USGS
science for a changing world

Terrestrial Remote Sensing of the Fort Cobb Watershed, Southwestern Oklahoma

Chapter 4 of

Assessment of Conservation Practices in the Fort Cobb Reservoir Watershed, Southwestern Oklahoma

Compiled by the U.S. Geological Survey and the Agricultural Research Service

Scientific Investigations Report 2010–5257

U.S. Department of the Interior
U.S. Geological Survey

Terrestrial Remote Sensing of the Fort Cobb Watershed, Southwestern Oklahoma

By Carol S. Mladinich

Chapter 4 of

Assessment of Conservation Practices in the Fort Cobb Reservoir Watershed, Southwestern Oklahoma

Compiled by the U.S. Geological Survey and the Agricultural Research Service

Scientific Investigations Report 2010–5257

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2011

This and other USGS information products are available at http://store.usgs.gov/
U.S. Geological Survey
Box 25286, Denver Federal Center
Denver, CO 80225

To learn about the USGS and its information products visit http://www.usgs.gov/
1-888-ASK-USGS

Suggested citation:
Mladnich, C.S., 2011, Terrestrial remote sensing of the Fort Cobb watershed, southwestern Oklahoma, chap. 4 *of* Becker, C.J., ed., Assessment of conservation practices in the Fort Cobb Reservoir watershed, southwestern Oklahoma: U.S. Geological Survey Scientific Investigations Report 2010–5257, 12 p.

Contents

Figures

Tables

Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Terrestrial Remote Sensing of the Fort Cobb Watershed, Southwestern Oklahoma

By Carol S. Mladinich

Abstract

Land-cover data is a key input to understanding the effects of conservation practices on the Fort Cobb Reservoir watershed in southwestern Oklahoma. Land use in this watershed is predominantly agriculture and a multidate, multisensory set of satellite images for 2006 was obtained to map the land cover in the watershed using an object-oriented approach with the Definiens Professional software. An object-oriented approach segmented the data into features including agricultural fields, tree stands, riparian vegetation, water bodies, and some anthropogenic features such as buildings and some road segments. The software also enabled simultaneous processing of all the imagery in spite of the different spatial and radiometric resolutions and geographic areal extents. A common practice by image analysts of incorporating previous land-cover classifications to aid interpretation was not used because of the changing character of agriculture in the watershed. The classification of land cover to the level of crop types was only partially successful due to limited ground-reference data. Winter wheat, summer crops, fallow fields, and areas of natural vegetation were identified with accuracies in the 90 percent range and were comparable to a 2005 land-cover classification produced by the U.S. Department of Agriculture, Agricultural Research Service Grazinglands Research Laboratory in Oklahoma.

Introduction

Fort Cobb Reservoir is a 16.6-square-kilometer reservoir in Caddo County, southwestern Oklahoma. The Fort Cobb Reservoir receives drainage from an 813-square-kilometer watershed characterized by predominantly sandy loam soils. The Bureau of Reclamation manages the reservoir for drinking water supply, irrigation sources, flood control, recreation, and fish and wildlife habitat (Fairchild and others, 2003). Land use in the watershed is dominated by agriculture. The primary row crops include winter wheat, peanuts, cotton, and other small grains. The peanut crop during the last 5 years has decreased. More crops are being converted to grass and small grains. Cash crops are converting to livestock operations because of fluctuating commodity prices. (Phil Perryman, U.S. Department of Agriculture, oral commun., 2007). Livestock operations are dominated by cattle pasture grazing and confined animal feeding operations used for hog production.

U.S. Geological Survey (USGS) scientists worked together to collect the phytoplankton and terrestrial vegetation data needed to determine nutrient pathways and possible sources of the distribution of organic matter and fine sediments in the Fort Cobb Reservoir watershed. This chapter describes the use of remote sensing to map the terrestrial land cover in the Fort Cobb Reservoir watershed. Remote sensing is used widely to identify and map the distribution of vegetation on the land surface. Multiple image sources and dates were used to map the terrestrial land cover for the 2006 growing season.

Methodology

Satellite Image Data

Multiple image sources and dates were used to map terrestrial land cover in the Fort Cobb watershed. Landsat 7 Enhanced Thematic Mapper Plus (ETM+) imagery was obtained for April 21 and June 6, 2006 as Level 1 Scan Line Corrector (SLC)-off with a 15-pixel interpolation to fully populate missing data (U. S. Geological Survey, 2009). This Landsat sensor has six spectral channels at a 30-meter spatial resolution and one panchromatic channel with a 15-meter spatial resolution. The U.S. Department of Agriculture (USDA) provided data for three time periods—April 15, July 1, and September 26, 2006—from the Indian Remote Sensing Satellite, IRS-P6 (ResourceSat-1), Advanced Wide Field Sensor (AWiFS). The AWiFS data has four spectral channels with a 56-meter spatial resolution (National Remote Sensing Agency, 1995). The Earth Observing (EO)-1 satellite, Advanced Land Imager (ALI) data were collected on October 24, 2006. The ALI sensor has nine spectral channels with a 30-meter spatial resolution and one panchromatic channel with a 10-meter spatial resolution (Beck, 2003) (table 1, fig. 1).

Table 1. The satellite specifications for the spectral and spatial resolutions used in terrestrial mapping for the Fort Cobb Reservoir watershed, 2006.

[The shading reflects the channels used in the processing; IRS, Indian Remote Sensing Satellite; NIR, near infrared; SWIR, shortwave infrared]

Landsat 7 Enhanced Thematic Mapper Plus (ETM+)			Earth Observing-1 Advanced Land Imager (ALI)			IRS-P6 Resourcesat-1 Advanced Wide Field Sensor (AWiFS)		
Channels	Spectral wavelength (micrometers)	Spatial resolution (meters)	Channels	Spectral wavelength (micrometers)	Spatial resolution (meters)	Channels	Spectral wavelength (micrometers)	Spatial resolution (meters)
Band 1 (blue)	0.45-0.52	30	Band 1	0.048-0.69	10	Band 2 (green)	0.52-0.59	56
Band 2 (green)	0.53-0.61	30	Band 2 (blue)	0.433-0.453	30	Band 3 (red)	0.62-0.68	56
Band 3 (red)	0.63-0.69	30	Band 3 (blue)	0.45-0.515	30	Band 4 (NIR)	0.77-0.86	56
Band 4 (NIR)	0.78-0.90	30	Band 4 (green)	0.525-0.605	30	Band 5 (SWIR)	1.55-1.70	56
Band 5 (SWIR)	1.55-1.75	30	Band 5 (red)	0.63-0.69	30			
Band 6	10.40-12.50	60	Band 6 (NIR)	0.775-0.805	30			
Band 7	2.09-2.35	30	Band 7 (NIR)	0.845-0.89	30			
Band 8	0.52-0.90	15	Band 8	1.2-1.3	30			
			Band 9 (SWIR)	1.55-1.75	30			
			Band 10	2.08-2.35	30			

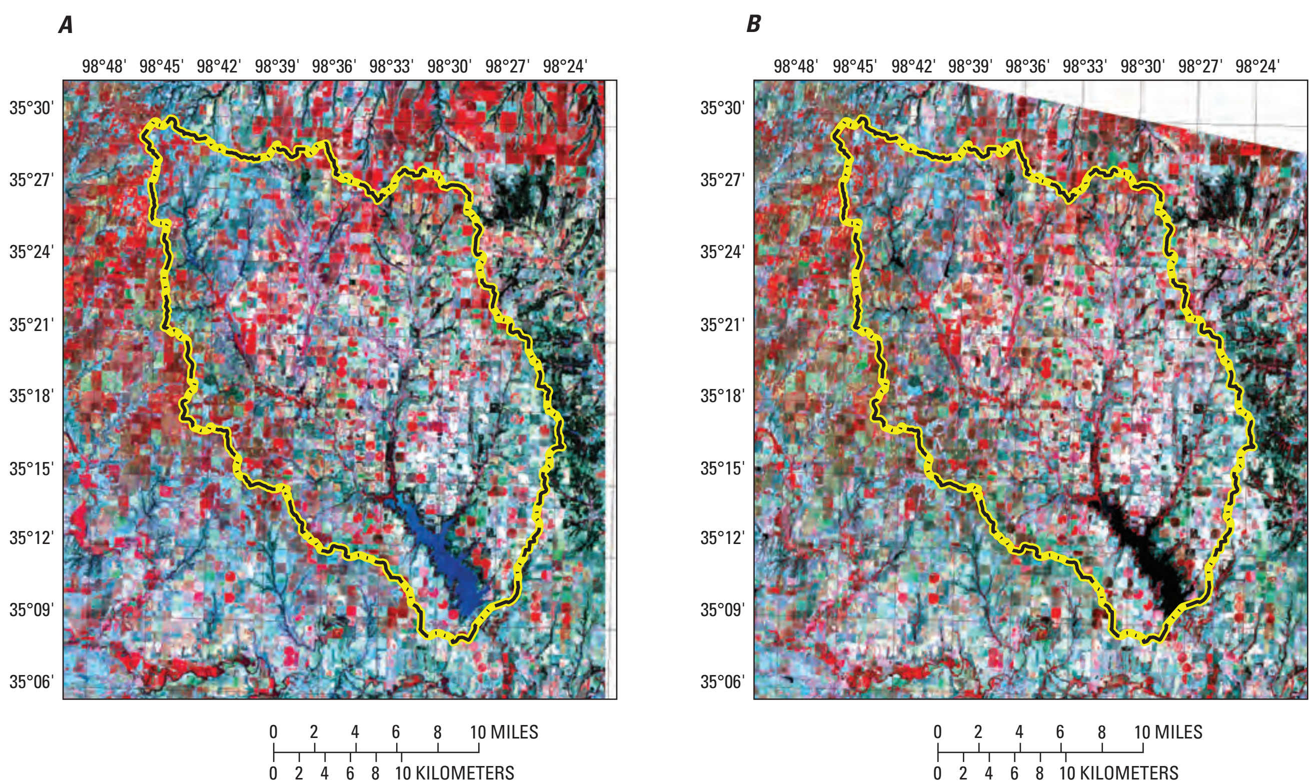
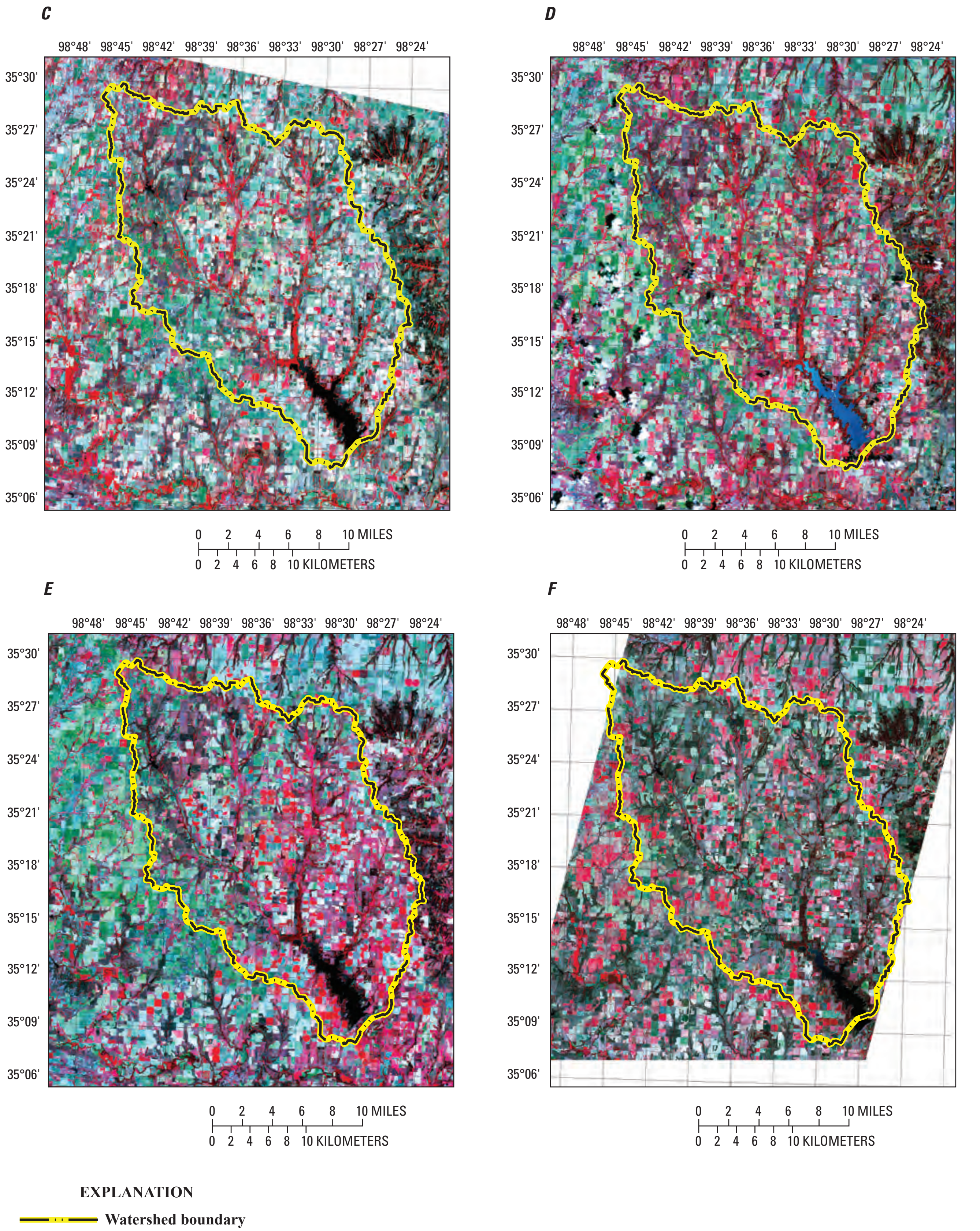


Figure 1. Color infrared display of multitemporal datasets used in the terrestrial land-cover mapping in the Fort Cobb Reservoir watershed, southwestern Oklahoma. A, Advanced Wide Field Sensor (AWiFs), April 15, 2006. B, Landsat 7, April 21, 2006. C, Landsat 7, June 6, 2006. D, AWiFS, July 1, 2006. E, AWiFS, September 26, 2006. F, Advanced Land Imager (ALI), October 24, 2006.


C
D
E
F
98°48' 98°45' 98°42' 98°39' 98°36' 98°33' 98°30' 98°27' 98°24'
35°30'
35°27'
35°24'
35°21'
35°18'
35°15'
35°12'
35°09'
35°06'
0 2 4 6 8 10 MILES
0 2 4 6 8 10 KILOMETERS
EXPLANATION
Watershed boundary

Data Analysis

Some preprocessing of the satellite image data was required before the land-cover classification could begin. The datasets with a pan band were considered for pan-sharpening to improve the clarity of the imagery. All of the datasets were co-registered to one another for a more accurate multidate classification.

The ALI data were pan-sharpened by using the PCI Geomatica PANSHARP module. Pan-sharpening merges the multispectral and the pan imagery producing a multispectral dataset with the spatial resolution of the pan band. The module is based on the least number of squares to an approximate gray-value relationship between the original multispectral image, panchromatic image, and fused image (Zhang, 2002; PCI Geomatics, 2005). This model retains as many as possible of the original spectral values from the bands. The other datasets were not pan-sharpened. The AWiFS imagery had no pan band. The Landsat imagery, though having pan bands, was not pan-sharpened because the imagery emphasized the interpolation of the missing data in the image sets.

Each set of images used for classification were independently referenced to the ground surface. As a result, when each dataset was overlain on each other, the datasets did not lineup or were misregistered. The imagery must be co-registered to each other when performing a multidate analysis. The imagery was co-registered by using the ALI 10-meter pan-sharpened imagery as the base. The ALI imagery was used as the base because ALI imagery had the highest spatial resolution. The same set of ground-control points were used to register the imagery and a second-degree polynomial fit within a pixel was calculated.

Classification Approach

Research findings to date, and results from other studies (Blaschke and others, 2000; DeFries and Chan, 2000; Herold and others, 2002; Hay and others, 2003; Erbek and others, 2004; Özkan and Erbek, 2005), support classifying land cover obtained from high-resolution imagery by incorporating a cognitive or object-oriented approach. Cognitive or segmentation algorithms (segmentation), such as those used in Definiens AG Professional (Definiens AG, 2007), take into account the shapes of multipixel features and the shapes of surrounding features. In contrast, a pixel-based (spectral and textural) approach uses algorithms that assess the spectra and statistics of a single pixel and a matrix of neighboring pixels. The pixel-based approach can be limiting because the relation of a pixel group making up a complete feature, such as a stand of trees or a field of wheat, is processed independently from the shape of the feature or association of multiple pixels that actually defines the feature. The result of segmentation is a data layer of objects of various shapes defined by similar characteristics. The features are then defined and identified by using a suite of tools that are spectral- and feature-based. This approach is based on the concept that valuable information needed to interpret an image is not represented by a single pixel but in meaningful image objects and the associated relations. The software used also allows for the simultaneous processing of multiple imagery sets with different spectral, spatial, and radiometric resolutions (Definiens AG, 2007).

The entire multidate, multiresolution dataset was processed together. A series of segmentations were performed to account for different time periods and areas of data overlap. The land-cover classes were defined with descriptive rules defining color, shape, texture, size, and context. The spectral information in terms of mean, standard deviation, and ratio, and the Normalized Difference Vegetation Index (NDVI) were determined for each image-set band and evaluated to determine the best feature definitions for each class. Each land-cover class may contain one or many feature definitions, as shown in figures 2 and 3, which are the basis for formulating rules for data analysis. The rules are meant to define each class so that one class is distinguishable from the other classes with as little overlap as possible. The lack of detailed ground reference data precluded the use of many samples to build the rule base for the land-cover classes. A single class could have several rules from different image sets and bands defining that class (fig. 3).

A two-tier classification was created in Definiens Professional software to identify the land cover in the watershed. General land-cover classes (Definiens classes) were first identified including the base classes of water, natural vegetation, and then the parts of the agricultural fields that were actively growing during each growing season or seasons (spring, summer, and autumn). Fallow fields in all three growing seasons were labeled “fallow.” Three types of “natural vegetation” were identified: (1) grasses, which could include maintained pasture; (2) trees; and (3) natural vegetation, which could include bushes, shrubs, scrub, and riparian areas in the watershed. The last class identified was developed. The developed class included towns, areas of large development or operations, and roads. Large developed areas were easily confused with grasses and fallow fields and were manually assigned to the developed class. Road sections that were sufficiently wide or in high contrast to the surrounding area also were identified. Dark water bodies were easily identified; the lighter water bodies were manually assigned to the water class. Whenever possible, the classes were consistent with the 2005 classification categories developed by the USDA Agricultural Research Station (ARS) Grazinglands Research Laboratory (GRL) in Oklahoma, a collaborator on the project (chapter 5 of this volume). The Definiens classification scheme is described in table 2. According to Phil Perryman [USDA National Resources Conservation Service (NRCS) Anadarko Field Service Center for Caddo County, Oklahoma, oral commun., 2007)], previous classifications, such as the 2005 land-cover classification by the USDA ARS GRL, were deemed unusable as additional ancillary information for classification because the cropping patterns in the watershed have changed on an almost seasonal basis with many farmers growing the crops that will bring a positive cash flow.

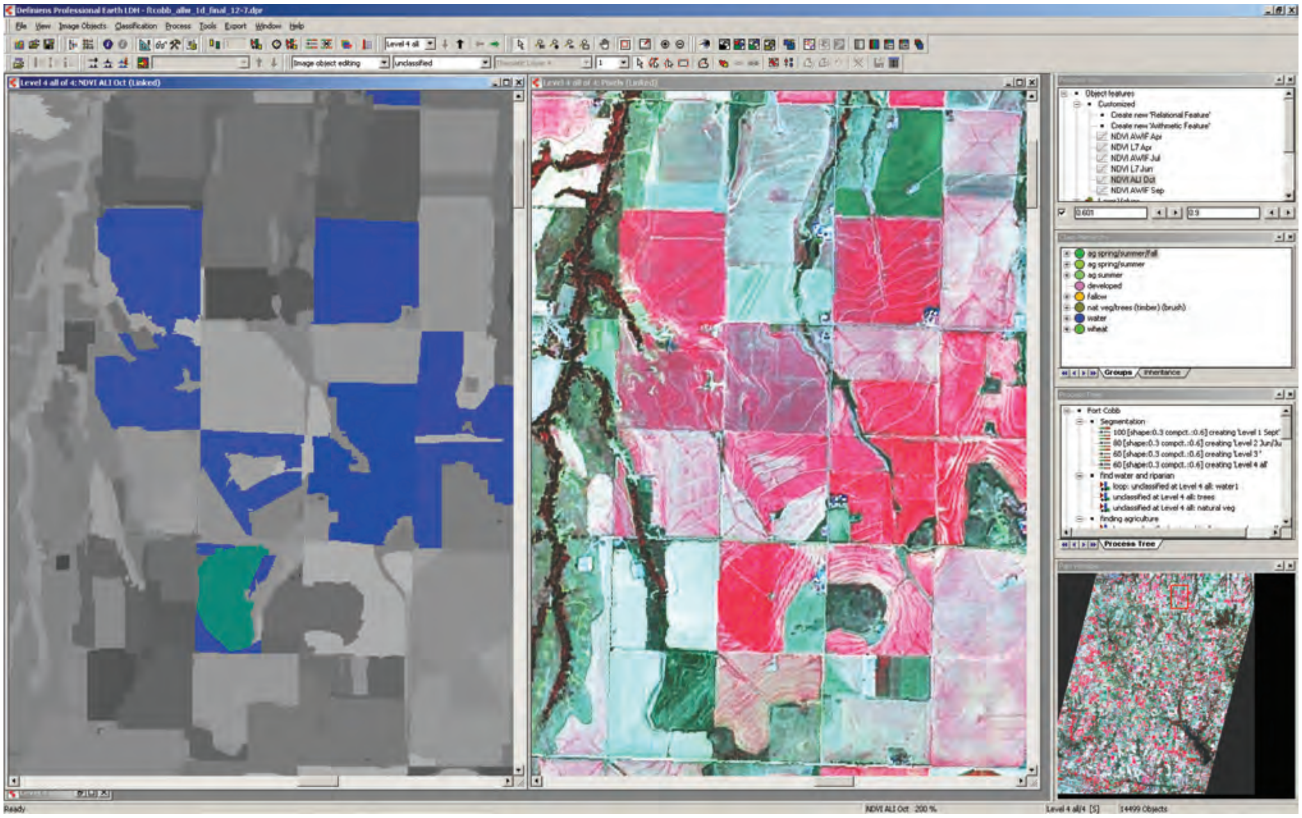


Figure 2. An example of a method to identify actively growing fields (bright red) for a portion of the Advanced Land Imager (ALI) October image (color infrared image in center). Using the Normalized Difference Vegetation Index (NDVI) layer, a range of low (.601) and high (.9) NDVI values are determined (top right box) to identify the active fields. The feature view window on the left displays in blues and greens those image objects meeting the criteria.

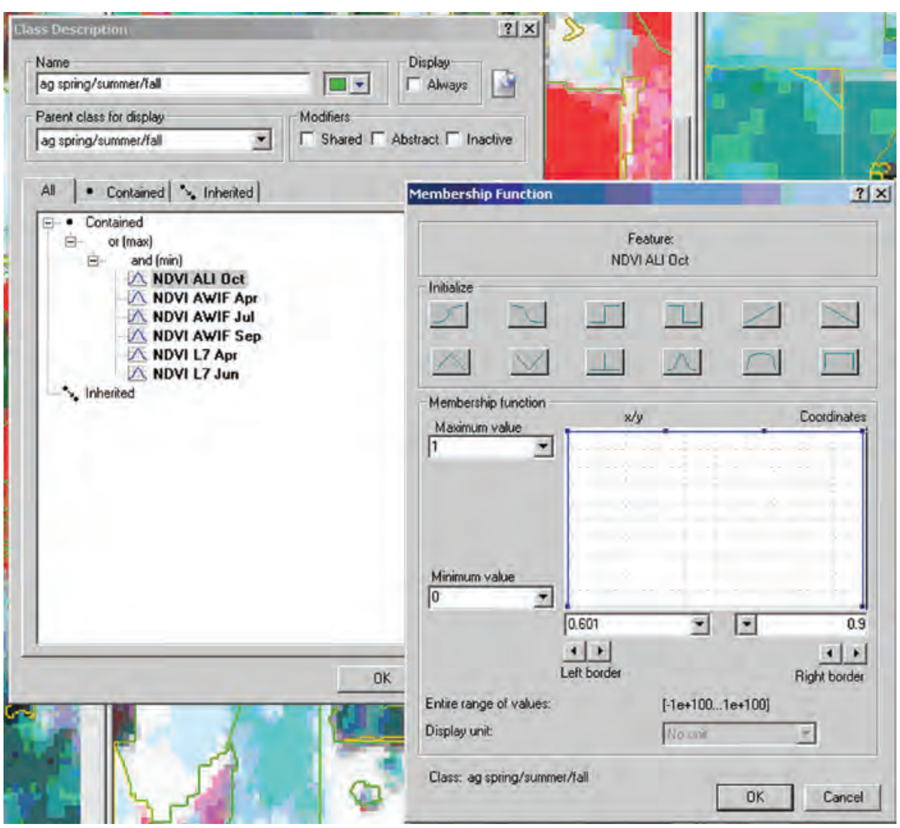


Figure 3. An example of the class description (rules) for the land-cover class "agriculture spring/summer/fall" is shown in the back window (left). The rule uses the Normalized Difference Vegetation Index (NDVI) values for each dataset. The membership function for the NDVI Advanced Land Imager (ALI) October image is shown in the front window (right).

Table 2. Final land-cover classes, 2006; the ground reference classes; and U.S. Department of Agriculture (USDA), Agriculture Research Station (ARS) 2005 classification classes developed for the Fort Cobb Reservoir watershed.

[The shading represents class groupings relative to the final Definiens classes, 2006; Ag, agriculture]

Definiens classes	Final classes, 2006	Ground reference classes	Classes from USDA ARS, 2005
Ag spring	Winter wheat	Wheat	Winter wheat
Ag autumn		Wheat/grass	
Ag spring/autumn		Water/rye/grass	
		Wheat/grass (native)	
		Wheat/grass/trees	
		Rye/grass	
Ag spring/summer	Other summer crop	Wheat/soybeans	
		Wheat/ purple hull peas	
		Wheat/ peanuts	Peanut/cotton
		Wheat/ cotton	
Ag summer		Milo/black-eyed peas	Other summer crops
Ag summer/autumn		Oats/grass	
		Soybeans	
Ag spring/summer/autumn		Grass/wheat/sudan/oats	
		Wheat/oats/cotton/sorghum forage	
Fallow	Fallow	Fallow	
Natural vegetation	Natural vegetation (trees)	Natural vegetation	Forest
Trees			
Grass	Grass		Grass/pasture
Developed	Developed		Roads
Water	Water		Water

The agricultural classification is based on the growing cycle of the crops found in the watershed. Features with high infrared (IR) values (lush growing vegetation) were identified for the spring (April dates), summer (June/July dates), and autumn (September/October dates) and classed as “agriculture” (ag). Each temporal combination of agriculture also was identified: spring/summer/autumn – spring/summer – spring/autumn – summer/autumn. A field that showed high IR values in the spring, low IR (fallow) in the summer, and high IR values in the autumn would be classified as winter wheat (ag spring/autumn) (fig. 4). After determining which fields were growing during a particular season, a crop type was assigned. The watershed is predominately agricultural, with trees and other natural vegetation growing along the streams. Winter wheat (and/or rye, canola) is generally planted from September to November and harvested the next June to July. Any high infrared values in the spring and or autumn datasets were identified as winter wheat. The growing season in this region also allows for double cropping, the practice of planting more than one crop in a field during a single growing season. Winter wheat might be harvested and then the fields replanted in a summer crop. Cotton, a summer crop, is generally planted from May to July and harvested from October to December. Because of differing harvest practices among farmers, the identification of cotton from the spectral properties can be difficult. One field may be senesced because of chemical defoliation although another field may still be reflecting in the infrared range because that farmer is letting the field senesce naturally. Peanuts, another summer crop, are similar in growing pattern to cotton, making the two crops easy to confuse. Grass was assumed to have a more uniform response throughout the growing season.

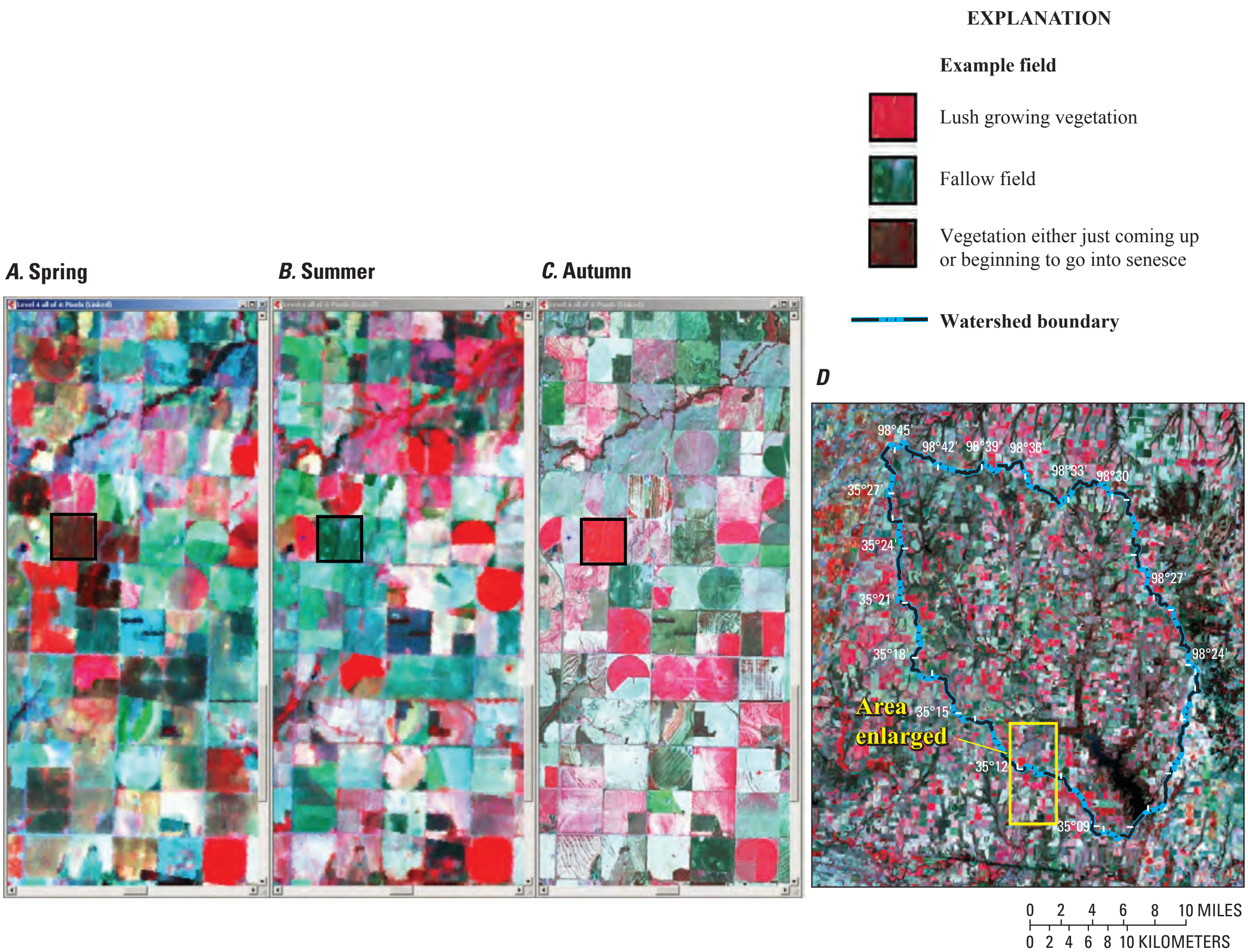


Figure 4. An example of multidate images displayed as color infrared (near-infrared band in red, green band in green, and blue band in blue). A, Area enlarged in spring. B, Area enlarged in summer. C, Area enlarged in autumn. D, Overview of study area shown in figure 1.

Interpretation of Remote-Sensing Data

Land-Cover Classification Results

A final seven-class classification of land cover was determined from the remote-sensing data processing. The classification consisted of: Winter wheat, Other summer crop, Natural vegetation (including Trees), Grass, Fallow, Developed, and Water (table 2, fig. 5). A random selection of ground-reference points, based on Public Land Survey System quarter-section fields, were generated for the watershed for accuracy assessment of the final classification (fig. 6). The USDA NRCS Anadarko Field Service Center provided the land-cover information for the selected points in Caddo County. The land-cover information was for the entire quarter-section field (field) containing the point and may have listed multiple crops. The portion of the field containing the specific crop was not noted. For those points containing multiple cover classes, the point was copied and added in the section on the basis of the field delineation of the ALI pansharpened image set (fig. 7). To account for this subdivision in the accuracy assessment step, additional points were duplicated in each portion of the field where needed (boxes a - c in fig. 7). The ground reference data obtained from the NRCS had few single crop identification points, allowing for a high confidence of identifying the crop types. Winter wheat was the only single crop to be identified; the others were grouped as a combination of spring (wheat) and a

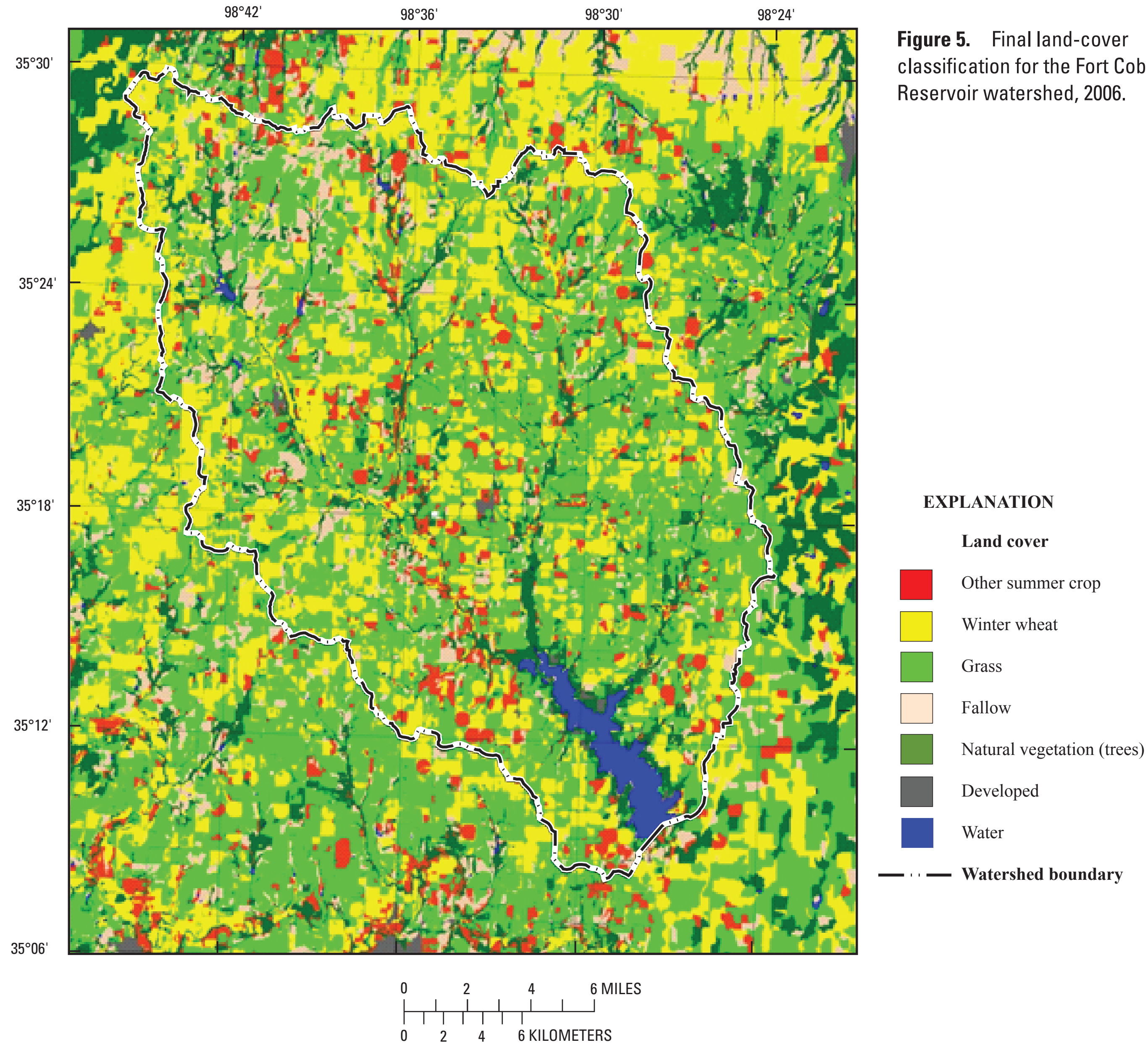


Figure 5. Final land-cover classification for the Fort Cobb Reservoir watershed, 2006.

summer crop, predominantly summer crops, and combinations of wheat, summer crops, and grasses. Using the ground reference points reserved for accuracy assessment, the class labels of the ground points are compared to the corresponding class labels of the classification. An error matrix was generated for the accuracy assessment calculations (table 3). The accuracy assessment for the land-cover classification was expressed in terms of the overall, producer's, and user's accuracy (table 4), using techniques discussed by Congalton and Green (1993). The overall accuracy was 94.85 percent, indicating the likelihood of all the classes being correctly classified, with a Kappa Statistic of 0.92, indicating a very good agreement between the classification and ground reference data with what might be expected by chance (Landis and Koch, 1977). In Navulur (2007), general interpretation rules for the strength of the agreement in thematic accuracy assessments showed Kappa values between 0.81 and 1.00 as almost perfect. These accuracies were expected because of the number of general land-cover classes in which the information was grouped. The more general the classification the higher the overall classification and the higher the Kappa Statistic (Congalton and Green, 1993). The ground reference data were not sufficient in detail to determine crop types. More detailed ground reference data as to which portion of a section contained which crop would be necessary to determine the summer crop types as illustrated in figure 7.

As a qualitative test, the percentage of total pixels of land-cover classes from the 2006 classification was compared to the USDA 2005 classification (table 5, fig. 5). The two classifications were generated independently and

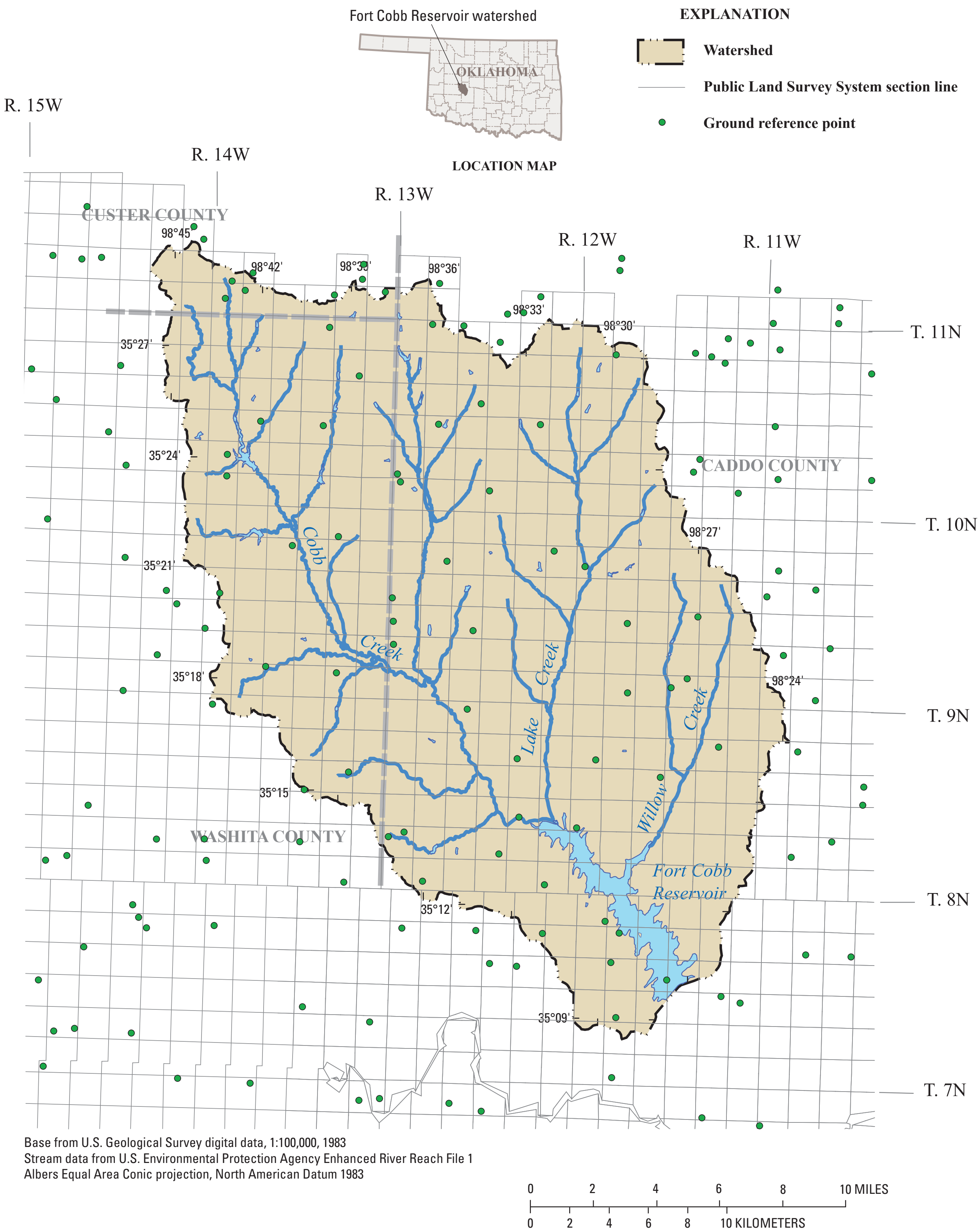


Figure 6. Location of ground reference points used in land-cover classification accuracy assessment of the Fort Cobb Reservoir watershed, southwestern Oklahoma.

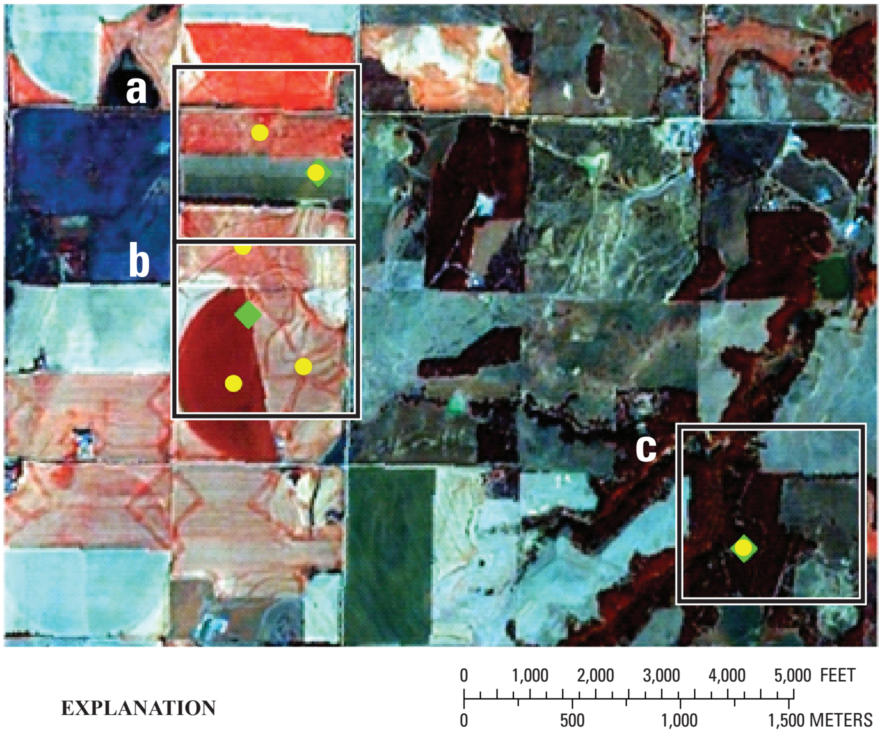


Figure 7. An example of ground reference points used for accuracy assessment overlaid on Advanced Land Imager (ALI) image. There was one ground reference point (green diamond) for each Public Land Survey System quarter-section field (black box). Many fields were labeled as containing multiple crops by the U.S. Department of Agriculture Natural Resources Conservation Service office, but the portion of the field was not noted. The classification process, though, was able to detect the subdivisions of a field. To account for this subdivision in the accuracy assessment step, additional points were duplicated in each portion of the field where needed (illustrated with boxes a, b, and c).

EXPLANATION

- Original ground reference point
- Accuracy assessment ground reference point

there was not a one-to-one match between classes. For ease of comparison, the 2006 classes were modified to match the 2005 classes. The grass class in 2006 and the grass/pasture class in 2005 were similar, and the water classes in both years were similar. The 2005 classification had a larger percentage of winter wheat than the 2006 classification, which was seen in the 2006 accuracy assessment. The larger percentage of natural vegetation/trees (2006, 14 percent) and forest (2005, 5 percent) was possibly due to the differences in class definition between 2006 classification including more vegetation than trees (forest) in the 2005 classification. The 2006 fallow class (not present in the 2005 classification) possibly accounted for the difference in summer crops and peanut/cotton.

Land Cover in the Fort Cobb Reservoir Watershed

The watershed is predominantly agricultural, with trees and other natural vegetation growing along the streams. The identification of winter wheat had the greatest confidence because of the spring/autumn planting and greenness. Any high infrared values in the spring and/or autumn datasets were identified as winter wheat. Many fields identified as a crop by the ground reference data were identified as fallow by the imagery, which was unexpected. There were no indications within the six dates of imagery used that the fields were actively planted during 2006.

As mentioned, the length of the growing season in this region also allows for double cropping. As a result, detailed ground reference data are needed to distinguish cotton, peanuts, and other summer crops. The spectral multitemporal information probably would have been sufficient for identification if coupled with the ground reference data. Grass was assumed to have a more uniform response and mottled appearance throughout the growing season. For the final classification, grass was combined with the other natural vegetation types of trees and other (shrubs and brush). Dark water bodies were easily identified by the low reflectance in the infrared bands. Identification of the lighter water bodies was more difficult, with many of those water bodies being added manually because of the similarity of those water bodies to the appearance of developed features and bright bare fields. The large developed areas also were easily confused with grasses and fallow fields and were manually added. Road sections that were sufficiently wide (no wider than the spatial resolution of the sensor) or in high contrast to the surrounding areas also were identified by the reflectance and shape properties (length/width).

Comparing this 2006 classification and the 2005 classification completed by the USDA ARS office can illustrate the effects of changing agricultural practices on the watershed. A comparison of the percentages of land cover

Table 3. The error or confusion matrix for the final classification for the Fort Cobb Reservoir watershed, 2006.

[By using ground reference data reserved for accuracy assessment, the class labels of the reference data were compared to the corresponding class labels of the classified data. Only those classes with ground reference information and used in the accuracy assessment are shown]

Classes	Reference data					
	Other summer crop	Winter wheat	Natural vegetation	Fallow	Water	Totals
Other summer crop	13	0	1	0	0	14
Winter wheat	0	52	2	0	0	54
Natural vegetation	0	3	50	0	0	53
Fallow	0	0	0	12	0	12
Water	0	0	0	0	2	2
Totals	**13**	**55**	**53**	**12**	**2**	**135**

Table 4. Accuracy statistics for the final classification grouping (grasses grouped with natural vegetation) for the Fort Cobb Reservoir watershed, 2006.

[Only those classes used for the accuracy assessment are shown; %, percent; Producer's accuracy, the ratio of correctly classified pixels to the total number of ground truth pixels and tells how well a class was correctly classified; User's accuracy, the ratio of the total number of correct pixels in a class to the total number of pixels that were classified in that class and is a reliability measure; *Kappa Statistic,* an index which compares the agreement against that which might be expected by chance]

Classes	Producer's accuracy	95% confidence interval	User's accuracy	95% confidence interval	Kappa Statistic
Other summer crop	100.00%	(96.154% 103.846%)	92.86%	(75.795% 109.919%)	0.921
Winter wheat	92.86%	(85.219% 100.495%)	96.30%	(90.333% 102.259%)	0.937
Natural vegetation	94.34%	(87.175% 101.504%)	94.34%	(87.175% 101.504%)	0.9073
Fallow	100.00%	(95.833% 104.167%)	100.00%	(95.833% 104.167%)	1
Water	100.00%	(75.000% 125.000%)	100.00%	(75.000% 125.00%)	1
Overall accuracy			**94.85%**		**0.92**

Table 5. A comparison of the percentage of terrestrial land-cover classes between the 2005 and 2006 classifications for the Fort Cobb Reservoir watershed.

[NA, not available; Percentages do not add to 100 because of rounding; classes in parenthesis indicate a different class name in 2006 than in 2005]

Classes	Percentage of watershed area	
	2005	2006
Winter wheat	43	30
Grass/pasture (grass)	34	35
Other summer crop	4	7
Peanut/cotton	9	NA
Forest (natural vegetation/trees)	5	14
Roads (developed)	5	1
Fallow	NA	11
Water	2	1

for two time periods is seen in table 5, but this comparison is not comprehensive. Whether these differences are in error or the result of changing agricultural practices is uncertain. Temporal issues which could be evaluated include whether (1) the cropping pattern intensified or waned over time, (2) wheat being the major crop in the watershed, and (3) planting locations have changed relative to the drainages in the watershed. Such issues would be addressed by having a more complete temporal view of the terrestrial landscape and would help to illustrate how agricultural practice changes in the watershed may have affected water quality of the reservoir.

Summary

The final classification described the terrestrial land cover for the 2006 growing season. An object-based approach allowed for smooth and efficient processing of the different imagery datasets. The ground reference data from NRCS was helpful in classifying the agricultural land cover classes. In the future more detailed ground reference data to the individual field level is necessary to differentiate each crop type. Such classification will assist modeling and understanding of the sources and effects of nutrients derived from the agricultural land-use practices in the Fort Cobb Reservoir watershed for the 2006 growing season. Multitemporal land-cover data are needed in combination with water-quality data to determine what type of effect(s) agricultural practices are having on the reservoir.

References Cited

Beck, R., 2003, EO-1 User guide version 2.3: University of Cincinnati, 74 p.

Blaschke, T., Lang, S., Lorup, E., Strobl, J., and Zeil, P., 2000, Object-oriented image processing in an integrated GIS/remote sensing environment and perspectives for environmental applications, *in* Cremers, A., and Greve, K., eds., Umweltinformation für planung, politik und öffentlichkeit/Environmental information for planning, politics and the public: Marburg, Metropolis Verlag, p. 555-570.

Congalton, R.G., and Green, K., 1993, A practical look at the sources of confusion in error matrix generation: Photogrammetric Engineering and Remote Sensing, v. 59, no. 5, p. 641-644.

Definiens A.G., 2007, Definiens Developer 7 user guide: München, Definiens AG.

DeFries, R.S., and Chan, J.C.W., 2000, Multiple criteria for evaluating machine learning algorithms for land cover classification from satellite data: Remote Sensing of Environment, v. 74, no. 3, p. 503-515.

Erbek, F.S., Özkan, C., and Taberner, M., 2004, Comparison of maximum likelihood classification method with supervised artificial neural network algorithms for land use activities: International Journal of Remote Sensing, v. 25, no. 9, p. 1733-1748.

Fairchild, J., Lakish, B., Echols, K., Chapman, D., Johnson, T., and Jones, S., 2003, An integrated assessment of the trophic status of Fort Cobb Reservoir, Oklahoma, 2001-2003: U.S. Geological Survey, Columbia Environmental Research Center, 89 p.

Hay, G.J., Blaschke, T., Marceau, D.J., and Bouchard, A., 2003, A comparison of three image-object methods for the multiscale analysis of landscape structure: ISPRS Journal of Photogrammetry and Remote Sensing, v. 57, no. 5-6, p. 327-345.

Herold, M., Scepan, J., Müller, A., and Günther, S., 2002, Object-oriented mapping and analysis of urban land use/cover using IKONOS data, *in* 22nd EARSEL Symposium Geoinformation for European-wide integration: Prague, Czech Republic, Millpress Science Publishers.

Landis, J.R., and Koch, G.G., 1977, The measurement of observer agreement for categorical data: Biometrics, v. 33, no. 1, p. 159-174.

National Remote Sensing Agency, 1995, IRS-1C data users handbook: Hyderabad, Department of Space, Government of India, p. 169.

Navulur, K., 2007, Multispectral image analysis using the object-oriented paradigm: Boca Raton, CRC Press, 165 p.

Özkan, C., and Erbek, F.S., 2005, Comparing feature extraction techniques for urban land-use classification: International Journal of Remote Sensing, v. 26, no. 4, p. 747-757.

PCI Geomatics, 2005, Geomatica version 10 help: Richmond Hill, PCI Geomatics.

U.S. Geological Survey, 2009, Landsat 7 (L7) Enhanced Thematic Mapper Plus (ETM+) Level 1 (L1) Data Format Control Book (DFCB): EROS Data Center LS-DFCB-04, 133 p.

Zhang, Y., 2002, Problems in the fusion of commercial high-resolution satellite as well as Landsat 7 images and initial solutions, in Proceedings of Symposium on Geospatial Theory, Processing and Applications, ISPRS Commission IV Symposium: Ottawa, Canada, July 8-12, 2002.

USGS

Mladinich—**Terrestrial Remote Sensing of the Fort Cobb Watershed, Southwestern Oklahoma**—Scientific Investigations Report 2010–5257