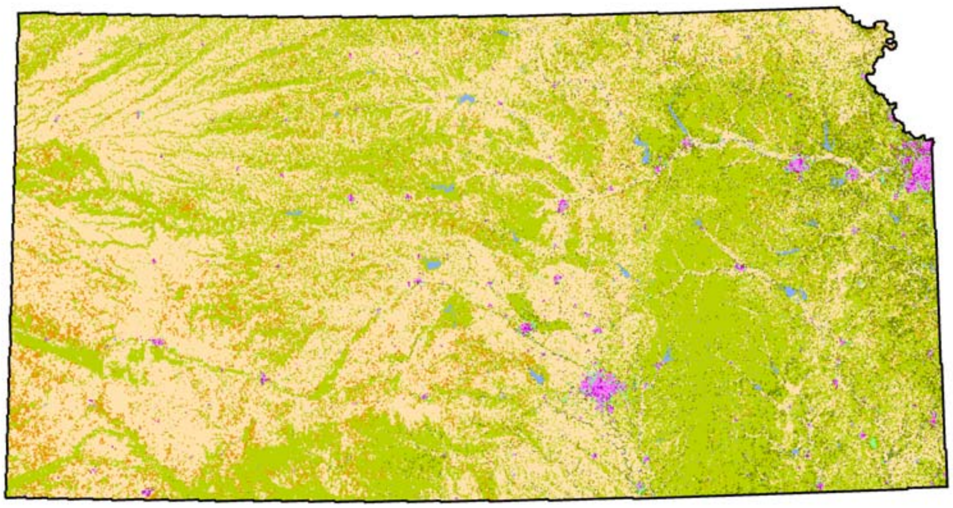
2005 KANSAS LAND COVER PATTERNS
PHASE I - FINAL REPORT



KBS Report # 150
Kansas Applied Remote Sensing Program
Kansas Biological Survey
University of Kansas
Lawrence, Kansas 66047

July 2008

Report Prepared by:

Dana L. Peterson
Jerry L. Whistler
John M. Lomas
Kevin E. Dobbs
Mark E. Jakubauskas
Stephen L. Egbert
Edward A. Martinko

Credits

The 2005 Kansas Land Cover Patterns map was created at the Kansas Applied Remote Sensing Program of the Kansas Biological Survey.

Funding Sources: The land cover mapping project was co-funded by the Kansas GIS Policy Board with funds from the Kansas Water Plan that are administered by the Kansas Water Office under the grant titled "*Kansas Next-Generation Land Use/Land Cover Mapping Initiative*" and the National Science Foundation EPSCoR Program under the research project titled "*Understanding and Forecasting Ecological Change: Causes, Trajectories and Consequences of Environmental Change in the Central Plains*."

Principal Investigators:
Edward A. Martinko, Mark E. Jakubauskas, Jerry L. Whistler, and Stephen L. Egbert

Principal Project Personnel:
Dana L. Peterson, Jerry L. Whistler, Mark E. Jakubauskas, John M. Lomas, Kevin E. Dobbs, and Stephen L. Egbert

Recommended Citation:
Peterson, D.L., J.L. Whistler, J.M. Lomas, K.E. Dobbs, M.E. Jakubauskas, S.E. Egbert, and E. A. Martinko. 2005. 2005 Kansas Land Cover Patterns Phase I: Final Report. *KBS Report 150*. Kansas Biological Survey, University of Kansas, 29pp.

Table of Contents

List of Tables

List of Figures

Executive Summary

The 2005 Kansas Land Cover Patterns map represents an update of the 1990 Kansas Land Cover Patterns map. The update, designed to be explicitly comparable to the 1990 Kansas Land Cover Patterns map, uses the same source data (Landsat Thematic Mapper (TM)), classification scheme (Modified Level I), classification approach (unsupervised classification), and spatial resolution (minimum mapping unit (MMU)). Using a similar methodology to produce the 2005 Kansas Land Cover Patterns map allows end-users to identify and examine changes in the Kansas landscape over the last 15 years.

The Modified Level I map was produced from multi-seasonal Landsat TM imagery acquired during the 2004 and 2005 growing seasons. The map contains eleven land use/land cover classes and has a positional accuracy and spatial resolution appropriate for producing 1:50,000 scale maps. The MMU varies by land cover class and ranges between 0.22 to 5.12 acres.

The 2005 Kansas Land Cover Patterns map has an overall accuracy of 90.72%, the highest overall accuracy level for a Level I map produced by the Kansas Applied Remote Sensing Program to date. While the overall accuracy level is high, User and Producer accuracies vary by land cover class.

The 2005 Kansas Land Cover Patterns map represents Phase 1 of a two-phase mapping initiative occurring over a three-year period. During Phase 2, subclasses will be mapped to produce a Modified Level II map of Kansas using 250-meter resolution time-series MODIS NDVI imagery.

Digital versions of the map, metadata, and accuracy assessment can be accessed from the Data Access and Support Center (DASC) website of the Kansas Geological Survey (http://www.kansasgis.org/).

Introduction

The Next-Generation Statewide Land Cover Mapping Initiative was co-funded by the Kansas State GIS Policy Board and the NSF EPSCoR Program. Work on the mapping initiative was split into two 18-month phases over a three-year period. The work and products described in this report correspond to Phase I of the land cover mapping initiative.

The modified Anderson Level I (Anderson *et al.*, 1976) land cover map developed in Phase I represents the fourth statewide land cover map created by the Kansas Applied Remote Sensing Program of the Kansas Biological Survey. The three other statewide land cover maps were (1) Kansas Land-Use Patterns: Summer 1973 (non-digital, hard copy only) (KARS, 1973), (2) the 1990 Kansas Land Cover Patterns map (KARS, 1997; Whistler *et al.*, 1996), and (3) the 1992 Kansas Vegetation Map created for the Gap Analysis Program (Egbert *et al.*, 2001; KARS, 2002).

Methods

This map was derived using three-date multi-seasonal (spring, summer, and fall) Landsat Thematic Mapper (TM) imagery and an unsupervised classification approach. The land cover map contains eleven land use/land cover (LULC) classes and was designed to be explicitly comparable to the 1990 Kansas Land Cover Patterns database. A two-stage generalization technique was used to refine the map classes to their specified minimum mapping units. A formal accuracy assessment was conducted using both existing databases and high-resolution digital aerial photography (using manual photo interpretation techniques) as ground reference data.

Mapping Standards and Data Sources

Table 1 summarizes the mapping standards used and data products developed for this land cover mapping initiative. The primary data source for map development was Landsat Thematic Mapper (Landsat TM) imagery. The land cover map has thematic detail based on an Anderson Modified Level I classification scheme and a minimum mapping unit that varies by class type. The goal for overall map accuracy was 85% or greater. The map is distributed as a statewide digital database in Geotiff and ArcInfo Grid formats.

Table 1. Mapping standards, data sources and products for the 2005 Kansas Land Cover Patterns map.

Item	Standard or Product
Primary Data Source	Landsat Thematic Mapper (30m resolution)
Thematic Detail	Anderson Modified Level I; eleven classes total
Minimum Mapping Unit (MMU)	Varies by LULC class (0.2224 to 5.115 acres)
Spatial Reference	Albers Conic Equal-Area (A Kansas Projection Standard) Spheroid GRS 1980 Datum NAD83 Latitude of 1st standard parallel: 29:50:00 N Latitude of 2nd standard parallel: 45:50:00 N Longitude of central meridian: 96:00:00 W * Latitude of origin of projection: 23:00:00 N * * National projection parameters
Spatial Accuracy	15 meters (0.5 pixels)
Thematic Accuracy	As determined through accuracy assessment; goal 85% or greater
Tiling Scheme	Statewide database with 300m buffer
Format	Geotiff and ArcInfo Grid
Product	Digital land cover database

Data Sources:

Landsat TM imagery from the 2004-2005 Kansas Satellite Image Database (KSID) (Whistler *et al.*, 2006), a database previously developed by the Kansas Applied Remote Sensing Program and funded by the Kansas State GIS Policy Board with assistance from the USGS AmericaView program, was the primary data source used for map development. Sixteen path/row scenes were required to provide complete coverage of the state. For each scene center in Kansas, the database contains terrain-corrected spring, summer, and fall TM triplicates, resulting in a total of 48 images needed for the project (Table 2). Imagery in the 2004-2005 KSID was selected based on the dates of available data and cloud contamination. Additional scenes were purchased by the NSF EPSCoR grant to supplement triplicates that had cloud-contaminated scenes, non-optimal dates for a scene, or an inter-annual triplicate (i.e., triplicates including scenes from both 2004 and 2005). Ancillary data sets listed in Table 3 were used at varying stages of the map development. Specifics on their use are described in applicable sections of the report.

Table 2. Landsat Thematic Mapper imagery by path/row.

Path/Row	Spring Image	Summer Image	Fall Image
26/34	03/11/05	06/15/05	10/02/04
27/32	05/21/05	08/09/05	10/28/05
27/33	04/16/04; 04/03/05	06/22/05	10/28/05
27/34	04/16/04; 03/18/05	07/24/05	09/10/05
28/32	03/22/04	07/12/04	11/04/05
28/33	03/22/04	07/12/04	11/04/05
28/34	03/22/04	07/12/04	11/04/05
29/32	04/14/04	07/19/04	10/23/04
29/33	04/1/05; 03/29/04	07/19/04	10/23/04
29/34	04/01/05	07/22/05	10/23/04
30/32	05/10/05	06/27/05	11/18/05
30/33	05/10/05	07/29/05	11/18/05
30/34	05/10/05	07/29/05	11/18/05
31/32	03/11/04	08/05/05; 08/02/04	10/24/05
31/33	03/30/05	07/20/05	10/24/05
31/34	03/27/04	07/20/05	10/24/05

Table 3. Ancillary data sets used to create the 2005 statewide land cover map.

Data Set	Source	Purpose
2005 FSA National Agriculture Imagery Program (NAIP)	USDA	Create Urban Mask, Classification QAQC, and Accuracy Assessment
2005 Common Land Unit (CLU) Database	USDA/NRCS	Generalization, Accuracy Assessment
Kansas State Highway System	KDOT	Generalization
Kansas Public Land Survey System (PLSS)	KGS	Accuracy Assessment
Kansas GAP Vegetation Database	KBS/KARS	Accuracy Assessment

Thematic Detail:

The classification scheme was designed to be explicitly comparable to the 1990 Kansas Land Cover Patterns database. The 2005 map contains the same ten classes as the 1990 map, with the addition of lands enrolled in the Conservation Reserve Program (CRP) (Table 4).

Table 4. The Modified Anderson Level I Land use/land cover classes mapped.

Level I Class Code and Name	Level II
10, Urban	11, Urban Commercial/Industrial
	12, Urban Residential
	13, Urban Openland (typically grassland - includes golf courses, cemeteries, and parks)
	14, Urban Woodland
	15, Urban Water
20, Cropland	
30, Grassland (includes rangeland and pasture)	31, Conservation Reserve Program (CRP)
40, Woodland	
50, Water	
60, Other (including sandbars, quarries, segments of major highways)	

The eleven mapped classes are defined as:

(11) Commercial/Industrial - commercial/industrial land consists of areas of intensive use with much of the land covered by structures or other hard surfaces. These areas are used predominantly for the manufacture and sale of products and/or services. This category includes the central business districts of cities, towns, and villages; suburban shopping centers and strip developments; educational, governmental, religious, health, correctional and institutional facilities; industrial and commercial complexes; and communications, power, and transportation facilities. The main buildings, secondary structures, and areas supporting the basic use are all included - office buildings, warehouses, driveways, parking lots, landscaped areas, streets, etc. Highways or interstate systems running through the core of urban areas, are also included in this class.

(12) Residential - residential land consists of areas of medium density housing characterized by a more or less even distribution of vegetative cover and houses/garages, to high density housing characterized by multi-unit structures such as apartment complexes. Linear residential developments along transportation routes extending outward from urban areas are included. Rural subdivisions not directly connected to the core of an urbanized area are also included. The main buildings, secondary structures, and immediate surrounding landscape are all included (i.e., houses, apartment complexes, streets, garages, driveways, parking areas, lawns, trees, etc.).

(13) Urban-Openland - urban-openland consists of areas primarily of open grassland, sometimes mixed with trees, with uses such as golf courses, zoos, urban parks, cemeteries, and undeveloped land within an urban setting. Low density rural residential areas may also be included in this category. This category also includes tracts of land that have been zoned residential or commercial, but have yet to be developed.

(14) Urban-Woodland - urban-woodland consists of wooded tracts within a town or city. These wooded tracts maybe associated with golf courses, zoos, urban parks, and other undeveloped land.

(15) Urban-Water - urban-water consists of any open surface water within a town or city. This includes ponds, lakes, sewage settling ponds, etc.

(20) Cropland - cropland includes all areas with actively growing row crops and small grains, as well as harvested land, fallow land, and large, uniform areas of bare, plowed ground.

(30) Grassland - this category includes all pasture (hayed land), rangeland, and other grasslands having insufficient trees and/or shrubs to be classified as "woodland". It does NOT include conservation reserve program (CRP) land.

(31) Conservation Reserve Program (CRP) Land - this category includes all lands enrolled in the Conservation Reserve Program as determined by the 2005 Common Land Unit (CLU) database.

(40) Woodland - this class includes any wooded areas having a canopy closure of 50% and greater.

(50) Water - all open water bodies, including reservoirs, lakes, ponds, rivers and streams. Ephemeral streams may not be represented.

(60) Other - the "other" class is used to identify land cover / land use classes not previously defined. In general, this class is used for exposed, bare ground other than cropland. Examples include rock quarries, sand and gravel pits, sandbars, and built-up areas less than 40 acres.

Positional accuracy and spatial resolution (minimum mapping unit - MMU) are appropriate for producing 1:50,000 scale maps (approximately 2 acres). MMU's varied by LULC class and match the MMU's used in the 1990 Kansas Land Cover Patterns database (Table 5).

Table 5. Minimum mapping units by LULC class.

LULC Class	**Landsat Pixels**	**Acres**
Urban Commercial/Industrial	15	3.11
Urban Residential	15	3.11
Urban Openland	15	3.11
Urban Woodland	3	0.67
Urban Water	1	0.22
Cropland	23	5.12
Grassland	23	5.12
CRP	23	5.12
Rural Woodland	3	0.67
Rural Water	1	0.22
Other	15	3.11

Land Cover Map Development

Data Preprocessing:

Although the imagery had already gone through some image pre-processing steps (i.e., terrain-correction), additional image pre-processing was still required in preparation for image classification. The pre-processing steps are listed below. Processing units were defined by the TM path/rows.

1. For each path/row, subset bands 3, 4, 5, and 7 from each scene and combine into one file using the ERDAS Imagine Layer Stack Function, creating a 12-band multi-seasonal image. Previous experience has shown this band combination to be most effective in multi-date land cover classification for Kansas.
2. Clean the edges of each 12-band image so that only pixels present in all three dates are preserved. This step was necessary due to slight positional offsets that occur from minor variations in the satellite's orbit over time.
3. Inspect the 12-band multi-seasonal image for cloud cover. If clouds exist:
    a. Digitize and mask clouds from the 12-band image.
    b. For cloud-contaminated areas, create a 2-date cloud-free layer stack as a separate sub-processing unit for image classification.
    c. If clouds overlap from two dates, create a 1-date cloud-free layer stack as a separate sub-processing unit for image classification. This was a rare occurrence and only represented a small percentage of the overall processing area.
4. Merge scenes from adjacent rows of the same path into one processing unit when they contain identical triplicate dates.
5. Subset the spatial extents of processing units to reduce the amount of overlap between processing units and then clip to the study area (the state boundary buffered by 300m, or 10 TM pixels, wide) where appropriate. Preference or priority was given (i.e. spatial extents were maximized) to processing units containing intra-annual triplicates (all within the same year) and to the 2005 TM data (vs. 2004). There were a few instances when the overlap areas between adjacent scenes were combined to provide a cloud-free triplicate or more optimal dates for image classification. These combined areas were treated as separate processing units.
6. Using a heads-up digitizing approach, create an urban mask. Developed areas exceeding 40 acres were digitized on a displayed image of the 2005 NAIP using ArcGIS 9.1 software. The urban mask was then used to create both a rural layer stack and an urban layer stack for each processing unit for image classification.

Image Classification:

Image classification was broken into four tasks, conducted in parallel, with specific mapping objectives for each task. The 12-band image file was run through an unsupervised statistical clustering classifier because time-consuming and expensive signature development and training used in supervised classification is not required and because our previous experience with land cover mapping has underscored the value of using unsupervised classification to identify these land cover classes. When all four tasks were completed, they were merged and the map generalized according to the minimum map unit defined for each class.

The objectives for each task are listed below:

1. Produce a map of cropland and grassland;
2. Produce a map of woodland;
3. Produce a map of water and;
4. Produce a map of urban classes.

For each task, the following processing steps were used:

1. Use the 12-band TM image file to generate N-spectral signatures (varied by class) using the ISODATA algorithm.
    a. Cropland and grassland: 100 spectral signatures
    b. Woodland: 100 spectral signatures
    c. Water: 100 spectral signatures
    d. Urban: 50 spectral signatures
2. Use the spectral signatures and the Maximum Likelihood Classifier to create the specified number of spectral clusters.
3. Display the three dates of TM imagery in separate windows with the spectral class image overlaid.
4. Highlight each spectral class and assign it to the appropriate LULC class:
    a. Cropland and grassland: Grassland, Cropland, or Confused
    b. Woodland: Woodland, Non-woodland, or Confused
    c. Water: Water, Non-water, or Confused
    d. Urban: Urban Commercial/Industrial, Urban Residential, Urban Openland, or Confused
5. Use an unsupervised cluster-busting technique (Jensen, 1996) on confused spectral classes. Create a TM image of the confused spectral classes (i.e. spectral clusters containing more than one land cover class), and break confused classes into additional spectral clusters (Typically, three times the number of confused classes). Highlight each class in the cluster-busted image on the TM imagery and assign a land cover class. Repeat the cluster busting process until all classes are interpreted.
6. Provide the spectral class assignments to a second analyst for QAQC. For QAQC, display the three dates of TM imagery with the spectral class image overlaid. Highlight each spectral class and evaluate the accuracy of the spectral class assignment. Document agreements and disagreements for spectral class assignments in the attribute editor. Evaluate feedback from the QAQC and resolve issues regarding the spectral class assignments.
7. Recode spectral classes from steps 4 and 5 to appropriate LULC classes.
8. Merge image classifications from steps 4 and 5 into one map for each processing unit.

Generalization Procedures

Introduction

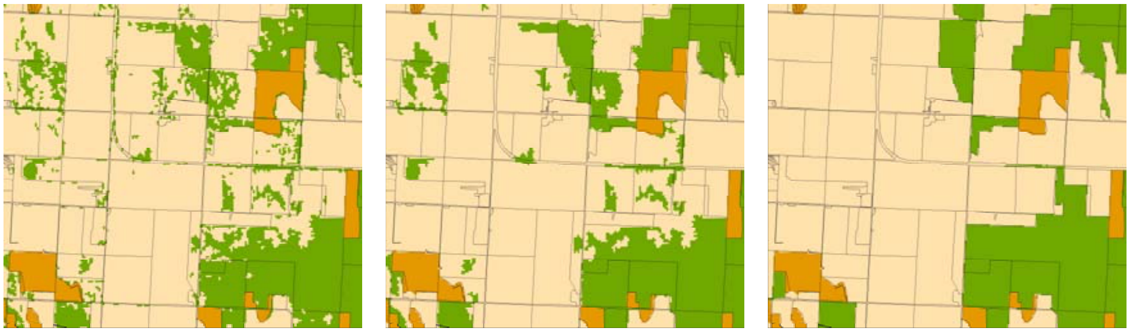
Cartographic generalization of the classified TM data was performed to eliminate “noise” in the classification and simplify the map. Noise is comprised of either extraneous misclassified pixels or small clumps of pixels that are insignificant at the suggested mapping scale of the map (1:50,000) (Figure 1a). Noise tends to create visual confusion and obscure overall patterns. Before designing and running the generalization procedures, the minimum mapping unit (MMU) was chosen for each land use/land cover class. The MMU size, or smallest number of contiguous pixels, chosen for a particular class was based on the following factors:

1) Is the class reliably detected by the classification?
2) Is the class accurately represented?
3) What level of thematic detail (i.e., how small an area) should be preserved at the suggested mapping scale?
4) MMUs that would be comparable to the 1990 Kansas Land Cover Patterns database.

Taking these factors into account, the MMU for each land use/land cover class was established. MMUs are listed in Table 5 (above).

Overview of the Generalization Procedure

Generalization was accomplished in three stages. The first stage consisted of visually examining the four classified component maps (i.e., urban, cropland/grassland, woodland and water), scanning for misclassified areas, and manually correcting them. In the second stage, conventional automated generalization procedures were used to simplify the manually cleaned classification by removing misclassified or spatially insignificant clumps of pixels (Figure 1b). During this stage, the objective was to achieve the MMU standard for the individual classes. After all processing units had gone through the second generalization, the individual units were brought together, or mosaicked, into a single raster. In the third stage, FSA Common Land Unit (CLU) field boundary data were used to fit the Cropland and Grassland classes from the mosaic into fields delineated in the CLU data (Figure 1c). The objective was to utilize the spatial precision of field boundaries provided by the CLU data to better depict the spatial extent of Cropland and Grassland.



(a) (b) (c)

Figure 1. An example of the map (a) prior to generalization, (b) following generalization using traditional techniques and (c) following generalization using CLU data.

Stage I Generalization – Manual Cleanup of Misclassified Pixels

Manual cleanup was performed on each individual map component for each processing unit using ERDAS Imagine. The procedure was initiated by displaying a map component for a processing unit in one window while displaying the corresponding 2005 NAIP imagery in another window as reference. The map component was then systematically examined by an analyst who looked for classification errors. For the woodland and water map components, the analyst was primarily focused on eliminating errors of commission. When commission errors were found, the analyst would recode the misclassified pixels to zero using heads-up digitizing with the Fill tool. If gross errors of omission were encountered, the analyst added the missing feature and recoded the polygon with the appropriate class code. For the urban and cropland/grassland map components, the analyst looked for misclassified areas greater than the MMU. Although correcting misclassified pixels was similar to the process used for water and woodland, the analyst often would use the Recode tool rather than the Fill tool. The Recode tool was used because areas to be corrected were often buried within a matrix of other class values and the Recode tool allowed targeting the misclassified pixels for recoding. With the Recode tool, the analyst could roughly, and quickly, delineate the area to be changed. An analyst using the Fill tool for the same task would have to digitize the exact boundary of the misclassified pixels, making correction extremely problematic and time consuming.

Stage II Generalization – Eliminating Small Clusters of Pixels

Generalization – Water

There was no generalization of the water class.

Generalization – Woodland

The generalization of the woodland class was accomplished using two functions in ERDAS Imagine 9.1. The first step utilized the CLUMP function to identify all contiguous pixels (i.e., clumps) of woodlands using the eight connected neighbors rule. The second step used the ELIMINATE function to remove clumps with less than three pixels.

Generalization – Urban Classes

The generalization of the Urban classes Industrial/Commercial, Residential, and Openland was accomplished using an Arc Macro Language (AML) script running under ArcInfo 9.1. An AML script allows the sequential automated processing of multiple individual functions in a formal and repeatable manner. The following outlines the generalization procedure for the Urban map.

1. Add Water and Woodland to the Urban map.
2. Use the REGIONGROUP function to identify all contiguous areas of Commercial/Industrial, Residential, and Openland.
3. Set to Zero (0) all areas less than the MMU.
4. Use REGIONGROUP to identify all contiguous areas of Zero.
5. Calculate the majority value for Zero areas larger than the MMU and reassign the Zero area to the majority value.
6. Use the EXPAND function to fill remaining Zero areas. This function fills the Zero area with surrounding class value(s) excluding Woodland and Water. This step is run iteratively until Zero areas are filled.
7. Recode any remaining Zero areas (e.g., areas embedded in Woodland, a class that was not allowed to expand in the previous step), as Woodland.

Generalization – Cropland, Grassland, and Other Classes

The generalization of the classes Cropland, Grassland, and Other was accomplished using an Arc Macro Language (AML) script running under ArcInfo 9.1. The following outlines the generalization procedure for these classes.

1. Add manual edits to the Cropland/Grassland map.
2. Recode the Cropland around 4-lane highways to Grassland. Use a 45m buffer around the highway's centerline (90m total; 3 TM pixels wide) to delineate the recode area.
3. Overlay the CRP map onto the Cropland/Grassland map.
4. Add Water and Woodland to the Cropland/Grassland map.
5. Use the REGIONGROUP function to identify all contiguous areas of Grassland and Cropland.
6. Set to Zero (0) all areas less than 2-pixels (i.e., 1-pixel areas).
7. Calculate the majority value on the Cropland/Grassland classes map using a 3x3 window for Zero Areas and reassign the Zero Area to the majority value.
8. Convert current Cropland/Grassland raster grid to a polygon coverage for later use.
9. Use the ELIMINATE function to remove polygons less than the MMU for Grassland, Cropland, and Other. Eliminated polygons are merged with the class having the longest shared edge.
10. Convert the Cropland/Grassland polygon coverage from Step 9 to raster grid for later use.
11. For irregularly shaped cropland slivers less than 45 pixels that are embedded in grassland areas and assessed to be noise, calculate the perimeter-to-area ratio in the polygon coverage in preparation for removal from the map.
12. Save irregularly shaped Cropland polygons to a new coverage.
13. Convert irregularly shaped Cropland polygon coverage to a raster grid.

14. Use REGIONGROUP function to identify all contiguous areas of irregularly shaped Cropland.
15. Identify *isolated* (i.e., areas surround by only one cover type) irregularly shaped Cropland surrounded entirely by Grassland.
16. Update the Cropland/Grassland raster grid from Step 10 with the raster grid from Step 15.
17. Clean up Woodlands and Water, which may have been altered in previous processing, by removing them from the Step 15 raster and adding back the original Woodlands and Water classes.
18. Use REGIONGROUP to identify any remaining clusters of the value Zero (0).
19. For clumps greater than or equal to the MMU, calculate the majority value and fill Zero Areas with it.
20. For clumps less than the MMU, use the EXPAND function to fill remaining Zero Areas. This function fills the Zero Area with surrounding value(s). This step is run iteratively until Zero Areas are filled.

Mosaic of Stage II Generalizations

The MOSAIC function (ArcInfo) was used to merge the individual raster grids from the Stage I generalization process. Due to overlap between the processing units, the order in which the individual grids were specified in the function was important. Grids specified first had the highest priority during the merge, and their values would not be overwritten. Subsequently listed grids had lower priority and their values would only fill zero (0) areas.

As discussed earlier, the quality of the classification for the individual processing units was influenced by the dates of the source imagery used in the classification, with the ideal situation being that all images were from a single growing season. In practice, the classification for some processing units was based entirely on either 2004 or 2005 imagery (see Table 2). In other cases, the classifications were based on a non-optimal combination of 2004 and 2005 imagery. Therefore, to maximize the most ideal set of imagery during the run of the MOSAIC function, priority was given to processing unit classifications in the following order: (1) all imagery from 2005; (2) all imagery from 2004; (3) spring and summer imagery from the same year, fall imagery from an off-year or a non-optimal spring or summer date; and (4) inter-annual imagery and/or imagery possessed significant cloud problems.

Stage III Generalization – Fitting to CLU Boundaries

To conduct the Stage III generalization, individual unattributed CLU field-boundary shapefiles, roughly corresponding to a county, were merged into one file covering the state and then converted to a raster grid. Output raster cells were assigned the feature identifier (FID) of the shapefile during the conversion to a grid because the value was unique and thus could be used to identify unique zones. The following outlines the procedures for the Stage III generalization.

1. Create a Cropland/Grassland grid by recoding all values other than Cropland (20) and Grassland (30) on the Stage I generalization to NODATA.

2. For each Zone in the CLU grid, calculate the ZONALMAJORITY for the Cropland/Grassland grid.
3. Using the Stage I generalization grid, write all values other than Cropland and Grassland to a new output grid, recoding Cropland and Grassland areas to Zero (0)
4. Write the ZonalMajority values from Step 2 to the new grid, filling only Zero areas.

Results

The end product for Phase I of the Next-Generation Kansas Land Cover mapping project is an updated digital Level 1 land cover map of Kansas (Figure 2). A summary of the land cover types, their area mapped in square kilometers, and the percent of the total area in Kansas represented by each type is presented in Table 6. The broad patterns of land cover are readily apparent in the table and the map. The effects of human activity upon the Kansas landscape are clearly reflected in the fact that nearly 46% of the state's land area is devoted to cropland while an additional 5% are CRP land.

The major grassland areas of Kansas, including the Flint Hills of eastern Kansas, the Smoky Hills of north-central Kansas, and the Red Hills of south-central Kansas are easily distinguished, as are grasslands along the reaches of rivers and streams in western Kansas. Large areas of nearly continuous cropland dominate the western two thirds of the state, with large tracts of CRP land evident. Woodlands interspersed within grasslands and croplands characterize the heterogeneous eastern third of Kansas. The eastern third of Kansas also contains the major population centers of Kansas City, Lawrence, Manhattan, Pittsburgh, Topeka, and Wichita, which are clearly visible, as well as numerous smaller towns.

Table 6. Modified Anderson Level I land cover classes, their area mapped (sq. km. and sq. mi.), and the percent of the State's total area represented by each land cover class. Calculations include the 300m buffer around the state boundary.

LULC Class	LULC Code	Pixel Count	Percent Mapped	Area (km^2) Mapped	Area (mi^2) Mapped
Commercial/Industrial	11	800,291	0.34	720.26	278.09
Residential	12	1,637,774	0.69	1,474.00	569.11
Urban Openland	13	1,404,319	0.59	1,263.89	487.99
Urban Woodland	14	213,004	0.09	191.70	74.02
Urban Water	15	44,660	0.02	40.19	15.52
Cropland	20	109,164,694	45.98	98,248.22	37,933.64
Grassland	30	99,643,822	41.97	89,679.44	34,625.23
CRP Land	31	12,773,479	5.38	11,496.13	4,438.66
Woodland	40	9,672,588	4.07	8,705.33	3,361.13
Water	50	1,875,701	0.79	1,688.13	651.79
Other	60	202,238	0.09	182.01	70.28
Total		***237,432,570***	***100.00***	***213,689.31***	***82,505.44***

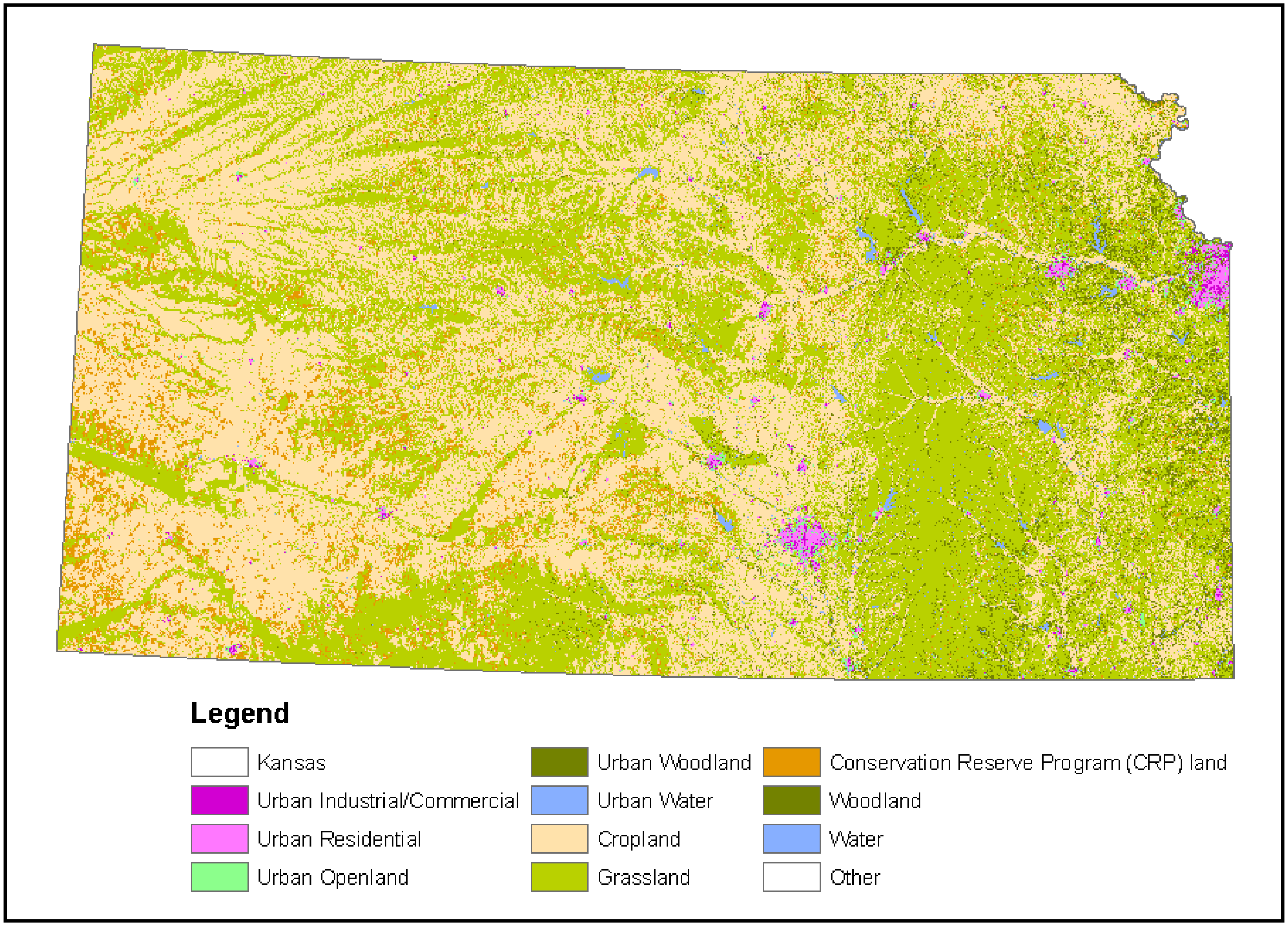


Figure 2. The 2005 Kansas Land Cover Patterns map developed using multi-seasonal Landsat Thematic Mapper (TM) imagery.

Accuracy Assessment

Field campaigns for accuracy assessments can be costly and time-consuming endeavors. Rather than conducting an independent field campaign for the accuracy assessment, two existing databases were used to assess the accuracy of the 2005 land cover map. The 2005 Common Land Unit (CLU) dataset was used to assess the accuracy of mapped grassland and cropland and the Kansas GAP vegetation database was used to assess the accuracy of mapped woodlands. The Kansas GAP vegetation database is a digital database of sample sites used for training and validation of the Kansas Vegetation Map (Egbert *et al.*, 2001). Urban and water databases were unavailable, and therefore, manual photo interpretation of high-resolution digital aerial photography was used to assess the accuracy of these land cover classes.

More than thirty thousand sample sites were used to generate the formal accuracy assessment. The formal accuracy assessment consists of an error matrix, an overall accuracy figure, Cohen's Kappa statistic (1960), and for each class, omission accuracy (often referred to as producer accuracy) and commission accuracy (user accuracy).

Sampling Unit:

According to Congalton and Green (1991), the sampling unit dictates the level of detail in the accuracy assessment and the same MMU used for map development should also be used for reference data development. The MMU and the spatial detail of the map were the two factors considered for selecting the appropriate sampling unit.

With the exception of the urban and rural water classes, all land use/land cover classes had MMU's greater than a single pixel. Therefore, single pixels were deemed inappropriate sampling units for the accuracy assessment. Since the land cover map depicts landscape features (i.e., fields of cropland or grassland, stands of trees, etc.), polygon features were selected as the most appropriate sampling unit for the accuracy assessment. The MMU for each land cover class was used as an area threshold for site selection (i.e. polygon features less than the MMU were excluded from the accuracy assessment).

Site Selection and Sample Size:

A stratified random sample by land use/land cover class was used to select sites for the accuracy assessment. Sample size was roughly proportionate to the percent area mapped for each land use/land cover class. According to Congalton and Green (1991), a minimum of 75-100 samples should be used per land use/land cover class when mapping large areas. Seventy-eight sites were selected from the smallest class mapped (Commercial/Industrial, representing 0.28% of the total study area). The numbers of samples selected for the additional map classes were determined using roughly the same sample-size-to-area-mapped ratio, with the exception the woodland class, which lacked the available data to maintain a similar proportion (Table 6). A total of 31,298 sites were used to assess the accuracy of the land cover map.

Table 7. Number of samples for the accuracy assessment by LULC class, proportioned by mapped area.

LULC Class	Sample Size	Area Mapped (%)
Urban Commercial/Industrial	78	0.28
Urban Residential	114	0.57
Urban Openland	187	0.48
Cropland	15,719	48.39
Grassland	13,278	42.20
CRP	0	3.98
Urban and Rural Woodland	673	3.30
Urban and Rural Water	1231	0.65
Other	0	0.07
Total	*31,298*	*100*

The approach and methods used to generate ground reference data for land cover class are described below.

Urban:

Polygons within urban areas were randomly selected from the land cover map. Randomly selected polygons were visually interpreted using the 2005 NAIP as ground reference and assigned an urban class. For the accuracy assessment, urban water and urban woodland were grouped with rural water and woodland classes.

Water:

Two hundred two-square mile areas were randomly selected from the statewide public land survey system (PLSS) data layer. For each selected area, water bodies larger than 30 m x 30 m (one TM pixel) were identified on the NAIP and digitized. Because many streams in the study area are ephemeral, only standing water bodies were represented in the accuracy assessment.

Grasslands:

Dominant grass types (e.g. Fescue, Brome, Native, Big Blue, etc.) specified by the attribute "TYPE_ABBR" in the CLU database were subset from the CLU database. Several grassland features and types were excluded from the accuracy assessment. The description and rationale for the exclusions follow.

- Uncommon grass types, defined as representing less than 100 acres in the state (as determined by the CLU database), and grasses grown in a crop type fashion for sod (e.g. Crabgrass, Turf, Zoysia), were excluded from the site selection process.
- CRP land was excluded from the grassland accuracy assessment since this land cover class was derived directly from the CRP layer in the CLU database.

- The 30m spatial resolution of Landsat Thematic Mapper is too coarse to map many grass waterway features (grass planted in drainage routes in crop fields to reduce soil erosion). Because of this limitation, grass waterway features were excluded from the accuracy assessment. These features were identified as having a relatively high perimeter-to-area ratio. Specifically, grassland features with a perimeter-to-area threshold greater than 45.2 were eliminated from the accuracy assessment site selection process.

Woodlands:

Accuracy levels for the rural and urban woodland classes were assessed using the Kansas GAP vegetation database. The woodland polygons from the GAP database were overlaid on 2005 NAIP and sample sites with positional accuracy problems or sample sites that fell on non-woodland, were modified or deleted from the database. To ensure adequate class representation, additional urban woodland sites were collected using manual photo interpretation techniques.

Other:

The "other" class was not included in the accuracy assessment since the class represents such a small percentage (0.07%) of the study area and is a rare, catch-all class, (e.g. the class represents bare earth (other than tilled cropland), rock outcrops, sandbars, and man-made features). Therefore, a random, non-clustered dataset for use in the accuracy assessment could not be developed.

Accuracy Assessment Results:

The overall accuracy of the map was 90.72%, easily surpassing the goal of achieving an accuracy level greater than 85%. The Cohen KAPPA statistic was 83.54%. These results represent the highest overall accuracy level for a Level I map produced by the Kansas Applied Remote Sensing Program to date.

Table 8. User and Producer accuracy levels by land use/land cover type.

LULC Class	LULC Code	User Accuracy (%)	Producer Accuracy (%)
Urban Commercial Industrial	11	61.05	74.36
Urban Residential	12	48.35	77.19
Urban Openland	13	78.43	64.17
Cropland	20	90.92	93.37
Grassland	30	91.23	88.58
CRP	31	NA	NA
Woodland (rural and urban)	14 & 40	95.77	80.68
Water (rural and urban)	15 & 50	95.81	92.93
Other	60	NA	NA

During initial tabulations of the error matrix, confusion between cropland and grassland classes raised concern regarding the accuracy of the CLU data, which had been used as ground reference data for parts of the accuracy assessment. To determine whether the reported accuracy levels were reflecting error in the CLU database, CLU features contributing to errors of omission and commission in the grassland and cropland classes were visually interpreted using the 2005 NAIP as reference. A total of 2020 grassland features and 1205 cropland features were visually interpreted.

Of the 2020 grassland sites evaluated in the CLU database, 166 were visually interpreted to be cropland or woodland and 137 features were labeled as confused or undecided. These 303 sites were eliminated from the final accuracy assessment. Likewise, 124 cropland fields in the CLU database were interpreted as grassland, 3 as woodland, 1 as water and 34 undecided. These 162 sites were also eliminated from the final accuracy assessment.

Interestingly, a large number of problematic CLU's were clustered in one county. Combining the grassland and cropland CLU assessments, this particular county had an error rate of 43%. The high error rate may have been a function of database management error, specifically, how the attribute database was joined to the polygon feature database. Because of the high error rate, all sample sites from this county were dropped from the accuracy assessment. After the errors in the CLU database were identified and eliminated, accuracy levels were recalculated.

Even though user and producer accuracy levels for cropland and grassland were relatively high (88-93%), there were some misclassification errors (omission and commission errors) between these two land cover classes (Table 8). The sections below explore and discuss multiple scenarios in which these misclassification errors occur.

Difficulties Mapping Grasslands:

There were 1,457 fields, or features, mapped as cropland that the CLU database identified as grassland (Table 8). Approximately 47% of these grassland areas were cool-season grasslands and 53% were warm-season grasslands. The majority of these fields were relatively small (Figure 3).

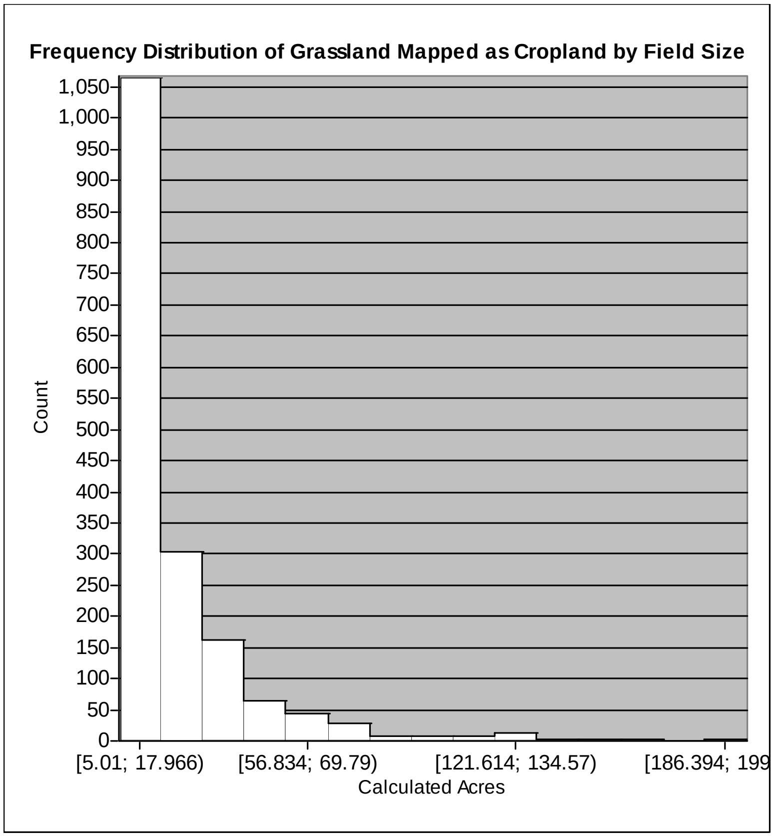


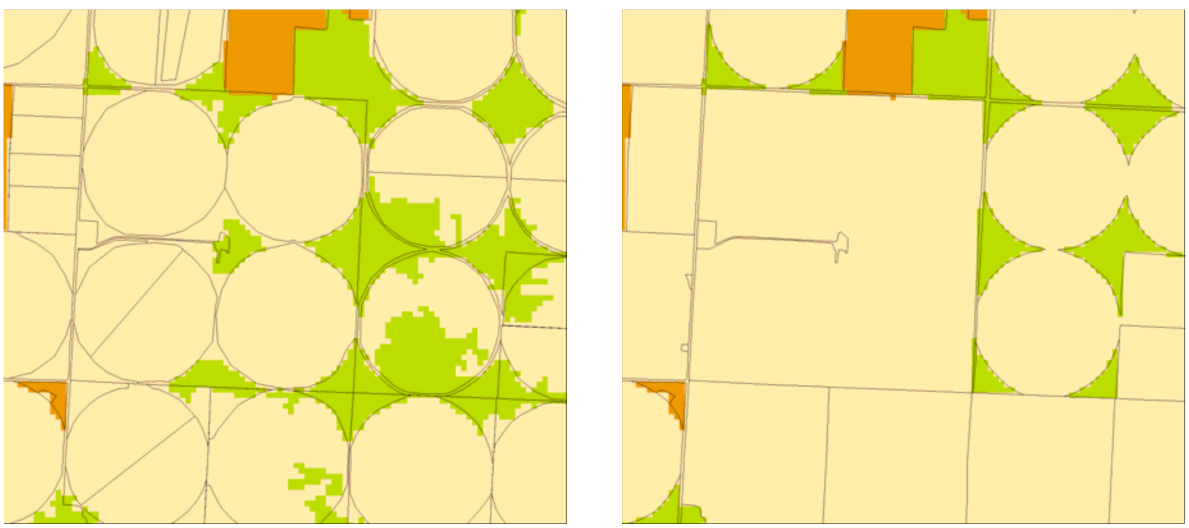
Figure 3. The frequency distribution of grassland areas mapped as cropland (grassland omission and cropland commission errors). A large proportion were relatively small center pivot field corners that were either not mapped or were mapped but eliminated during either stage 2 or stage 3 of the generalization process.

Misclassifying cool-season grasslands as cropland. Seventy-six percent (527 fields) of the cool-season grasslands misclassified as cropland were either brome or smooth brome fields and were located primarily in the eastern half of the state. Common management practices on cool-season grasslands (brome and fescue) include fertilizing, grazing, and haying and the frequency and duration of these management practices varies. It is likely that these management practices caused spectral confusion between cool-season grasslands and cropland in the image classification. Using three dates of TM imagery, the lush spring vegetation in brome fields was spectrally similar to winter wheat fields, while haying events generated a spectral response similar to a harvested spring or summer crop, depending on the timing of the haying event.

Misclassifying warm-season grasslands as cropland. There were 768 fields of warm-season grassland inaccurately mapped as cropland. Eighty percent of these warm-season grasslands were located in western half of the state. Upon further investigation, we found that a large number of these features were corners of center pivot fields (Figure 4). While some of these small corners were not detectable or mapped using TM data, others were successfully mapped, but subsequently eliminated during the generalization process.

Center pivot corners less than the MMU (5 acres or 23 pixels) were eliminated in stage 2 of our generalization procedure. And, some of the center pivot corner features exceeding the MMU were eliminated during stage 3 of the generalization procedure. During stage 3 of the generalization procedure, which used the unattributed CLU data, the zonal majority within each CLU polygon was calculated and pixels within the CLU were reassigned to the zonal majority value. Unfortunately, there were discrepancies in the level of detail between the 63-county attributed CLU data (used for the accuracy assessment) and the statewide unattributed CLU data (used for stage 3 of the generalization). More specifically, there were instances where center pivot corners were delineated in the attributed CLU data but not in the unattributed CLU database (Figure 4).

Figure 4a shows center pivot corners mapped as grassland that were larger than the MMU (after stage 2 of the generalization) with the attributed CLU data overlaid. Figure 4b shows how these center pivot corners were eliminated during stage 3 of the generalization due to the more coarse field representation in the unattributed CLU data. Although the use of the unattributed CLU data in the generalization process caused a few undesirable outcomes such as this, we believe the overall benefits of its use in cleaning up misclassified areas and improving cartographic representation far exceeds the loss of these smaller features.



(a) (b)

Figure 4. (a) An example of grassland corners mapped and maintained following stage 2 of the generalization procedure shown with the attributed CLU data (used for accuracy assessment) overlaid. (b) Same area after stage 3 of the generalization with the unattributed CLU overlaid. The unattributed CLU data does not include all center pivot corners and therefore many of these areas were recoded to the zonal majority land cover class, cropland.

Difficulties Mapping Cropland Features:

Misclassifying cropland as grassland. Of 15,836 cropland reference sites used in the accuracy assessment, 1,012 were misclassified as grassland (Table 8). Over 70% of these sites were soybeans, fallow land, or winter wheat. According to the CLU database, 172 (17%) soybean sites were misclassified as grassland, with half of those sites falling within TM path/row 27/33 in northeastern Kansas. The TM triplicate for this processing unit had a summer date of June 22, 2005, a date potentially too early in the growing season to classify all instances of late summer crops such as soybeans.

Of the 1,012 cropland sites misclassified as grassland, 246 (24%) were labeled as fallow land in the CLU database. The potential for fallow land to be defined as a land use and also as a land cover type explains a large portion of these "classification errors". From a land use perspective, fallow land has been temporarily removed from cultivation as a land management strategy for weed control and/or to conserve soil nutrients and soil moisture. However, from a land cover perspective, during the first year fallow land is composed of crop stubble and bare soil, with little or no vegetation cover. Lands removed from cultivation for one or more years, would no longer be bare soil but would be in the early stages of plant succession. Therefore, bare fields were typically mapped as cropland, while fields idle or fallow for one or more years with established vegetation cover were mapped based on the dominant land cover type. And in many instances the dominant vegetation cover was (weedy) grassland and in rare instances, woodlands. The CLU data lacks information regarding the timing or duration of fallow status.

Approximately 316 (31%) cropland features misclassified as grassland were non-irrigated winter wheat fields. In some areas, the date of the spring image may have been too early (mid- to late-March) to differentiate all non-irrigated winter wheat from grassland. In contrast, irrigated wheat fields in these same areas were lush and consequently were more spectrally distinct from grassland.

Difficulties Mapping Urban Features:

The inherent heterogeneity and fragmentation typical of urban landscapes can make image classification of urban areas using 30 m TM data challenging. For example, four-lane highways traverse residential and commercial areas alike. Small strip malls reside in the midst of residential areas. Wooded streams flow along highways and through industrial bottomlands. Compounding the mapping challenge, most urban land use classes are a mix of land cover types. For example, the residential land use class is composed of several cover types; concrete/asphalt roads, drives, and sidewalks, trees and grass-covered lawns, and a variety of rooftop types. In a mature neighborhood, the overall mix of these cover types will generally be detected by a TM pixel as a distinct land use class. However, this ideal falls apart very quickly in low density residential areas such as suburbs and small towns, where the spacing between the various cover types tends to increase and grass and tree cover become the dominant features detected within the TM pixel. Similar situations of classification confusion can be found in other urban land use classes. Therefore it should not be altogether surprising that user and producer accuracy levels for the urban classes were relatively low. In spite of these challenges, the classification of urban areas holds up quite well when a visual comparison is made with the 2005 NAIP photography.

Misclassification of Openland as Residential. Commission errors for the residential class were relatively high, meaning residential areas were overestimated. The relatively low user accuracy level (48.35%) for the residential class was largely the result of two scenarios: 1) urban openland areas possessing moderate densities of roads were often misclassified as residential (Figure 5) and 2) very low density residential areas were often classified as urban residential rather than urban openland (Figure 6). These scenarios also explain the relatively low producer accuracy level (high omission error) for the urban openland class. The confusion between urban residential and openland largely hinges on difficulties developing mutually exclusive spectral class signatures for these two land use classes, especially for rural residential areas that include varying proportions of both residential and openland.

Contributing to the poor classification accuracy for the residential and urban openland classes was the decision to delineate suburban residential areas as an urbanized area. Because there are numerous suburban residential areas located outside urban boundaries in many parts of Kansas, the decision was made that they constitute an import feature to map. However, the lot size in these developments are often 5 acres or greater. Consequently, the dominant cover types are often grasses and these areas were classed as urban openland. In hindsight, it could be argued whether these areas should have been included in the urban delineation.

Figure 5. Examples of urban openland areas classified as residential. Typically, these areas had moderate road densities and a mix of land cover types.

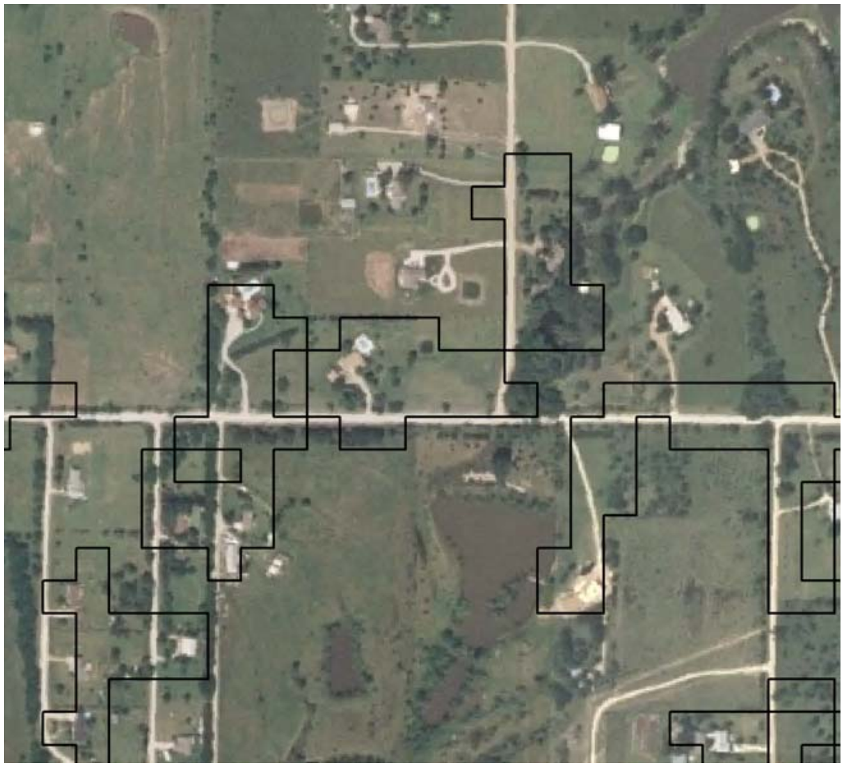


Figure 6. Rural residential areas classified as residential are highlighted in black. The density of roads and houses and lot size were among the factors determining whether such areas were mapped as residential or urban openland.

Table 9. Error matrix for the 2005 Kansas Land Cover Patterns map. The error matrix is a cross-tabulation between the map and ground reference data and is used to calculate accuracy levels.

Ground Reference Data

Classified Map

Land Cover Class	**Code**	**Commercial/ Industrial** 11	**Residential** 12	**Urban Openland** 13	**Cropland** 20	**Grassland** 30	**CRP** 31	**Woodland** 40	**Water** 50	**Other** 60	***Row Total***
Commercial/Industrial	**11**	**58**	13	21	0	0	NA	1	2	NA	*95*
Residential	**12**	14	**88**	46	0	0	NA	19	2	NA	*182*
Urban Openland	**13**	2	13	**120**	0	0	NA	10	5	NA	*153*
Cropland	**20**	0	0	0	**14,753**	1,639	NA	9	0	NA	*16,401*
Grassland	**30**	0	0	0	1,037	**11,941**	NA	53	65	NA	*13,096*
CRP	**31**	0	0	0	33	55	NA	1	13	NA	*102*
Woodland	**40**	0	0	0	6	18	NA	**543**	0	NA	*567*
Water	**50**	4	0	0	5	2	NA	37	**1,144**	2	*1,194*
Other	**60**	0	0	0	2	3	NA	0	0	NA	*5*
Column Total		*78*	*114*	*187*	*15,836*	*13,658*	*0*	*673*	*1,231*	*2*	***31,795***

Summary

The 2005 Kansas Land Cover Patterns map represents Phase 1 of a two-phase mapping initiative occurring over a three-year period. The map is designed to be explicitly comparable to the 1990 Kansas Land Cover Patterns map. Using a similar methodology to produce the 2005 Kansas Land Cover Patterns map provides opportunities to identify and examine how the Kansas landscape has changed over a 15-year period.

The map contains eleven land use/land cover classes. The positional accuracy and spatial resolution of the map are appropriate for producing 1:50,000 scale maps. The map is not intended to define precise boundaries between landscape features and while the source satellite images have a spatial resolution of 30 m x 30 m, the minimum map unit varies by land cover class and ranges between 0.22 to 5.12 acres.

The formal accuracy assessment reports an overall accuracy level of 90.72%. User and Producer accuracies vary by land cover class and rural classes have higher accuracy levels (88-95%) than urban classes (48-78%). Users are encouraged to reference the reported accuracy levels in this report and/or metadata when using the 2005 Kansas Land Cover Patterns map. Digital versions of the map, metadata, and accuracy assessment can be accessed from the Data Access and Support Center (DASC) website of the Kansas Geological Survey (http://www.kansasgis.org/).

During Phase 2, subclasses will be mapped to produce a Modified Level II map of Kansas using 250-meter resolution time-series MODIS NDVI imagery. To produce the Modified Level II map, cropland and grassland will be broken into subclasses. Cropland from the Level I map will be used as a mask to identify and isolate cropland areas in the MODIS imagery. An unsupervised classification approach will be used to map the following cropland subclasses: row crops, small grains, double crop, and fallow land. The cropland pixels in the Level I map will be reassigned to the cropland subclass. Likewise grassland from the Level I map will be used to identify and isolate grassland pixels in the MODIS imagery. An unsupervised classification will be used to map cool-season and warm-season grasslands. Next, grassland pixels in the Level I map will be reassigned to the grassland subclass. A formal accuracy assessment of the Level II map will be performed and delivered along with the digital map and final report.

References

Anderson, J., E. Hardy, J. Roach, and R. Witmer. 1976. A Land Use and Land Cover Classification System for Use with Remote Sensor Data, *Geological Survey Professional Paper # 964*, USGS, Washington, D.C.

Cohen, J. 1960. A coefficient of agreement for nominal scales. *Educational and Psychological Measurement*, Vol. 20(1): 37-40.

Congalton, R. G. and K. Green. 1999. *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*. Lewis Publishers: Boca Raton, Florida.

Egbert, S.L., D.L. Peterson. A.M. Stewart, C.L. Lauver, C.F. Blodgett, K.P. Price, and E.A. Martinko. 2001. The Kansas GAP land cover map final report. *Kansas Biological Survey Report #99*, University of Kansas, Lawrence, Kansas.

Jensen, J.R. 1996. *Introductory Digital Image Processing*. Prentice-Hall, Upper Saddle River, NJ.

KARS (Kansas Applied Remote Sensing). 1973. *Kansas Land Use Patterns*. Lawrence, Kansas: Kansas Biological Survey, University of Kansas.

KARS. 1997. *Kansas Land Cover Patterns*. Lawrence, Kansas: Kansas Biological Survey, University of Kansas.

KARS. 2002. *Kansas Vegetation Map*. Lawrence, Kansas: Kansas Biological Survey, University of Kansas.

Whistler, J.L., B.N. Mosiman, J. Campbell, and D.L. Peterson. 2006. The Kansas Satellite Image Database 2004-2005: Final Report. *Kansas Biological Survey Report #127*. Lawrence, Kansas.

Whistler, J., M.E. Jakubauskas, S.L. Egbert, E.A. Martinko, D.W. Baumgartner, and R. Lee. 1995. Kansas Land Cover Mapping Project: Regional Scale Land Use/Land Cover Mapping Using Landsat Thematic Mapper Data. *ACSM/ASPRS Annual Convention and Exposition Technical Papers*, Vol. 3, pp773-785.

List of Acronyms and Abbreviations

AML	Arc Macro Language
CLU	Common Land Unit
CRP	Conservation Reserve Program
DASC	Data Access and Support Center
EPSCoR	Experimental Program to Stimulate Competitive Research
FID	Feature ID
FSA	Farm Service Agency
KARS	Kansas Applied Remote Sensing Program
KBS	Kansas Biological Survey
KGS	Kansas Geological Survey
KDOT	Kansas Department of Transportation
KSID	Kansas Satellite Image Database
LULC	Land Use / Land Cover
MMU	Minimum Mapping Unit
NAIP	National Agriculture Imagery Program
NSF	National Science Foundation
NRCS	Natural Resources Conservation Service
PLSS	Public Land Survey System
TM	Thematic Mapper
USDA	US Department of Agriculture