Determination of land use and irrigated crop acres by remote sensing

Enhanced Thematic Mapper Plus (ETM+) (U. S. Geological Survey, 2002a) imagery was used to map land use and irrigated croplands during the 2000 growing season. Land use was mapped using a supervised clustering algorithm based on statistical signatures for 25 pixel classes (table 3). Ancillary information from the National Land Cover Dataset 1992 (NLCD) (U.S. Geological Survey, 2002b) and ground reference crop data from the FSA county offices were used to aid in the development of spectral signatures used to classify pixel classes. The NLCD is categorized into broad land-cover types and identifies three classes of agriculture: row crops, small grains, and hay/pasture. These classes were used as an ancillary data source to aid in the crop delineation.

Irrigated crop acres were determined using a ratio vegetation index consisting of a near infrared band (band 4) divided by a visible red band (band 3) ratio to create the vegetation index (Qi and others, 2002). The near infrared band and visible red band ratio enhances certain features such as greenness of vegetation not generally visible. The resulting images consisted of a single gray-scale band with bright white pixels representing irrigated crop acres (fig. 2). Non-irrigated vegetation was displayed as ranges of gray. A threshold value was selected at which everything greater than that value was considered to be irrigated; everything less than that value was considered to be non-irrigated. Threshold values were selected for each Landsat scene based on the radiometric balancing applied to each Landsat scene. Some editing was required to remove riparian areas or to add known irrigated agriculture that was less than the threshold value. Appendices 1 through 10 provide county-specific information on the number of pixels and number of acres for 25 land use classes in parts of each county in the drainage basin determined from the mapping process. A null pixel class is listed in the appendices and represents the part of a county that is outside the portion of the drainage basin in the county.

Identification of crop types with Landsat 7 ETM+ satellite imagery is a routine application of remote sensing technology. Image date selection is vital for successful identification of many vegetation covers, especially agricultural crops (Rundquist and others, 2002). Identification of agricultural crops using satellite imagery requires knowledge of crop phenology, climate for the particular growing season, and ground reference information about specific agricultural practices in the drainage basin. The best date range to identify winter wheat is between late March through early May, when wheat is at peak greenness. To identify corn and other summer crops, the best date range is late July to mid-August.

The original study plan was to use the same imagery used in the generation of the NLCD and in the High Plains Aquifer study (Qi and others, 2002) because two dates were used, a winter leaf-off date and a summer leaf-on date. However, these dates were less than optimal for crop delineation. The dates for the selected imagery used for this report were selected to occur

Table 3. Categories of pixel classes used to define land use and irrigated crop acres in the Lake Altus drainage basin during the 2000 growing season

Croplands	General land use	Irrigated croplands
Alfalfa	Fallow	Alfalfa
Corn	Grasslands	Corn
Cotton	Trees	Peanut
Cowpeas	Urban	Sorghum
Hay/Pasture	Water	Soybeans
Oats	Unknown crops	Wheat
Peanut	Unknown irrigated	
Rye		
Sorghum		
Soybeans		
Sunflowers		
Wheat		

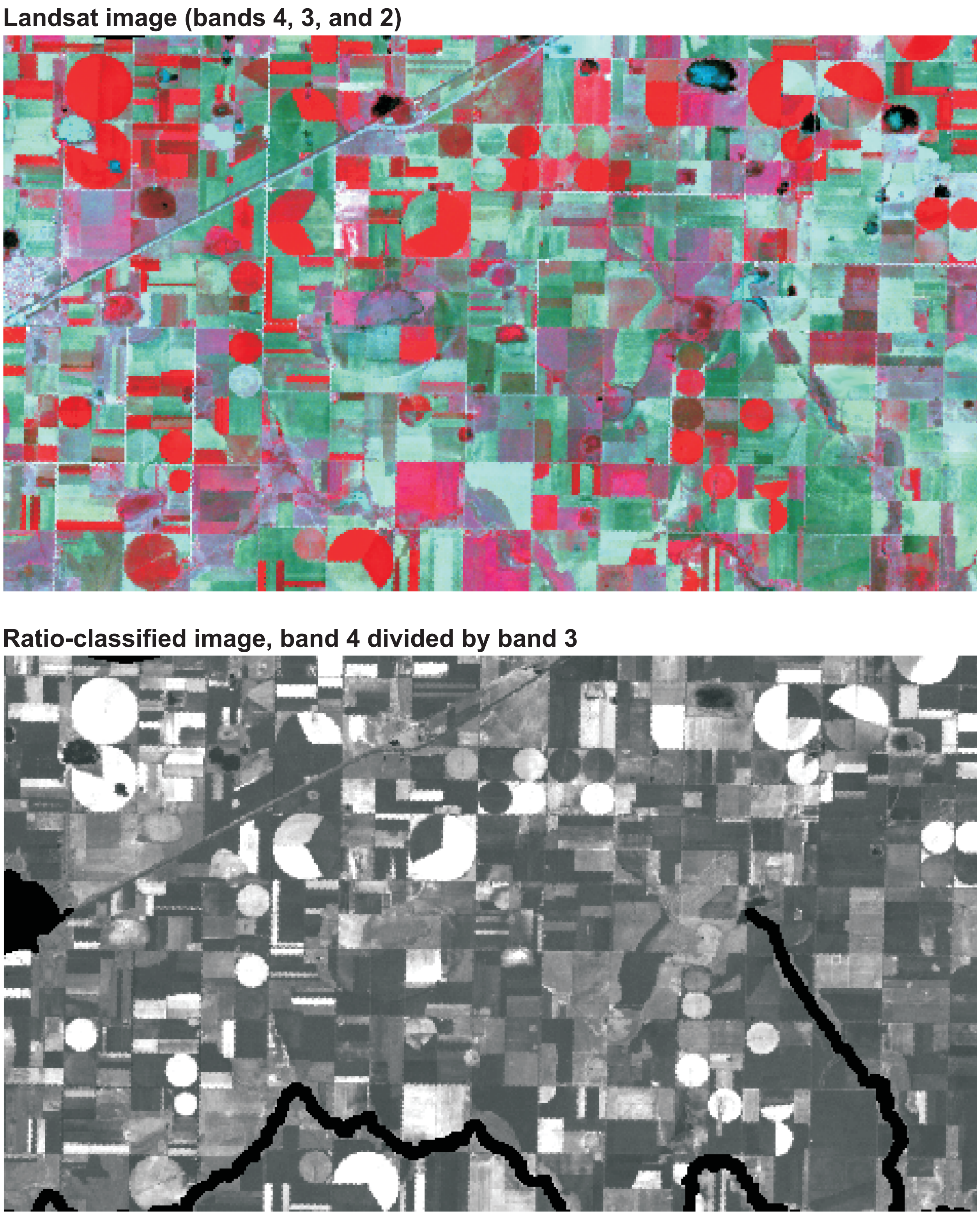

Figure 2. An example of a ratio-classified image. The brightness of pixels represents values for the ratio of band 4 to band 3. The brighter the pixel, the higher the ratio and the healthier and greener the vegetation.

Figure 3. Locations and names of Landsat scenes used to acquire Landsat 7 Enhanced Thematic Mapper Plus imagery.

during peak greenness periods for both winter wheat and summer crops. The Lake Altus drainage basin spans four Landsat scenes used to acquire ETM+ images, Path/Row 30/35,36 and Path/Row 29/35,36 (fig. 3). Two dates were originally selected for analysis. A spring date (Path/Row 30/35,36 – 5/20/2000, Path/Row 29/35,36 – 5/13/2000) to map the winter wheat and a summer date (Path/Row 30/35,36 – 7/23/2000, Path/Row 29/35,36 – 8/1/2000) to map the remainder of the crops in the basin. Imagery from a third date (Path/Row 30/35,36 – 4/18/2000, Path/Row 29/35,36 – 3/26/2000) was analyzed because the winter wheat green-up was earlier in the season, which caused harvesting to occur earlier than normal in Texas counties. The 2000 growing season was selected because it was extremely dry all season in the Texas counties and dry in the fall, winter, and late summer in the Oklahoma counties. Therefore, more irrigation was required than in a normal growing season, thus enabling better delineation between irrigated crops and non-irrigated cropland and rangeland.

Preprocessing

The ETM+ is a multispectral scanning radiometer that is carried on the Landsat 7 satellite. The ETM+ radiometer provides data from eight spectral bands and can be ordered in varying levels of calibration. Systematic correction Level 1G images were used for this report. The Level 1G product incorporates both a radiometric and geometric correction to images. The images are rotated to north, aligned, coarsely georeferenced to the Universal Transverse Mercator (UTM) projection, and resampled to 28.5-meter pixel resolution using a nearest neighbor algorithm (Research Systems Incorporated, 2001). Two of the spectral bands are eliminated from processing: spectral band 1 because of data redundancy and thermal spectral band 6 because it measures transmitted energy (the other bands measure reflected energy).

The images were referenced to the UTM projection and projected to fit the Albers equal-area projection. Individual image scenes were merged and cropped to the basin boundary to speed and facilitate processing. The final classification images consisted of three composite images for the study area two in early spring to map winter wheat and one in summer to map the remaining crops. Mapping of land use and irrigated croplands was done in two stages. The first stage consisted of determining land use, the second stage consisted of determining specific irrigated crops.

Ground-reference data were compiled from FSA and NRCS county offices for each county in the basin using a ran-

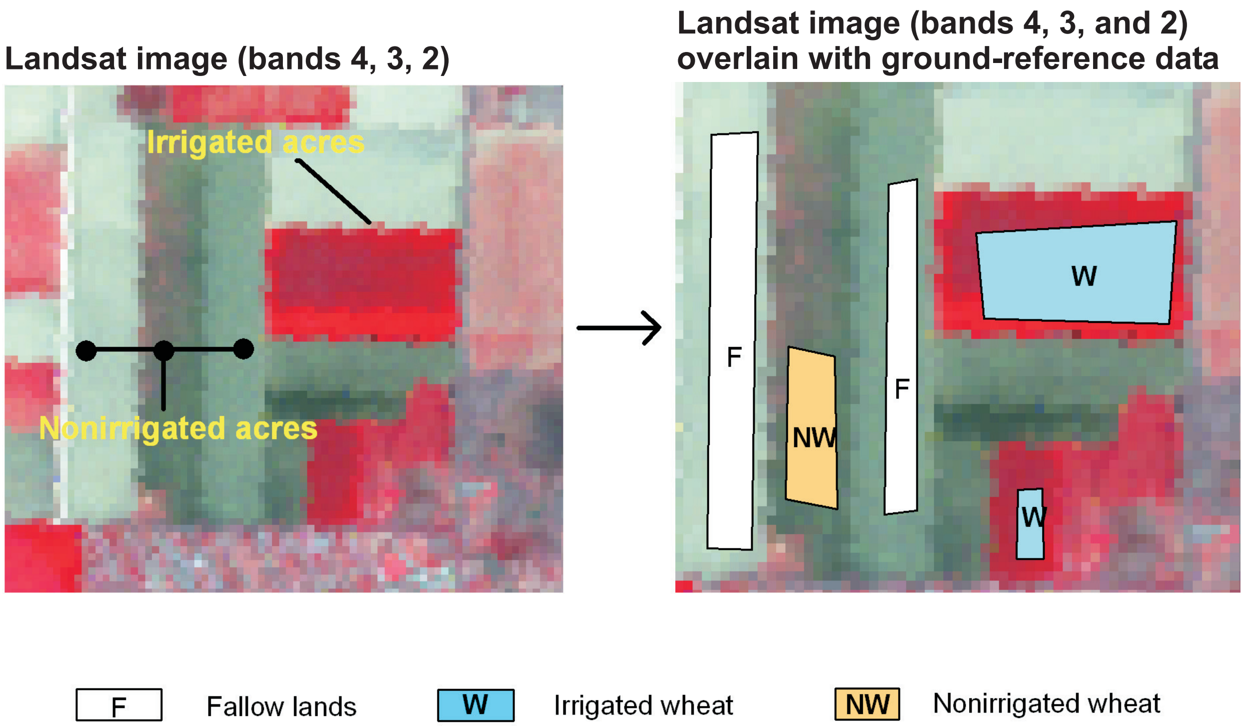

Figure 4. Example of ground-reference data used to overlay and classify imagery.

dom approach. A random selection of points was generated for areas known to be, or thought to be, irrigated in the drainage basin. Maps of these areas were sent to each FSA county office in the drainage basin. County offices were asked to identify the crop types and irrigation status. The data were generally provided as an annotated photocopy of the office aerial photograph of the particular field in question. The field boundaries were then digitized using the satellite image and annotated with the comments provided by the FSA office (fig. 4). Half of the returned ground-reference data were used in the generation of training signatures and the other half were used for accuracy assessment at the end of the analysis.

Accuracy Assessment

An accuracy assessment of the cell classifications was completed for the drainage basin using ground-reference data. Segments from four counties (Beckham, Carson, Gray, and Greer) were used for the assessment. Confusion matrices (probability matrices of land-use classes) were generated using the final classified image and the accuracy segments. An accuracy of 69.6960 percent with a kappa coefficient of 0.0007 was achieved. The low kappa coefficient was a result of the low number of accuracy segments and the lack of representation of all classes in the final classified image. In addition to the class confusion matrix, errors of commission/omission, producer and user accuracies also were examined.

Suggestions to Increase Accuracy

Two of the primary determinants of accuracy in defining irrigated crops are the dates of the Landsat images and number of the ground-reference data samples. To correlate the peak growth of individual crops with the best Landsat image date, there must be sufficient ground-truth data regarding the distribution of crop types and irrigation practices. Required information includes: (1) date of planting and harvest in order to interpolate the dates of peak growth and greenness, and (2) number of harvested acres for each crop by county to determine the number of ground-truth data to collect for each crop. With knowledge of peak greenness of each crop in a given season, the number of Landsat image dates can be better determined. For example, the peak greenness for corn during the 2000 growing season may have been in mid-June, but peak greenness for soybeans may have been in early June. In that case, two Landsat image dates would be required to achieve the greatest accuracy in determining irrigated crops.

Limitations of Landsat

Even with the correct date selection and ground-reference data, there are limitations to using Landsat multispectral satellite imagery because of limitations of spectral range and spatial resolution (5 multispectral bands at 30-meter spatial resolution). Some agricultural crops or vegetation species are too spectrally similar to be differentiated by Landsat. Hyperspectral sensors with broader spectral ranges and higher spatial resolutions may enable greater distinction of vegetation classes. With multispectral sensors such as Landsat, there are only 5 broad spectral bands (0.45 – 1.75 micrometers (µm)) of recorded information; hyperspectral sensors can range from 36 to 224 spectral bands (0.45 – 2.5 µm) of recorded information. With increased spectral range and spatial resolution, it is possible to identify subtle changes in chlorophyll absorption that relate to different vegetation species and health of a vegetation species. Currently, most hyperspectral sensors are on airborne platforms such as Advanced Visible Infrared Imaging Spectrometer (AVIRIS) and Compact Airborne Spectrographic Imager (CASI), but the number of satellite-borne hyperspectral platforms such as Hyperion are increasing. Presently (2002), there are two high spatial-resolution satellites (IKONOS and QUICKBIRD) with 4-meter multi-spectral sensors.

Remotely Sensed Irrigated Crop Acres

Remotely sensed irrigated crop acres were determined for portions of the following Oklahoma counties in the Lake Altus drainage basin: Beckham, Greer, Kiowa, Roger Mills, and Washita. Beckham County had the greatest number of irrigated crop acres, followed by Roger Mills, Greer, Kiowa, and Washita (table 4). Alfalfa, peanuts, and wheat were the only crops determined to be irrigated in the five counties. Irrigated acres of alfalfa, peanuts, and wheat were greatest in Beckham County. A total of 70 percent of irrigated wheat, 68 percent of irrigated alfalfa, and 51 percent of irrigated peanuts in the Oklahoma counties occurred in Beckham County.

Remotely sensed irrigated crop acres were determined for the following Texas counties: Carson, Donley, Gray, Potter, and Wheeler. Although a small portion of Randall County is included in the drainage basin, there were no reported irrigated crop acres in that county. Carson County had the greatest number of irrigated crop acres followed by Gray, Wheeler, Potter, and Donley (table 4). Irrigated acres of corn, sorghum, soybeans, and wheat were greatest in Carson County. A total of 92 percent of irrigated sorghum, 63 percent of irrigated corn, 51 percent of irrigated wheat, and 49 percent of irrigated soybeans in Texas counties occurred in Carson County. Wheeler County had the largest number of irrigated alfalfa acres, representing 94 percent of the irrigated alfalfa in Texas counties.

Seventy-four percent of the total irrigated crop acreage in the drainage basin occurred in Texas counties. One hundred percent of irrigated corn, sorghum, and soybeans in the drainage basin occurred in Texas. Eighty-nine percent or 38,677 acres of irrigated wheat occurred in Texas. Irrigated peanuts and irrigated alfalfa acres were greater in Oklahoma than in Texas. Eighty-one percent or 13,768 acres of irrigated alfalfa and 71 percent or 1,583 acres of irrigated peanuts were in Oklahoma.

There were 43,686 acres of irrigated wheat, or 56 percent of the total irrigated crop acres in the drainage basin (fig. 5). Irrigated alfalfa consisted of 22 percent of the total irrigated crop acres in the drainage basin, irrigated corn consisted of 11 percent, and irrigated soybeans consisted of 6 percent. The remaining 5 percent of irrigated crop acres in the drainage basin consisted of peanuts and sorghum.

Irrigated crop acres from state water boards

Irrigated crop acres from the OWRB and the TWDB were compiled and summarized for the 2000 growing season. The OWRB collects irrigation information in Oklahoma about specific irrigated crops by county and by 8-digit HUC watershed. Mail survey forms are sent out annually to registered water users. Approximately 66 percent of registered water users complete and return the irrigation surveys sent out by the OWRB (Phyllis Robertson, Oklahoma Water Resources Board, oral commun., 2002). Irrigated acres from the OWRB were compiled for portions of Oklahoma counties in the Lake Altus drainage basin (fig. 1) (Phyllis Robertson, Oklahoma Water Resources Board, written commun., 2002).

The TWDB collects water use and irrigation information for Texas using two survey compilation methods. The first survey reporting method collects information annually regarding the sum of irrigated acres in a county and by 8-digit HUC watershed, but not specific information about individual crops that are irrigated. The second survey is a detailed irrigation survey and is a cooperative effort between the NRCS, U.S. Department of Agriculture, the Texas State Soil and Water Conservation Board, and the TWDB. This detailed survey is conducted at 5-year intervals (Texas Water Development Board, 2000). Specific information about irrigated crop acres are recorded on a countywide basis, but not on a watershed basis. A detailed irrigation survey was conducted in Texas counties during the 2000 growing season.

Irrigated crop acres in the drainage basin for Donley, Gray, Potter, Randall, and Wheeler Counties in Texas were determined by dividing the portion of drainage basin in a county by the total area of the county and multiplying the result by the total irrigated crop acres in each county. Because the majority of irrigation in Carson County occurred in and around the drainage basin, a boundary was digitized outlining the area in Carson County where the majority of agriculture was present and irrigation was being applied. The irrigated crop acres in the drainage basin for Carson County were determined by dividing the portion of the drainage basin in the county by the digitized area instead of the total area of Carson County and multiplying

Table 4. Irrigated crop acres derived from remote sensing techniques and Landsat imagery for portions of counties in the Lake Altus drainage basin during the 2000 growing season

[–, not determined]

Counties	State	Irrigated crops (acres)						
		Alfalfa	Corn	Peanuts	Sorghum	Soybeans	Wheat	Total
Beckham	Okla.	9,297	–	807	–	–	3,490	13,594
Greer	Okla.	1,719	–	225	–	–	599	2,543
Kiowa	Okla.	691	–	225	–	–	440	1,356
Roger Mills	Okla.	2,003	–	315	–	–	470	2,788
Washita	Okla.	58	–	11	–	–	10	79
Total	**Okla.**	**13,768**	**0**	**1,583**	**0**	**0**	**5,009**	**20,360**
Carson	Tex.	1	5,573	0	1,897	2,360	19,650	29,481
Donley	Tex.	0	200	0	1	66	55	322
Gray	Tex.	187	2,792	0	149	1,407	11,986	16,521
Randall	Tex.	–	–	–	–	–	–	–
Potter	Tex.	1	1	0	7	42	2,239	2,290
Wheeler	Tex.	3,002	266	646	15	962	4,747	9,638
Total	**Tex.**	**3,191**	**8,832**	**646**	**2,069**	**4,837**	**38,677**	**58,252**
Basin Total		**16,959**	**8,832**	**2,229**	**2,069**	**4,837**	**43,686**	**78,612**

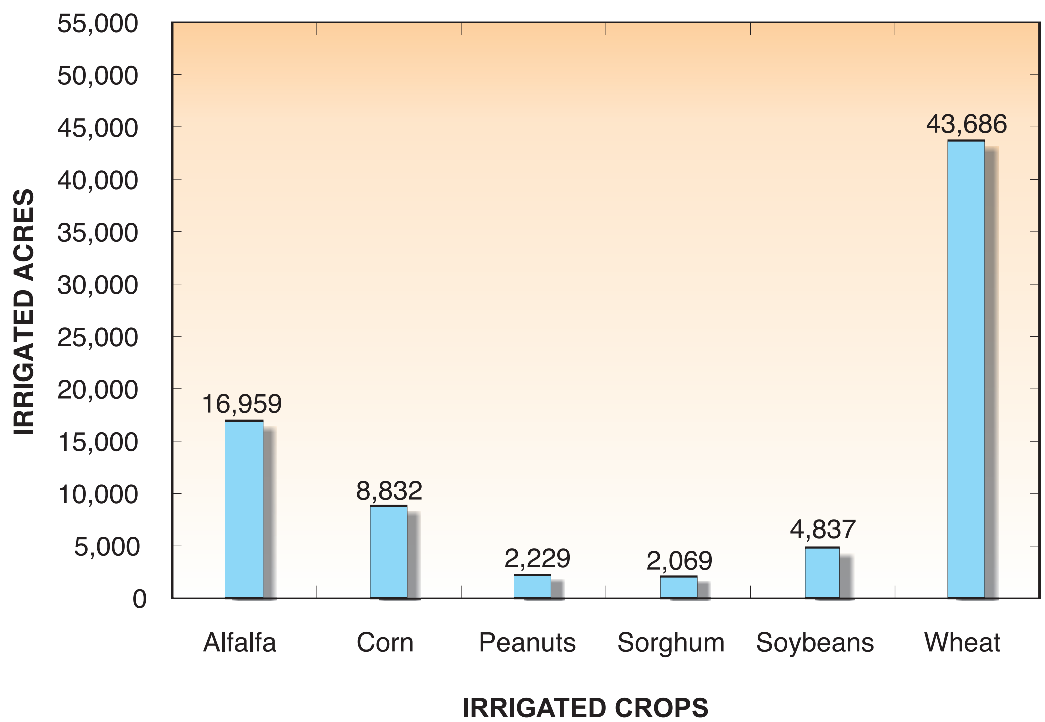

Figure 5. Irrigated crop acres in the Lake Altus drainage basin during the 2000 growing season, determined using remote-sensing techniques and Landsat imagery,

the result by the total irrigated crop acres in the county.

In the Oklahoma portion of the drainage basin, Beckham County had the greatest number of reported irrigated crop acres, followed by Greer, Kiowa, and Roger Mills (table 5). There were no irrigated crop acres reported for the portion of Washita County in the drainage basin. Alfalfa, corn, cotton, hay, peanuts, sorghum, and wheat were reported irrigated in the five Oklahoma counties. A total of 69 percent of irrigated hay, 64 percent of irrigated sorghum, 62 percent of irrigated peanuts, 53 percent of irrigated wheat, and 51 percent of irrigated alfalfa in Oklahoma counties occurred in Beckham County. A total of 99 percent of irrigated corn was reported in Kiowa County with 385 acres. Irrigated cotton was greatest in Roger Mills County, representing 89 percent of the total irrigated cotton reported for Oklahoma counties.

In the Texas portion of the drainage basin, Carson County had the greatest number of reported irrigated crop acres followed by Gray, Wheeler, Potter, Donley, and Randall Counties (table 5). Irrigated acres of alfalfa, corn, sorghum, soybeans, sunflowers, and wheat were greatest in Carson County. A total of 100 percent of irrigated sunflowers, 92 percent of irrigated sorghum, 79 percent of irrigated wheat, 76 percent of irrigated soybeans, 70 percent of irrigated corn, and 66 percent of irrigated alfalfa for Texas counties occurred in Carson County. Irrigated cotton, hay, and peanuts were greatest in Wheeler County. A total of 92 percent of irrigated peanuts, 73 percent of irrigated cotton, and 70 percent of irrigated hay for Texas counties occurred in Wheeler County.

Irrigated crop acres for Texas counties reported by the TWDB were 94 percent of the total reported irrigated acres in the Lake Altus drainage basin (table 5). One hundred percent of irrigated sunflowers and irrigated soybeans, 99 percent of irrigated wheat, 98 percent of irrigated sorghum and corn, and 91 percent of irrigated cotton in the drainage basin occurred in Texas. Only irrigated alfalfa and irrigated peanuts had more acreage in Oklahoma than in Texas (table 5).

There were 46,659 acres of irrigated wheat, or 47 percent of the total irrigated crop acres in the drainage basin (fig. 6). Irrigated corn comprised 17 percent of the total irrigated crop acres in the drainage basin, irrigated soybeans comprised 11 percent, irrigated sorghum comprised 10 percent, and irrigated hay comprised 5 percent. The remaining 10 percent of irrigated crops acres in the drainage basin consisted of peanuts, cotton, alfalfa, and sunflowers.

Irrigation water requirements

The irrigation water requirements is the depth of irrigation water, excluding precipitation, stored soil moisture, or ground water, that is required consumptively for healthy crop production (U.S. Department of Agriculture, 1970). The irrigation water requirement is calculated by subtracting crop evapo-

Table 5. Irrigated crop acres reported from the Oklahoma Water Resources Board and Texas Water Development Board for portions of Oklahoma and Texas Counties in the Lake Altus drainage basin during the 2000 growing season

[–, not reported]

Counties	State	Irrigated crops (acres)									
		Alfalfa	Corn	Cotton	Hay	Peanuts	Sorghum	Soybeans	Sunflowers	Wheat	Total
Beckham	Okla.	672	2	10	784	1,561	116	–	–	133	3,278
Greer	Okla.	536	0	15	100	797	0	–	–	60	1,508
Kiowa	Okla.	0	385	0	98	156	65	–	–	58	762
Roger Mills	Okla.	100	0	210	150	0	0	–	–	0	460
Washita	Okla.	–	–	–	–	–	–	–	–	–	–
Total	**Okla.**	**1,308**	**387**	**235**	**1,132**	**2,514**	**181**	**0**	**0**	**251**	**6,008**
Carson	Tex.	663	11,182	488	495	0	8,551	8,228	2,172	36,850	68,629
Donley	Tex.	30	16	75	33	43	33	7	0	34	271
Gray	Tex.	236	4,417	43	493	0	649	2,611	0	7,756	16,205
Potter	Tex.	79	24	14	79	0	29	0	0	185	410
Randall	Tex.	1	3	2	2	0	19	0	0	25	52
Wheeler	Tex.	0	300	1,711	2,612	506	60	0	0	1,558	6,747
Total	**Tex.**	**1,009**	**15,942**	**2,333**	**3,714**	**549**	**9,341**	**10,846**	**2,172**	**46,408**	**92,314**
Basin Total		**2,317**	**16,329**	**2,568**	**4,846**	**3,063**	**9,522**	**10,846**	**2,172**	**46,659**	**98,322**

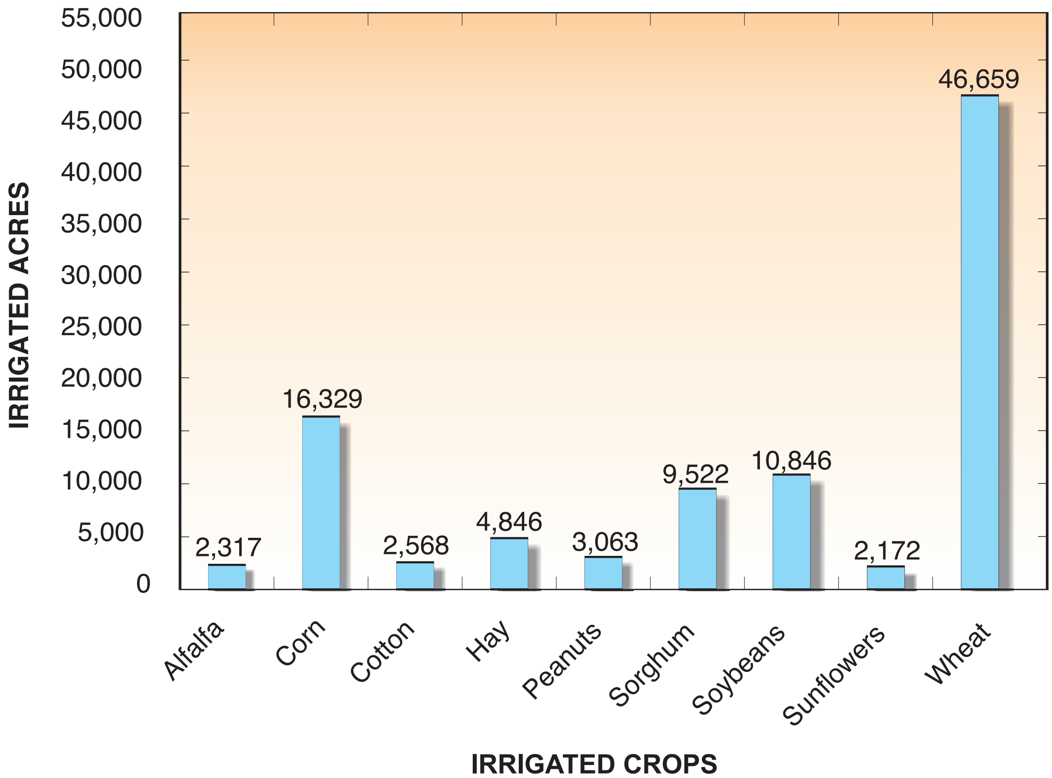

Figure 6. Irrigated crop acres in the Lake Altus drainage basin during the 2000 growing season, reported from the Oklahoma Water Resources Board and the Texas Water Development Board.

transpiration by the amount of water available to the crop through natural precipitation.

Climate conditions during the 2000 growing season were extremely dry and hot in most of the study area and were not representative of a typical growing season in the drainage basin. Most of the precipitation occurred in March and June, with little or no precipitation occurring in July, August, and September. During July and August, average monthly temperatures ranged from 80 degrees Fahrenheit in Roger Mills County to 90 degrees Fahrenheit in Kiowa County (Howard Johnson, Oklahoma Climatological Survey, written commun., 2001). There were several consecutive days in July, August, and September where temperatures exceeded 100 degrees Fahrenheit (Weldon E. Sears, Natural Resources Conservation Service, oral commun., 2002). Based on the extremely hot and dry weather conditions during the 2000 growing season, estimates of irrigation water use presented in this report are probably greater than for a normal year. The values of irrigation water use in this report are a measure of how much water crops could consume if it were available during the growing season. Climate data from September 1999 to October 2000 were used from weather stations listed in table 6.

Although the evapotranspiration model used for this report can accurately predict evapotranspiration in 5-day increments or longer in arid and non-humid environments (U.S. Department of Agriculture, 1993), other factors and assumptions made while calculating crop evapotranspiration and irrigation water requirements should be considered. Other factors such as irrigation practices, soil properties, water stress factors, and soil evaporation that affect crop water use were not considered when computing crop evapotranspiration for this report. The actual soil intake rate and the rainfall intensities were not considered when calculating the effective precipitation. A soil water storage factor of 1 was used to calculate the effective precipitation values used in this report. A soil water storage factor of 1 refers to a 3-inch available soil water capacity in the crop root zone.

The steps used to calculate the irrigation water requirements in this report include: (1) calculation of a referenced evapotranspiration; (2) determination of crop evapotranspiration, and (3) calculation of effective precipitation. The following sections provide an overview of the steps used to calculate irrigation water requirements.

Reference Evapotranspiration

An evapotranspiration model developed by Doorenbos and Pruitt (1977), based on climate data from September 1999 through October 2000, was used to calculate seasonal estimates of reference evapotranspiration (table 7) for major crops during the 2000 growing season. The reference evapotranspiration

Table 6. Weather stations used in study, climate data from September 1999 to October 2000

U.S. Weather Service weather stations			Oklahoma Mesonet weather stations		
Counties	State	Station name	Counties	State	Station name
BECKHAM	Okla.	ELK CITY	ROGER MILLS	Okla.	Cheyenne (CHEY)
BECKHAM	Okla.	ERICK	BECKHAM	Okla.	Erick (ERIC)
BECKHAM	Okla.	MORAVIA	WASHITA	Okla.	Retrop (RETR)
BECKHAM	Okla.	RETROP	KIOWA	Okla.	Hobart (HOBA)
BECKHAM	Okla.	SAYRE	GREER	Okla.	Mangum (MANG)
BECKHAM	Okla.	SWEETWATER	Texas A&M Agriculural Research and Extension Center weather stations		
GREER	Okla.	MANGUM	County	State	Station name
GREER	Okla.	WILLOW	CARSON	Tex.	White deer
KIOWA	Okla.	ALTUS DAM			
KIOWA	Okla.	HOBART			
KIOWA	Okla.	ROOSEVELT			
KIOWA	Okla.	SEDAN			
KIOWA	Okla.	SNYDER			
ROGER MILLS	Okla.	HAMMON			
ROGER MILLS	Okla.	REYDON			
WASHITA	Okla.	COLONY			
WASHITA	Okla.	CORDELL			
CARSON	Tex.	PANHANDLE			
DONLEY	Tex.	CLARENDON			
GRAY	Okla.	PAMPA			
GRAY	Okla.	MC LEAN			
POTTER	Tex.	AMARILLO			
RANDALL	Tex.	UMBARGER			
RANDALL	Tex.	CANYON			
WHEELER	Okla.	SHAMROCK			
WHEELER	Okla.	WHEELER			

Table 7. Reference evapotranspiration (ET_o) for crop growing seasons in the Lake Altus drainage basin during the 2000 growing season

[–, not determined]

Counties	State	Reference evapotranspiration for crop growing season (inches)								
		Alfalfa	Corn	Cotton	Hay	Peanuts	Sorghum	Soybeans	Sunflowers	Wheat
Beckham	Okla.	51.5	39.2	38.9	38.9	28.1	33.6	33.6	–	35.8
Greer[1], Kiowa[1], and Washita[1]	Okla.	53.4	41.4	41.4	41.2	30.0	33.6	35.6	–	37.1
Roger Mills	Okla.	52.3	40.4	40.7	44.8	29.6	35.3	35.3	–	35.6
Carson	Tex.	56.7	39.4	43.2	43.2	35.1	33.7	36.8	33.7	40.4
Potter[2]	Tex.	57.9	40.3	44.0	44.0	35.8	34.3	37.4	34.3	41.5
Gray[2]	Tex.	58.1	40.3	44.1	44.1	35.8	34.4	37.5	34.4	42.0
Wheeler[1]	Tex.	52.6	36.1	40.3	40.7	29.2	31.9	34.8	–	36.5

[1]Climate data from Beckham County was used to calculate reference evapotranspiration.

[2]Solar radiation data from Carson County was used to calculate reference evapotranspiration.

values differ due to the variable length of growing seasons for different crops. Average monthly values of precipitation, barometric pressure, relative humidity, solar radiation, temperature, and wind speed data were used to calculate reference evapotranspiration from October 1999 to September 2000. The Oklahoma Climatological Survey (OCS) provided climate data from multiple weather stations from the National Weather Service and the Oklahoma Mesonet to create monthly averages for portions of counties in the study area (Howard Johnson, Oklahoma Climatological Survey, written commun., 2001) (table 6). Additional solar radiation and barometric pressure data were acquired from Texas A&M Agricultural Research and Extension Center for Carson, Gray, and Potter Counties in Texas (U.S. Department of Agriculture, 2001).

The model by Doorenbos and Pruitt (1977) is referred to as the radiation method, which is very accurate in arid and subhumid areas (U.S. Department of Agriculture, 1993). The radiation method requires that a reference evapotranspiration rate (ET_o) be calculated and adjusted by a basal crop coefficient to compute the rate of evapotranspiration for a specific crop (crop evapotranspiration ET_c). Reference evapotranspiration (ET_o) is a baseline rate of evapotranspiration for a clipped grass growing under climatic conditions for a known time period. The radiation method from Doorenbos and Pruitt (1977) is expressed by equation 1:

$$ET_o=-0.012+(\Delta/\Delta+\Upsilon)*b_r*R_s/\lambda \quad (1)$$

where

ET_o = reference evapotranspiration for a clipped grass, in inches;
Δ = slope of the vapor pressure curve, in millibars per degree Fahrenheit;
Υ = psychrometric constant, in millibars per degree Fahrenheit;
b_r = adjustment factor depending on the average relative humidity and daytime wind speed, in miles per day;
R_s = incoming solar radiation in langleys per day; and
λ = heat of vaporization of water, in langleys per day

Crop Evapotranspiration

Crop evapotranspiration (ET_c) is an empirical estimate of the total amount of water required for a crop growing in an area under known climate conditions so that crop production is not limited by lack of water. Crop evapotranspiration is determined by adjusting the reference evapotranspiration (ET_o) to fit a basal crop coefficient curve. A basal crop coefficient curve represents the water use of a healthy, well-watered crop where the soil surface is dry (U.S. Department of Agriculture, 1993). The crop coefficient system developed by Doorenbos and Pruitt (1977) and modified by Howell and others (1986) was used to calculate monthly estimates of crop evapotranspiration (ET_c) for the nine major crops being irrigated during the 2000 growing season. Crop evapotranspiration (ET_c) is calculated using the reference evapotranspiration (ET_o) and a basal crop coefficient (K_{cb}). The formula used to calculate crop evapotranspiration is expressed by equation 2 (U.S. Department of Agriculture, 1993; Doorenbos and Pruitt, 1977):

$$ET_c=K_{cb}*ET_o \quad (2)$$

where

ET_c = rate of crop evapotranspiration, in inches;

K_{cb} = basal crop coefficient relating actual crop evapotranspiration (ET_c) to reference evapotranspiration (ET_o); and
ET_o = reference evapotranspiration for a clipped grass reference crop, in inches

The basal crop coefficient (K_{cb}) is a factor that relates reference evapotranspiration (ET_o) to actual crop evapotranspiration (ET_c). The method outlined by Doorenbos and Pruitt (1977) divides the growing season for a particular crop into four growing stages and calculates multiple basal crop coefficients at defined increments throughout each growing stage using equations and parameters in U.S. Department of Agriculture (1993, fig. 2-21 and table 2-20). Crop evapotranspiration for the growing season was calculated for alfalfa, corn, cotton, hay, peanuts, sorghum, soybeans, sunflowers, and wheat for portions of counties in the Lake Altus drainage basin (table 8).

Effective Precipitation

Effective precipitation (f_e) is the amount of precipitation that is available to meet the evapotranspiration requirements of crops. Monthly average values of precipitation for each county of the drainage basin from September 1999 to October 2000 were provided by the OCS (Howard Johnson, Oklahoma Climatological Survey, written commun., 2001) and were used to calculate effective precipitation. Equation 3 was used to calculate effective precipitation (f_e) (U.S. Department of Agriculture, 1970):

$$f_e=(0.7091747*r_t^{0.82416}-0.11556)*(10^{0.02426*ETc})*f \quad (3)$$

where
f_e = average monthly effective precipitation, in inches;
r_t = average monthly precipitation, in inches;
ET_c = rate of crop evapotranspiration, in inches; and
f = soil water storage factor (dimensionless)

Determination of Irrigation Water Requirements

The irrigation water requirement (U) is calculated by subtracting the amount of water available to the crop through natural precipitation (effective precipitation, f_e) from the crop evapotranspiration (ET_c). Irrigation water requirements (U) for the growing season were calculated on a countywide basis for each of the irrigated crops (table 9). The formula used to calculate irrigation water requirement is expressed by equation 4 (U.S. Department of Agriculture, 1970):

$$U=ET_c-f_e \quad (4)$$

where
U = irrigation water requirement, in inches;
ET_c = rate of crop evapotranspiration, in inches; and
f_e = effective precipitation, in inches

Table 8. Crop evapotranspiration (ET_c) for major crops in the Lake Altus drainage basin during the 2000 growing season

[–, not determined]

Counties	State	Crop evapotranspiration for crop growing season (inches)								
		Alfalfa	Corn	Cotton	Hay	Peanuts	Sorghum	Soybeans	Sunflowers	Wheat
Beckham	Okla.	38.9	31.0	33.6	29.1	20.9	27.0	28.8	–	26.5
Greer[1], Kiowa[1], and Washita[1]	Okla.	40.3	33.0	35.5	30.8	22.2	28.5	30.3	–	27.1
Roger Mills	Okla.	39.7	32.3	35.4	32.2	22.2	28.6	30.3	–	25.9
Carson	Tex.	42.9	31.0	37.0	32.1	26.5	26.8	31.5	27.4	30.3
Potter	Tex.	43.8	31.6	37.6	32.7	27.0	27.3	32.1	27.9	31.2
Gray	Tex.	43.9	31.6	37.8	32.7	27.1	27.0	32.2	28.0	42.0
Wheeler	Tex.	39.8	28.8	34.9	30.5	21.8	25.5	29.8	–	26.7

[1]Climate data from Beckham County was used to calculate crop evapotranspiration.