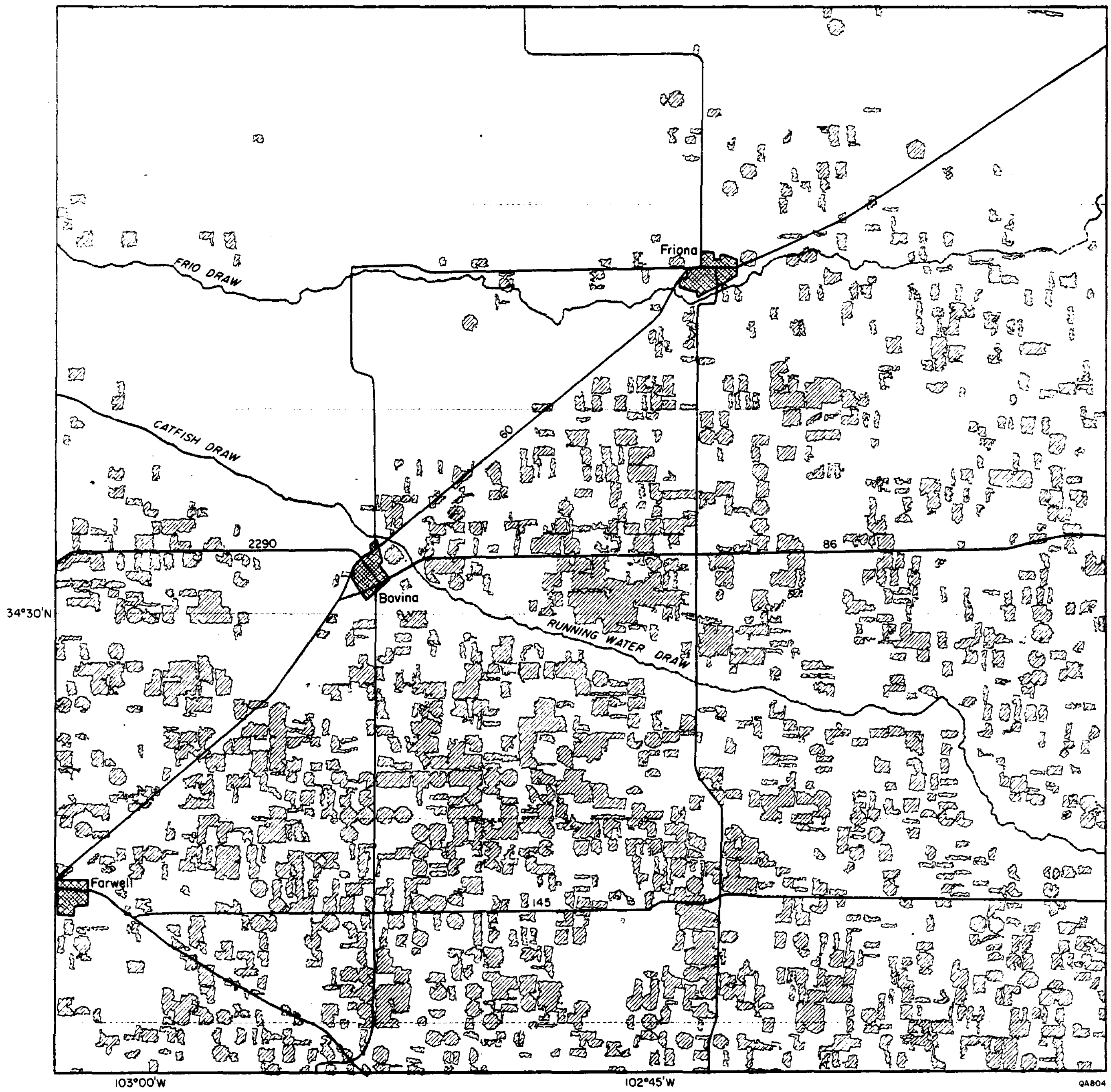

Figure 6. Irrigated land in Parmer County, Texas, July 15, 1980. Sum of irrigated fields larger than 20 acres (8.1 ha) is 101,913 acres (41,260 ha).

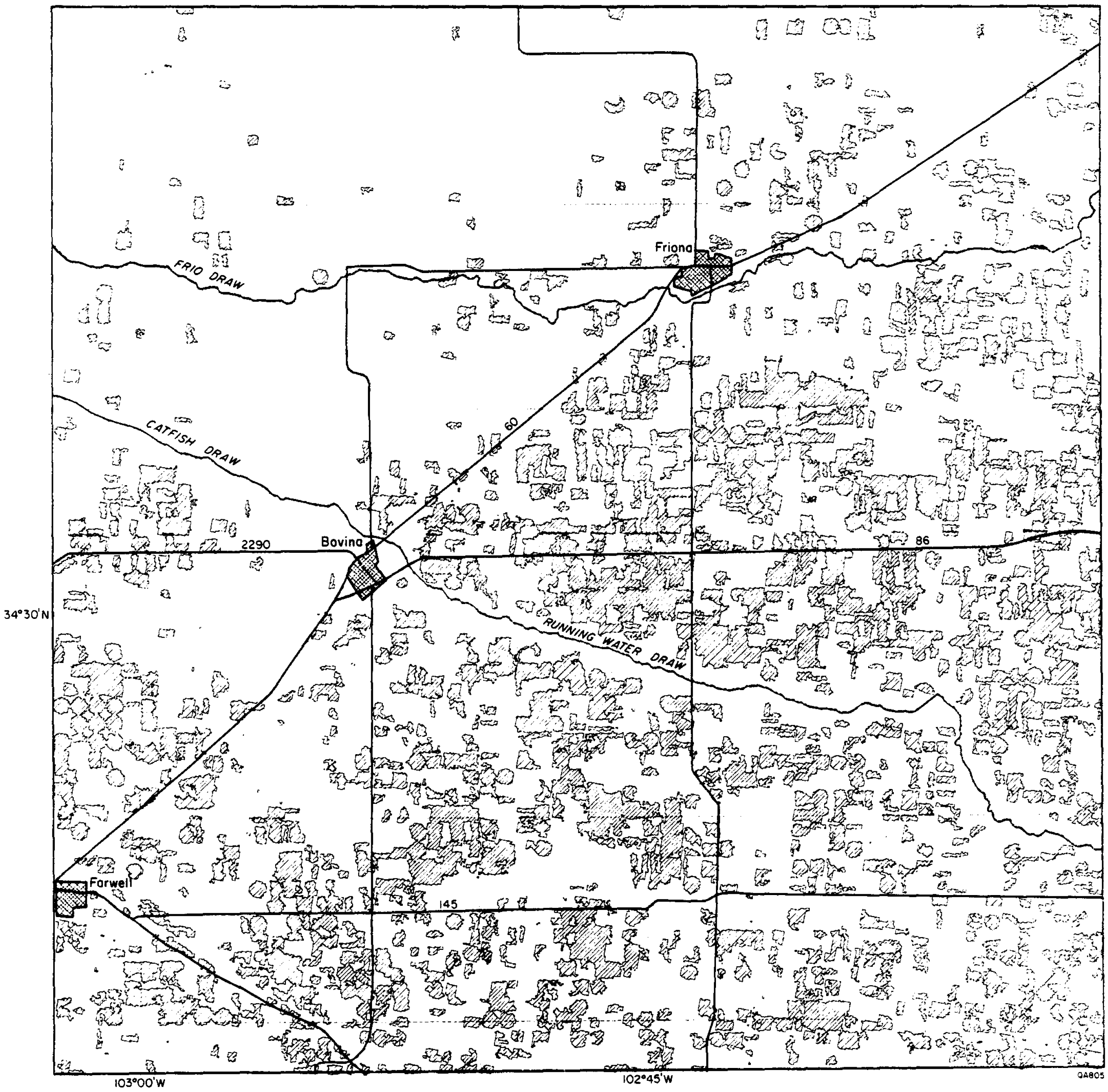

Figure 7. Irrigated land in Parmer County, Texas, August 29, 1980. Sum of irrigated fields larger than 20 acres (8.1 ha) is 116,745 acres (47,265 ha).

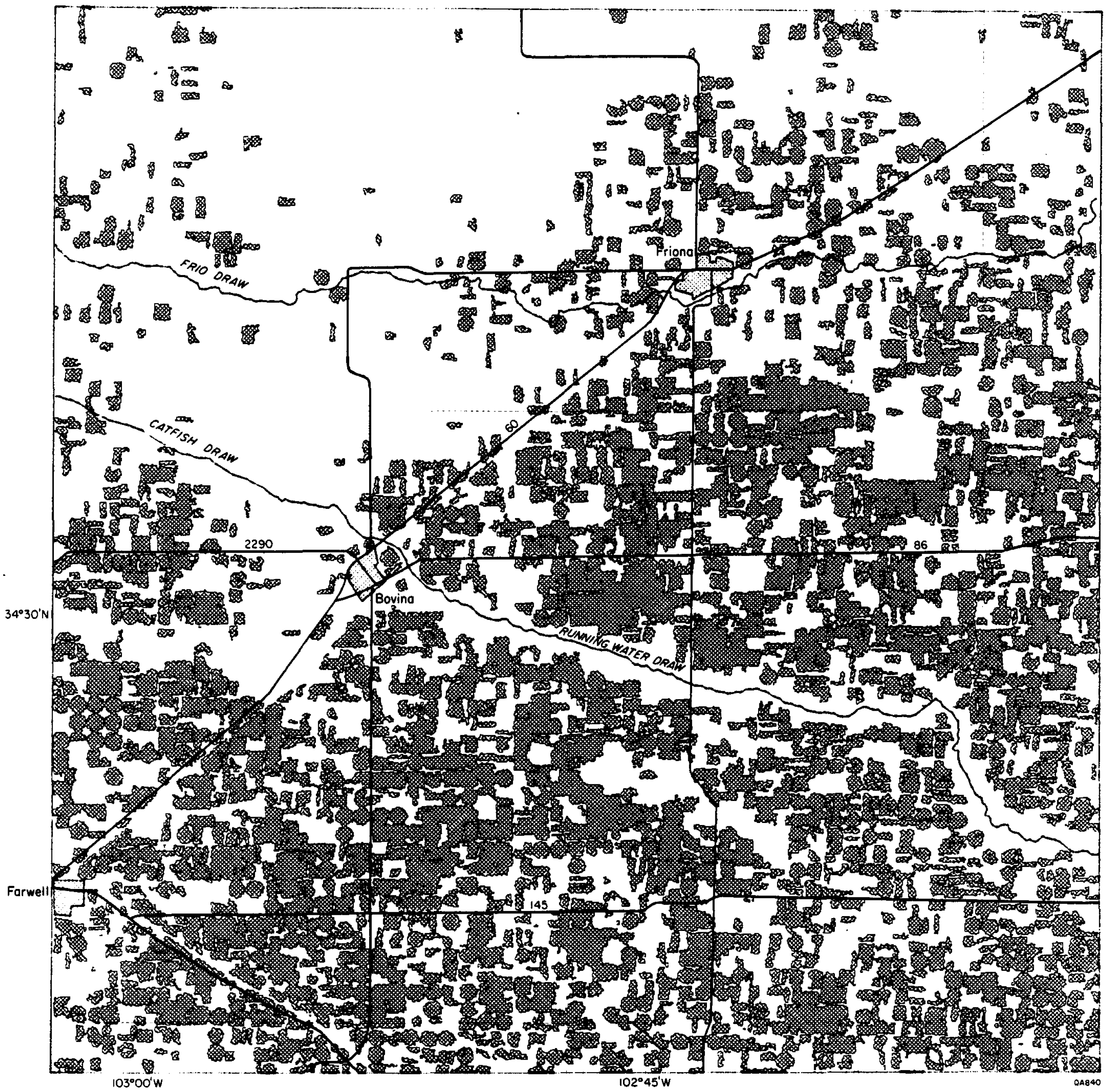

Figure 8. Composite map of irrigated land in Parmer County, Texas. All fields larger than 20 acres (8.1 ha) from three dates--May 13, July 15, and August 29, 1980--are shown. Sum of irrigated fields is 129,220 acres (52,320 ha).

The total amount of irrigated land for the three dates was obtained by using the Geographic Information System (GIS). The system was used to tally the irrigated land, eliminating any overlap from the total, and to produce a composite map (fig. 8) that shows all land that was irrigated on any of the three dates. The total area of different fields irrigated on those three dates is 129,220 acres (52,320 ha).

This estimate of irrigated area is the lowest of the three reported in table 2. Two reasons for the difference between this and the other estimates have already been mentioned. First, this study covers only the spring-summer irrigation period; therefore, any crop irrigated in fall or winter would not have been included. Second, land that was irrigated during the spring or summer but did not have a thick vegetation canopy on the three dates examined in this study would not have been counted as irrigated.

IV. CONCLUSIONS

This study indicates that an inventory of irrigated land in the High Plains of Texas based on Landsat data is a feasible supplement to present inventory methods and has two distinct advantages: timeliness and mappability. Results of irrigation inventories are not available until the beginning of the next calendar year, at the earliest (Archie Olson, U.S. Department of Agriculture, personal communication, 1983). A multidate Landsat inventory of a given county or other area of similar size (1,000 mi^2 [2,590 km^2]) could be completed, with the present TNRIS and GIS equipment and personnel, about 3 months after the data from the last overpass are received. Individual dates could be analyzed in about half that time. In addition, the growth of irrigated vegetation could be monitored throughout the growing season using the repetitive coverage of Landsat imagery. This is not possible using any of the present inventory methods.

The present inventory methods do not report location of irrigated fields, only total acreage per county. Field checking would be very time consuming. By using the map-registered Landsat imagery, the analyst can determine the latitude and longitude of any point in the scene and can locate irrigated field boundaries within $\pm$ 260 ft (79 m). This is accurate enough to pinpoint individual fields because most are much larger than 260 ft on a side or 1.6 acres (0.6 ha) in area.

In addition, historical studies of water use can be made by using Landsat data from any year since 1972. By combining rainfall data and archival ground truth data with Landsat data, one can supplement historical records of those years for which no irrigation inventories were made.

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