

# Statewide land cover derived from multiseasonal Landsat TM data A retrospective of the WISCLAND project

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## Abstract

Landsat Thematic Mapper (TM) data were the basis in production of a statewide land cover data set for Wisconsin, undertaken in partnership with U.S. Geological Survey's (USGS) Gap Analysis Program (GAP). The data set contained seven classes comparable to Anderson Level I and 24 classes comparable to Anderson Level II/III. Twelve scenes of dual-date TM data were processed with methods that included principal components analysis, stratification into spectrally consistent units, separate classification of upland, wetland, and urban areas, and a hybrid supervised/unsupervised classification called "guided clustering." The final data had overall accuracies of 94% for Anderson Level I upland classes, 77% for Level II/III upland classes, and 84% for Level II/III wetland classes. Classification accuracies for deciduous and coniferous forest were 95% and 93%, respectively, and forest species' overall accuracies ranged from 70% to 84%. Limited availability of acceptable imagery necessitated use of an early May date in a majority of scene pairs, perhaps contributing to lower accuracy for upland deciduous forest species. The mixed deciduous/coniferous forest class had the lowest accuracy, most likely due to distinctly classifying a purely mixed class. Mixed forest signatures containing oak were often confused with pure oak. Guided clustering was seen as an efficient classification method, especially at the tree species level, although its success relied in part on image dates, accurate ground truth, and some analyst intervention.

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## 1. Introduction

In 1992, the most current land cover data available for Wisconsin were the U.S. Geological Survey (USGS) Land Use and Land Cover (LULC) data (U.S. Geological Survey, 1990). The LULC data were compiled from aerial photographs dating from 1971 to 1982, with a majority of the classes having a minimum mapping unit of 40 acres. A

number of data users involved in biodiversity studies or landscape analysis were interested in updated and finer-scale land cover data. At that time, the Environmental Remote Sensing Center (ERSC) at the University of Wisconsin-Madison had been investigating the use of Landsat Thematic Mapper (TM) data to derive land cover maps for Wisconsin. The studies had proven promising enough to use satellite data for mapping land cover over the entire state. Lillesand (1992) documented this in a report to the Soil Conservation Service and proposed a set of methods, a classification scheme, and an organizational structure for large-area land cover mapping. On the basis of this document, several state agencies and the USGS Biological Resources Division's Gap Analysis Program (GAP) (Scott et al., 1993) undertook a satellite-assisted land cover mapping project for Wisconsin.

Previous research had been conducted to refine remote sensing methods applicable to Great Lakes states' vegetation.

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Studies indicated that image stratification could improve classification (Harris & Ventura, 1995; Homer, Ramsey, Edwards, & Falconer, 1997; Nagel, 1995; Stewart, 1994; Stewart & Lillesand, 1995), that dual-date imagery was useful for obtaining species-level classification in both forest (Coppin & Bauer, 1994; Polzer, 1992; Schriever & Congalton, 1993; Wolter, Mladenoff, Host, & Crow, 1995) and agriculture (Lillesand, 1992; Stewart, 1998; Stewart & Lillesand, 1995), and that a combination of classification methods could be used to better distinguish tree species (Bauer et al., 1994; Wolter et al., 1995). Most of these studies had concentrated on one or two satellite scenes but had not been applied to an entire state. GAP projects previous to 1992, mainly conducted in western and southern states, were not identically applicable to Wisconsin as they had different classification schemes and resolutions (e.g., in some western GAP projects, the final minimum mapping unit was 100 ha). In creating new land cover data, users required that the classification scheme be compatible with existing schemes and applicable to vegetation classes accurately mapped using Landsat TM data. The scheme also needed to be suitable for the neighboring states of Minnesota and Michigan, also involved in Upper Midwest GAP (UMGAP) at that time.

In 1993, the Wisconsin Department of Natural Resources (DNR) and the Wisconsin State Cartographer's office began organizing a consortium to purchase and process satellite imagery necessary for a statewide land cover layer. Wisconsin Initiative for Statewide Cooperation on Landscape Analysis and Data (WISCLAND) was formed, ultimately consisting of five federal government agencies, four state agencies, the Wisconsin Land Information Board, one private sector organization, and one university representative (Lillesand, 1994). In total, \$1.48 million were contributed in cash and in-kind donations to support the project from January 1994 to June 1998.

Steps leading up to the project have been described in Gurda (1994) and Lillesand (1994). This paper provides information specific to a large area image processing effort as seen in retrospect. Materials are described, such as multiseasonal Landsat TM imagery and an extensive ground truth database. The methods included a number of different stratifications of the TM imagery, such as urban versus rural stratification, wetland versus upland stratification, and stratification of each TM scene into separate classification units based on spectral similarity. Guided clustering, a hybrid supervised/unsupervised classification, was used to achieve a better species-level classification. Results are given in the form of accuracy assessment matrices with discussion following.

## 2. Project area

Wisconsin lies in the Midwestern United States between 42°30'–47°00' N and 87°15'–93°00' W and

covers about 14 million ha (Fig. 1). Elevation ranges from 177 to 576 m above sea level, with little local relief except in the southwestern “unglaciated” area of the state. A northern region of boreal and mixed deciduous forests is separated from a southern region of agriculture and temperate forests by a fairly distinct belt that Curtis (1959) termed “the tension zone.” The northern forests are a northern hardwood forest type consisting primarily of (in alphabetical order) balsam fir (*Abies balsamea*), red, silver, and sugar maple (*Acer rubrum*, *Ac. saccharinum*, and *Ac. saccharum*), yellow and paper birch (*Betula lutea* and *B. papyrifera*), various species of ash (*Fraxinus* spp.), tamarack (*Larix laricina*), bigtooth and trembling aspen (*Populus grandidentata* and *P. tremuloides*), white and black spruce (*Picea glauca* and *P. mariana*), jack, red, and white pine (*Pinus banksiana*, *Pin. resinosa* and *Pin. strobus*), white, northern pin, and red oak (*Quercus alba*, *Q. ellipsoidalis*, and *Q. rubra*), American arborvitae (*Thuja occidentalis*), basswood (*Tilia americana*), and hemlock (*Tsuga canadensis*). The southern portion of the state, while now primarily agricultural, was previously tall-grass prairie, oak savanna, and sugar maple-basswood forest. Wetlands originally covered approximately one-quarter of the state. Today, more than half (amounting to 2 million ha) of the original wetlands



Fig. 1. The state of Wisconsin.

Table 1  
Landsat TM scenes used in Wisconsin land cover mapping project

Geographic location	Dominant cover type	Path/row	Date 1: spring or summer	Date 2: summer or fall
North	Forested	26/27	May 10, 1992	August 28, 1991
North	Forested	26/28	May 13, 1993	October 1, 1992
North	Forested	25/28	May 6, 1993	September 8, 1992
North	Forested	24/28	July 31, 1992	October 3, 1992
North	Forested and agricultural	23/28	May 5, 1992	July 24, 1992
Central	Forested and agricultural	24/29	July 31, 1992	October 3, 1992
Central	Agricultural	26/29	May 13, 1993	October 1, 1992
Central	Agricultural	25/29	May 19, 1992	September 8, 1992
Central	Agricultural	23/29	May 5, 1992	July 24, 1992
South	Agricultural	25/30	May 19, 1992	September 8, 1992
South	Agricultural	24/30	July 31, 1992	October 3, 1992
South	Agricultural and urban	23/30	May 5, 1992	no cloud-free date

have been converted to agriculture or urban land uses (Nagel, 1995).

### 3. Materials

#### 3.1. Satellite data

Twelve full Landsat TM scenes were needed to cover Wisconsin, and dual dates for each scene were acquired to improve species discrimination. For the mixed northern forests, it was preferred to have a summer date representing leaf-on conditions and an early fall date depicting senescence, while late spring and midsummer dates were preferred to show intra-annual crop conditions in the agricultural areas (Lillesand, 1992). When available, data within the same year were acquired to keep the effects of potential land cover changes over time to a minimum. Imagery was contributed by the GAP program, part of the Multi-Resolution Land Characteristics (MRLC) consortium. Final image dates were determined by the MRLC participants' specifications and availability of cloud-free data. Image dates are given in Table 1. While the images obtained were as cloud-free as possible, several scenes had a small amount of cloud cover. These clouds and their corresponding shadows were identified visually and a mask was delineated manually.

The Landsat 5 TM data were geometrically precision corrected by the EROS Data Center (Sioux Falls, SD) to less than 1/2 pixel root mean square error, registered to Universal Transverse Mercator coordinates, zones 15 and 16, North American Datum 1983, and resampled to 30-m pixels by cubic convolution.

Three different image band combinations were tested for classification efficiency: a 12-band file (all six reflective bands from both dates), a six-band file (TM bands 3, 4, and 5 from both dates), and principal components calculated on the six reflective bands of each image separately and combined thereafter. Principal components gave the best classification result, reduced the file size, and eliminated

redundant information due to interband correlation (Lillesand & Kiefer, 2000).

#### 3.2. Facilities and personnel

Data processing and analysis were done at Wisconsin DNR's Geographic Information System Section on DEC Alpha workstations, running UNIX Arc/Info and ERDAS Imagine. Three full-time and one half-time remote sensing analysts, one full-time administrator, one half-time GIS specialist, and three summer employees were responsible for data processing. Work began in early 1994 and was completed around June 1998. Approximately 1260 person hours were required to classify a full scene once a routine was established.<sup>2</sup> This figure includes work done on training set selection, classification, postclassification smoothing, and accuracy assessment. In addition, there was work on ground truth data: initial delineation took 3–4 weeks per scene, fieldwork was done at a rate of approximately 80 polygons (three National Aerial Photography Program or NAPP photos) per work day, and total processing time for incoming ground truth data was approximately 1400 person hours.

### 4. Preclassification work

#### 4.1. Classification scheme

Definition of a classification scheme is an initial step in any classification project. In the WISCLAND project, this task required more discussion than any other. The project used Lillesand's (1992) suggested classification scheme as a point of departure. Several existing classification schemes were also considered and incorporated to varying

<sup>2</sup> Calculated as 240 h/upland area, 240 h/wetland area, and 80 h/urban area for a total of 560 h to classify a single classification unit. Multiply the 560 h by 27 (the total number of classification units) and divide by the number scenes (12).

degrees, including Anderson's classification (Anderson, Hardy, Roach, & Witmer, 1976), the preferred GAP classification scheme from The Nature Conservancy/UNESCO (Faber-Langendoen, 1993; Grossman et al., 1998; United Nations Educational, Scientific, and Cultural Organization, 1973), NOAA Coastal-Change Analysis Program's classification (C-CAP) (Dobson et al., 1995), the Wisconsin Wetland Inventory's (WWI) classification, and additional University of Wisconsin projects. Because the land cover layer was to be interpreted from TM data, the final classification scheme and definitions were based on the abilities and limitations of the sensor as much as on the

vegetation of the Upper Midwest. The scheme went through rigorous review by partner states in UMGAP, potential users of the data, and other remote sensing experts.

The final classification scheme included classes present in Wisconsin's vegetation but not always successfully determined from remote sensing. This was termed the "extended" classification. A subset of the extended classification was proposed as a "base minimum" classification, which the project would commit to classifying. This subset contained classes previously attained using remote sensing data with an accuracy of at least 70% and

Table 2  
WISCLAND/UMGAP classification scheme

<b>1 Urban/developed</b>	
1.1 <b>High intensity</b>	4.2.2.3 Red oak
1.2 <b>Low intensity</b>	4.2.3 White birch
1.3 Golf course	4.2.4 Beech
1.4 Transportation	4.2.5 Maple
<b>2 Agriculture</b>	4.2.5.1 Red maple
2.1 <b>Herbaceous/field crops</b>	4.2.5.2 Sugar maple
2.1.1 <b>Row crops</b>	4.2.6 Balsam-poplar
2.1.1.1 <b>Corn</b>	4.2.7 <b>Mixed/other broad-leaved deciduous</b>
2.1.1.2 Peas	<b>4.3 Mixed deciduous/coniferous forest</b>
2.1.1.3 Potatoes	4.3.1 Pine-deciduous
2.1.1.4 Snap beans	4.3.1.1 Jack pine-deciduous
2.1.1.5 Soybeans	4.3.1.2 Red/white pine-deciduous
2.1.1.6 <b>Other row crops</b>	4.3.2 Spruce/fir-deciduous
2.1.2 <b>Forage crops</b>	<b>5 Open water</b>
2.1.2.1 Alfalfa	<b>6 Wetland</b>
2.1.3 Small grain crops	6.1 <b>Emergent/wet meadow</b>
2.1.3.1 Oats	6.1.1 Floating aquatic
2.1.3.2 Wheat	6.1.2 Fine-leaf sedge
2.1.3.3 Barley	6.1.3 Broad-leaved sedge-grass
2.2 Woody	6.1.4 Sphagnum moss
2.2.1 Nursery	6.2 <b>Lowland shrub</b>
2.2.2 Orchard	6.2.1 Broad-leaved deciduous
2.2.3 Vineyard	6.2.2 Broad-leaved evergreen
2.3 Cranberry bog	6.2.3 Needle-leaved
<b>3 Grassland</b>	6.3 <b>Forested</b>
3.1 Cool season grass	6.3.1 <b>Broad-leaved deciduous</b>
3.2 Warm season grass	6.3.1.1 Red maple
3.3 Old field	6.3.1.2 Silver maple
<b>4 Forest</b>	6.3.1.3 Black ash
4.1 <b>Coniferous</b>	6.3.1.4 Mixed/other deciduous
4.1.1 <b>Jack pine</b>	6.3.2 <b>Coniferous</b>
4.1.2 <b>Red pine</b>	6.3.2.1 Black spruce
4.1.3 Scotch pine	6.3.2.2 Tamarack
4.1.4 Hemlock	6.3.2.3 Northern white cedar
4.1.5 White spruce	6.3.3 <b>Mixed deciduous/coniferous</b>
4.1.6 Norway spruce	<b>7 Barren</b>
4.1.7 Balsam fir	7.1 Sand
4.1.8 Northern white cedar	7.2 Bare soil
4.1.9 White pine	7.3 Exposed rock
4.1.10 <b>Mixed/other coniferous</b>	7.4 Mixed
4.2 <b>Broad-leaved deciduous</b>	<b>8 Shrubland</b>
4.2.1 <b>Aspen</b>	9 Cloud
4.2.2 <b>Oak</b>	
4.2.2.1 White Oak	
4.2.2.2 Northern pin oak	

Table 3  
Definitions for forest classes training sets

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Forest: upland area covered with woody perennial plants, with trees reaching a mature height of at least 6 ft tall and crown closure of at least 70%.

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Coniferous: meets forest definition, and no less than 2/3 (67%) of the makeup of the canopy should be coniferous, and if deciduous is present, should not exceed 1/3 (33%) the makeup of the canopy.  
 Species level (e.g., jack pine): meets definition of coniferous forest, and no less than 80% of the canopy is that species (e.g., jack pine).  
 Mixed coniferous: meets definition of coniferous forest, but no more than 70% of the canopy is of a single coniferous species but rather a mix of coniferous species (e.g., canopy total is 80% and made up of 50% jack pine, 30% white pine, and 20% maple).

Broad-leaved deciduous: meets forest definition, and no less than 2/3 (67%) of the makeup of the canopy should be deciduous, and if coniferous is present, should not exceed 1/3 (33%) the makeup of the canopy.  
 Species level (e.g., aspen): meets the definition of deciduous forest, and no less than 80% of the canopy is that species (e.g., aspen).  
 Mixed deciduous: meets definition of deciduous forest, but no more than 70% of the canopy is of a single deciduous species but rather a mix of deciduous species.

Mixed deciduous/coniferous forest: meets forest definition, and no more than 2/3 (67%) should be from either species group (e.g., canopy is 90% and made up of 55% Northern pin oak and 45% jack pine).

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classifiable in the project's time frame. Table 2 shows the extended classification scheme with the base minimum classes in bold.

#### 4.2. Class and training set definitions

Precise definition of the land cover classes was difficult, in part because Wisconsin's forests can have a heterogeneous mixture of species. Due to the categorical nature of thematic maps, however, characteristics that separate classes must be defined. In reality, the classes can be more complex and the boundaries between them are not always so clear. Two issues concerning class definitions needed addressing: (1) wording of class definitions and (2) defining percentages of species composition for information class training sets. Discussion regarding class definitions can be found in UMGAP's protocol (Lillesand et al., 1998). The following discussion pertains particularly to forest class training set definitions.

In some of the classification schemes reviewed (e.g., Anderson et al., 1976; Dobson et al., 1995), forest was defined with a minimum of 10% canopy closure. This definition was representative of the fact that some classification schemes were based on vegetation structures and did not always correspond well to definitions used for remote sensing training sets (Schriever & Congalton, 1993; Treitz, Howarth, & Suffling, 1992). When using Landsat TM data, an area that, for example, had 10% canopy closure and 90% grass understory would have a spectral signature more similar to grass than forest. In these cases, the traditional definition of 10% canopy cover did not work well as a training set definition for forest. We therefore decided to use a level of 70% canopy closure to define a forest type training set. Other studies have also used 70% canopy closure as a threshold (Boresjö, 1989; Mickelson, Civco, & Silander, 1998).

After deciding on the forest class training set definition of at least 70% canopy closure, subclass training sets needed definition. The questions to address were, for example, should a "mixed forest" training set be defined

as a canopy containing 60% deciduous and 40% coniferous trees, while a "deciduous forest" training set could be defined as a canopy containing 70% deciduous and 30% coniferous trees? The species compositions of training sets needed to be defined and spectrally separable. At the outset, it seemed there were few guidelines on how to define these classes according to a remote sensing-derived scheme. The decisions made regarding species composition percentages were based on the assumption that the majority of reflectance from any pixel should be from the information class targeted (i.e., because canopy closure for forest was at least 70%, then the canopy should contain a minimum of 80% of the information class's species). Training set definitions are described in Table 3. For the sake of brevity, only forest class definitions are described.

#### 4.3. Ground truth data collection

An adequate ground truth database for classification and accuracy assessment across the 14 million ha mapping area did not exist and had to be created. A sampling strategy was devised meeting the following criteria: have both systematic and random components (Ott, 1988), have a statistically appropriate sample density (Thomas & Allcock, 1984), and be contemporary, accurate, and compatible with the classification scheme. Congalton (1991) recommended collecting 50 ground truth samples for each cover type within each mapping unit. The WISCLAND project had 27 classification units in all (from stratification of TM scenes into spectrally consistent classification units or "SCCU"s), resulting in a total of 31,450 reference samples needed:<sup>3</sup> 11,350 upland nonagricultural/nonurban, 5400 agricultural, 1200 urban, and 13,500 wetland. In actuality, WISCLAND used a total of 29,000 reference samples: 16,000 field-measured upland nonagricultural/nonurban samples, 4000 agricultural samples

<sup>3</sup> Assumes number of classes actually classified for a classification unit. The number would be higher still if multiplied by number of potential classes.

from farm reports, 1000 urban accuracy assessment samples interpreted from aerial photography, and 8000 wetland accuracy assessment samples digitized from aerial photography. However, the samples were not evenly distributed among individual classes (e.g., jack pine may have had 50 ground truth samples in a mapping unit, while birch had 20). It was relatively easy to get the requisite 50 samples for dominant classes within a classification unit. In poorly represented classes such as shrubland, barren, or northern pin oak, it was difficult to obtain, on a random basis, even 10 good ground truth samples per classification unit.

After comparing raw TM imagery printouts, 1:15,480 scale DNR Forestry photographs, USGS 1:24,000 scale 7.5' topographic quadrangles, and 1:40,000 scale NAPP panchromatic photos, NAPP photos were selected as a basis for ground truth collection. They had sufficient resolution, were easy to handle in the field, familiar to field personnel, imaged the same year as the TM data (1992), and flown based on the 1:24,000 scale quadrangle system. Each 7.5' USGS quadrangle in the state was systematically selected and then nominally divided by four rows and four columns into "quarter-quarters." Random selection of one quarter-quarter per 7.5' quadrangle was made. This area approximated the same extent as one NAPP photo, in which ground truth sampling was carried out. For a more detailed description of the sampling strategy, see Lillesand (1996).

Upland, agriculture, urban, and wetland classes each required different ground truth collection methods. For upland classes (forest, grassland, water, barren, and shrubland classes), 30 ground truth polygons, each a minimum size of 5.5 acres (25 pixels), were identified within each quarter-quarter. The remote sensing analysts identified these sites visually, looking at TM bands 4, 3, and 2 of both dates to find homogenous areas that also represented the spectral variability in the sampling area. Ground truth sites were then digitized into an Arc/Info database using imagery as a backdrop and simultaneously delineated on a mylar sheet placed over the NAPP photo. Field collection of upland ground truth data used the NAPP photos, the mylar overlay of ground truth polygons, and a form for recording percent canopy cover, percent of each species (adding up to 100% total), understory type, method of observation, confidence in assessment, and space for comments (see form in Lillesand et al., 1998). Ground truth collection methods were tested in a pilot area (one full TM scene) by the remote sensing analysts and revised before being put into operation. This proved to be useful in understanding the ground truth data as well as fine tuning the procedure. The bulk of ground truth data collection was done by Wisconsin DNR Forestry and Wildlife personnel who carried out this task in addition to their daily work. Their contribution greatly reduced the cost of the project. In a few cases, when photo interpretation was done by people with less local knowledge, additional field checks were needed. Of the approximately 1000 NAPP photos sent out, 3% of the photos were never returned and approximately two ground truth sites per photo were found to be inaccessible.

Agricultural ground truth data were obtained from 1992 Farm Service Agency (FSA) reports. Because of annual crop rotations, only data from the same year as the TM image acquisition could be relied upon. Lillesand (1992) found that in Wisconsin, for every 1:24,000 quadrangle area, two to three sections of FSA data should be requested for training data and another two to three for accuracy assessment. For each FSA section obtained, approximately 20 ground truth polygons were digitized, resulting in 4000 agriculture polygons for the state.

Urban area training sites were not delineated, as an unsupervised classification derived the classes of low-density or high-density urban. Golf courses were visually identified in the satellite data and confirmed using ancillary map data and photos. Accuracy assessment ground truth for urban classes was generated as random points within delineated urban areas and same-year NAPP photos were photointerpreted by a separate analyst to determine the class.

Wetland ground truth was taken from the WWI, which was digitized from 1:20,000 scale aerial photographs and had a minimum mapping unit that varied in size by county. Nagel (1995) found WWI to have an overall categorical accuracy of 78% with higher accuracy for separating wetlands from nonwetlands. The WWI database was used for both training and accuracy assessment.

## 5. Methods

The steps taken in processing the data occurred in this order: urban versus rural stratification, unsupervised classification of urban areas, stratification of the scene into spectrally consistent classification units (SCCUs), creation of principal components in each classification unit, upland versus wetland stratification, and finally classification using guided clustering. Postprocessing involved smoothing and assembly of the classifications.

### 5.1. Urban versus rural stratification

Urban areas, due to confusion with bare soil, can be classified more accurately if done separately from rural areas (Harris & Ventura, 1995; Luman, 1992; Northcutt, 1991; Robinson & Nagel, 1990). For this reason, TIGER/Line files (Bureau of the Census, 1989) were overlaid on the imagery to aid visual identification of urban areas. To separate urban from rural areas more precisely than in the TIGER/Line files, careful manual delineation was done around urban areas greater than 100 contiguous pixels. NAPP photos were visually checked for this delineation. Urban areas were then clipped out of the image data and classified separately with an ISODATA unsupervised classification. Pixels classified as low-density or high-density urban were masked out of the TM data, while nonurban pixels were "put back" into the image data.

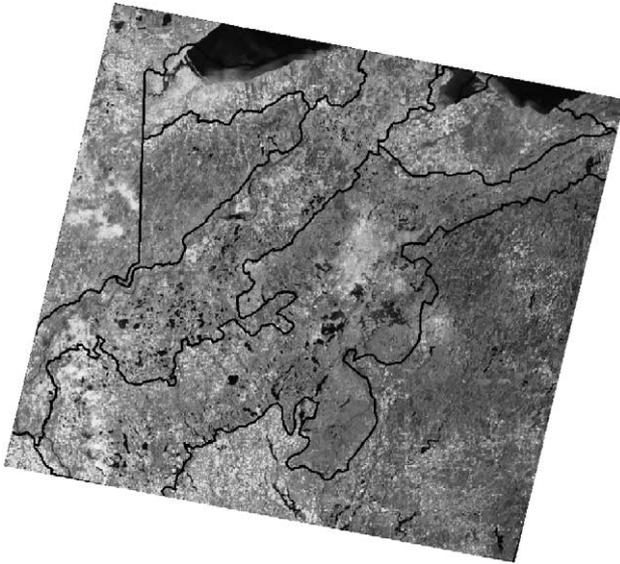


Fig. 2. The SCCU boundaries displayed over a Landsat TM image (Path 26 Row 28).

### 5.2. Spectrally consistent classification units

Within each TM scene, spectrally similar areas, referred to as SCCUs, were delineated and used as the basic classification unit. Because vegetation is influenced

by both climatic and physiographic factors, ecoregion maps can be used to guide this stratification (Stewart, 1994, 1998; Stewart & Lillesand, 1995). Different maps were considered for guiding this stratification, including the STATSGO soils map (U.S. Department of Agriculture-SCS, 1991), Omernik's ecoregions (Omernik, 1986), Bailey's ecoregions (Bailey, 1995), and Albert's ecoregions (Albert, 1995). Albert's ecoregions, derived from evaluating multiple abiotic factors—including bedrock geology, glacial landforms, soils, hydrology, and regional climatic regimes—visually correlated best with the spectral variation in the TM imagery. SCCUs were digitized using Albert's ecoregion map as a guide, although boundaries were modified where the TM imagery seemed to deviate from the ecoregion. Boundaries between TM scenes were edge matched. No more than five SCCUs were defined for a single TM scene, as using too small a classification unit might over-reduce available ground truth for that area. The mean size of a SCCU was approximately 5200 km<sup>2</sup>. An example of SCCUs delineated over a TM scene are shown in Fig. 2.

### 5.3. Principal components analysis

Before transforming the data using principal components analysis, clouds and urban areas were masked out, as these influenced the principal components results. The

Table 4  
Accuracy assessment for upland classes at Anderson Level II/III

	Reference data									
	High-density urban	Low-density urban	Agriculture	Corn	Other row crops	Forage crops	Grassland	Jack pine	Red pine	White spruce
Classified data										
High-density urban	<b>248</b>	7	0	0	0	0	0	0	0	0
Low-density urban	6	<b>275</b>	0	0	0	0	0	0	0	0
Agriculture	2	19	<b>167</b>	5	0	2	9	0	0	0
Corn	0	0	4	<b>560</b>	36	22	15	0	0	0
Other row crops	0	0	0	25	<b>180</b>	20	10	0	0	0
Forage crops	0	0	2	16	32	<b>475</b>	69	0	0	0
Grassland	0	0	16	14	18	78	<b>472</b>	1	0	0
Jack pine	0	0	0	0	0	0	0	<b>74</b>	5	0
Red pine	0	0	0	0	0	0	0	2	<b>455</b>	2
White spruce	0	0	0	0	0	0	0	0	1	<b>4</b>
Mixed/other coniferous	0	0	0	0	0	0	0	7	16	0
Aspen	0	0	0	1	2	2	10	0	0	0
Oak	0	0	0	0	1	1	1	1	0	0
Maple	0	0	0	2	0	0	1	0	0	0
Mixed/other deciduous	0	0	8	2	2	3	10	3	15	0
Mixed forest	0	0	0	0	1	0	0	3	9	1
Water	0	0	0	0	0	0	0	0	0	0
Barren	0	0	4	0	3	3	11	0	0	0
Shrubland	0	0	5	0	2	3	14	0	0	0
Total	256	301	206	625	277	609	622	91	501	7
Percent producer's Accuracy	96.88	91.36	81.07	89.60	64.98	78.00	75.88	81.32	90.82	57.14
Total correct	5493									
Total reference plots	7123									
Overall accuracy (%)	77.12									
KHAT (%)	74.52									

first three principal components (containing about 98% information of the six bands) were then calculated on each single-date SCCU from each TM scene of a date pair and merged into a single six-band file for that SCCU.

5.4. Wetland versus upland stratification

Wetlands were separated from uplands within each SCCU by using the WWI vector data as a mask. This limited confusion between spectrally similar wetland and upland types such as corn and cattails (Nagel, 1995). Errors in vector to image registration were corrected by manually warping wetland arcs to fit the imagery.

5.5. Classification with guided clustering

A hybrid supervised/unsupervised classification called “guided clustering” (Bauer et al., 1994; Lime & Bauer, 1993) was used to classify upland areas (i.e., forest, agriculture, grassland, water, barren, and shrubland classes). Land cover classes to be classified in each SCCU were determined by the presence of at least 10 ground truth sites meeting the training set definition and quality level, recorded in field as “high” (very good), “medium,” or “low” (questionable). Only “medium” and “high” confidence sites were used for training. Within each information class, ground truth sites

were randomly divided 50-50 into training and accuracy samples.

In guided clustering, an unsupervised classifier (ISO-DATA) was first run on the pixel values for all of an information class’ training sites in the SCCU, with an average output of 20 clusters. From these clusters, a subset was chosen on the basis of transformed divergence values, visual assessment, and spectral space plots and was then labelled with its information class. Eventually all subsets for each upland information class were assembled into a single signature set. With these signatures, a maximum likelihood classification was run on the upland area principal components data for the SCCU. Results were examined, and if necessary, signatures were removed and the classification was run again.

For wetland classes, WWI polygons were initially used as training sets in guided clustering. This did not work well because the TM imagery often had more spectral heterogeneity than the WWI category implied, the polygons were sometimes quite large and did not register well to the imagery, and some WWI classes were defined as mixes of different cover types. Therefore, the analyst created smaller training polygons, as guided by the WWI data, and used them in a guided clustering classification, giving an improved result.

If clouds were present in one date of imagery, the cloud-free date was used to classify the area beneath the clouds using an unsupervised classification to obtain general (non-

Mixed/other coniferous	Aspen	Oak	Maple	Mixed/other decidous	Mixed forest	Water	Barren	Shrublend	Total	Percent user's accuracy
0	0	0	0	0	0	0	0	0	255	97.25
0	0	0	0	0	0	0	0	0	281	97.87
0	1	0	1	2	0	0	1	3	212	78.77
0	0	2	0	1	0	0	3	1	644	86.96
1	0	0	0	0	0	0	0	0	236	76.27
1	0	5	1	12	0	0	0	0	613	77.49
2	8	3	3	14	0	0	3	11	643	73.41
5	0	0	0	1	10	1	0	0	96	77.08
55	1	0	0	8	16	0	0	0	539	84.42
3	0	0	0	0	0	0	0	0	8	50.00
<b>112</b>	2	1	0	3	9	0	0	0	150	74.67
3	<b>245</b>	5	16	69	9	0	0	6	368	66.58
6	6	<b>311</b>	1	108	8	0	0	0	444	70.05
0	6	37	<b>130</b>	71	1	0	0	2	250	52.00
12	129	157	75	<b>1306</b>	31	1	0	6	1760	74.21
26	12	10	2	27	<b>84</b>	0	0	1	176	47.73
0	0	0	0	0	0	<b>244</b>	0	0	244	100.0
0	0	0	0	0	0	0	<b>97</b>	0	118	82.20
0	4	0	0	4	0	0	0	<b>54</b>	86	62.79
226	414	531	229	1626	168	246	104	84	<b>7123</b>	
49.56	59.18	58.57	56.77	80.32	50.00	99.19	93.27	64.29		



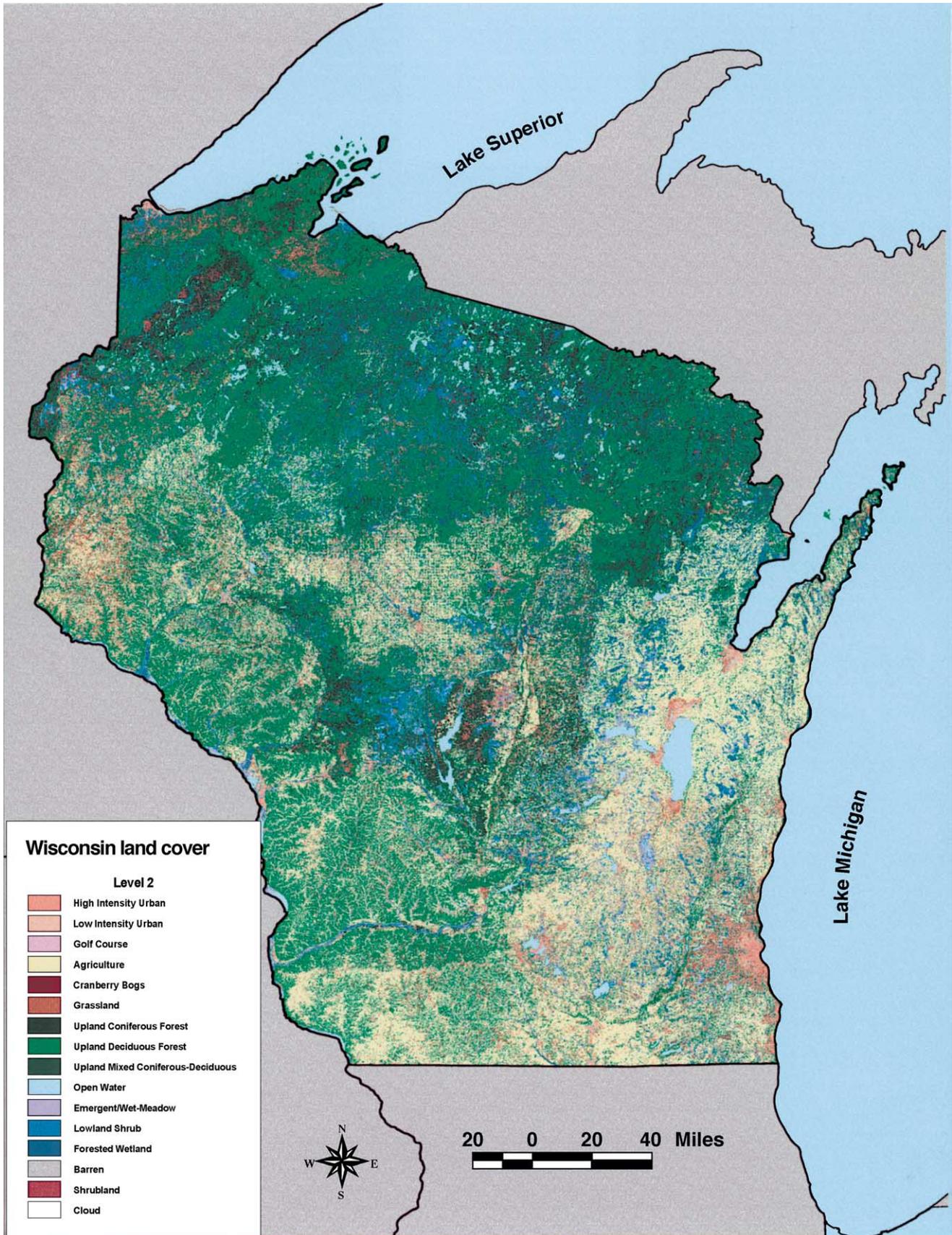


Fig. 3. The final WISCLAND classification at Anderson Level II.

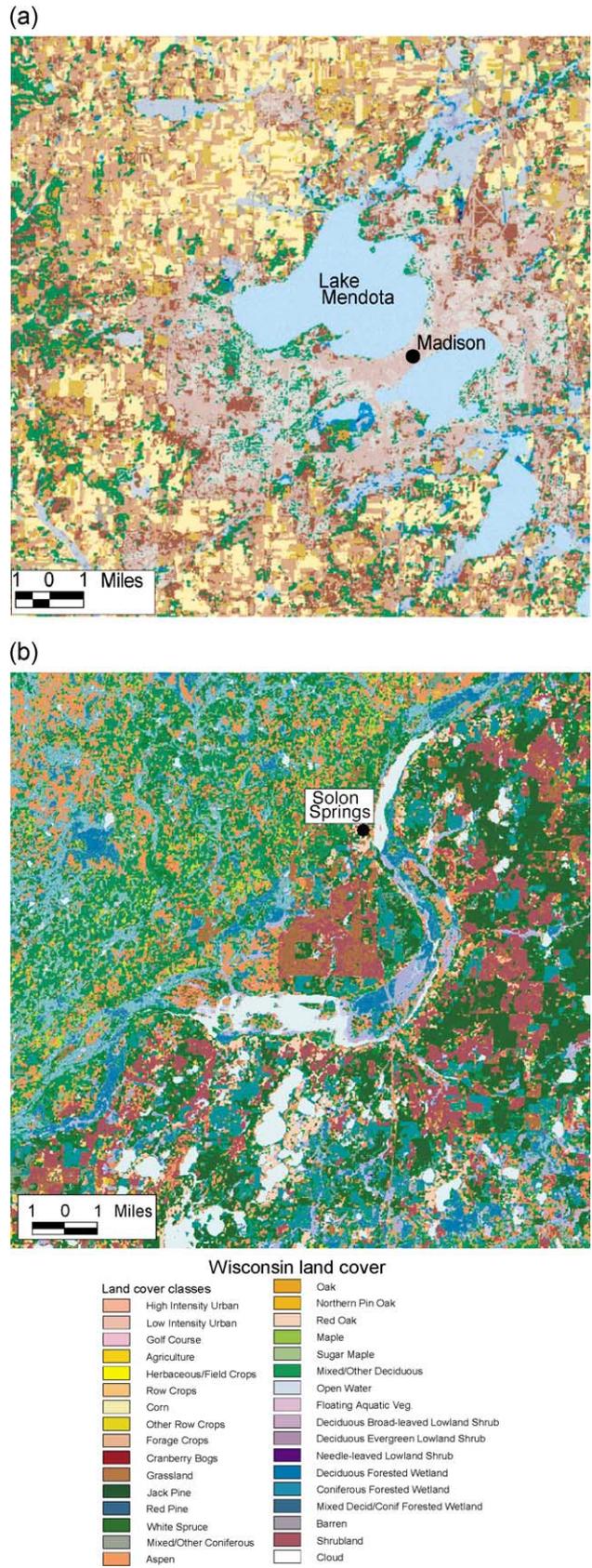


Fig. 4. A subset of the WISCLAND classification at Anderson Level II/III. The city of Madison in southern Wisconsin (a) and the St. Croix Flowage in northern Wisconsin (b).

Level II/III accuracies of 75%, and in general, these levels were reached. Upland classes exhibited a Level I overall accuracy of 94% (KHAT 90%) and Level II/III classes had an overall accuracy of 77% (KHAT 75%). Wetland classes showed a Level II/III overall accuracy of 84%.

“Guided clustering” seemed well suited to forest species classification, a process involving spectrally similar classes. It was less automatic than hoped, requiring analyst intervention to separate “good” and “bad” spectral signatures within each class. However, the method worked more efficiently in the forest and wetland classifications than a purely unsupervised or supervised approach would have.

Multiseasonal imagery was essential for discriminating among forest species and particularly between agricultural crops and grassland. Using single-date imagery, the distinction between grassland and some agricultural crops could be difficult to make. However, using dual dates, the grassland spectral signature was not as likely to change significantly between two dates, whereas agricultural fields exhibited larger differences between image dates as a result of growth or change of crop.

Accuracies for deciduous forest species were sometimes lower than anticipated given the amount of ground truth and effort. When deciduous species were misclassified, they were often confused with the mixed/other deciduous class. One explanation may be found in the imagery dates. A number of scenes were from May (9 out of 12 scenes), with some dates as early as May 5. This was an early date in Wisconsin’s growing season, and while a spring date might have been useful for differentiating agricultural classes, it was disadvantageous for species-level classification in forested areas. Fourteen SCCUs using a May scene had average accuracies of 62% for aspen, 58% for oak, and 73% for maple compared to 11 SCCUs with summer/fall dates and average accuracies of 81% for aspen, 75% for oak, and 73% for maple. In areas with both forest and agriculture cover types, it may be ideal to use three dates of imagery (spring, summer, and fall—from the same year if possible) for the best classification.

Mixed deciduous/coniferous forest was one of the classes with the lowest accuracy (50% producer’s accuracy) and was most often confused with species of coniferous or deciduous forest (22% and 29% commission error, respectively). This may have been due to the difficulty of classifying a heterogeneous class as well as labelling a distinct training set for mixed deciduous/coniferous forest (or “mixed forest”). In order for mixed forest to be classified as such, it needed in reality to be well mixed in each pixel over the 5.5-acre polygon area. A reassessment or different way to define and classify the mixed forest class (e.g., subpixel classifiers or postclassification neighborhood operations) might yield better results.

During the project, the question arose as to whether percentage limits set for training set definitions were independent of the species in the mixture. This arose

when training sets containing oak and defined as mixed deciduous (e.g., 50% oak and 50% aspen) or mixed forest (e.g., 50% oak and 50% pine) would consistently result in areas classified as oak. It seemed oak’s contribution to the reflectance from mixed forest areas was spectrally overlapping with the class defined as oak. This agrees with Mickelson et al. (1998) who found that mixed forest classes possessing a large oak component were likely to be confused with other pure oak classes. Oak was the only tree species for which we noticed this effect, although it was not investigated further.

The assumption behind using SCCUs was that delineation was based on spectral characteristics related to the vegetation and that field data were an approximate representation of the species found in each stratum. Although it was not assessed in this study, delineation of SCCUs most likely improved discrimination of forest species. However, on a large scale, the use of SCCUs resulted in variable classifications from stratum to stratum. This may cause comparison or analysis issues across SCCU borders.

Regarding the number of ground truth polygons collected for this effort, it was at no time felt that the amount of ground truth data was excessive. There was more likely a lack of ground truth data for some classes. The accuracy assessment of shrubland was low (64% producer’s accuracy) and more ground truth sites might have improved this. Approximately half of the SCCUs did not have the sufficient number of samples required to classify a shrubland class. For SCCUs with sufficient shrubland ground truth, an average of five polygons (the minimum required) were available each for accuracy assessment and training. However, other studies have also had difficulty classifying shrubland in particular (Scott et al., 1993).

While the method used for delineating ground truth polygons seemed to work well, the larger problem was that of surveying a 5.5-acre area as a single ground truth polygon. This was perhaps too large an area to cover on foot in the forest with so many ground truth sites to visit. Global Positioning System (GPS) units were not used in ground truth collection. If they had been used to survey smaller polygons, it might have provided more locational certainty.

## 8. Summary

A land cover database created from Landsat TM data was completed for the state of Wisconsin as part of the UMGAP and the WISCLAND consortium’s efforts. This project combined various methods from previous land cover mapping studies for Wisconsin and areas with similar vegetation. To classify the heterogeneous forest and agricultural areas at a species level, multiseasonal imagery, principal components analysis, extensive ground truth, stratification, and “guided clustering” were used. The project took 4-1/2 years and \$1.48 million to complete.

Overall accuracy for 7 Anderson Level I upland classes was 94%, 9 Anderson Level II/III wetland classes exhibited an 84% overall accuracy, and 15 Anderson Level II/III upland classes had a 77% overall accuracy. Accuracy results for deciduous forest species were lower than anticipated but might be partially explained by use of an early May date in imagery pairs. Summer/fall date pairs generally had higher deciduous species accuracies than the May/other date pairs. The class with the lowest accuracy was mixed deciduous/coniferous forest. This result was most likely due to attempting to distinctly classify a purely mixed class. Mixed forest signatures containing oak were often confused with pure oak, similar to reports by Mickelson et al. (1998). Stratification of the scenes into similar spectral classification units may have been effective but also resulted in variable classifications from unit to unit. Guided clustering was seen as an efficient and relatively easy way of classifying at the species level, although its success relied in part on image dates, accurate ground truth, and some analyst intervention.

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