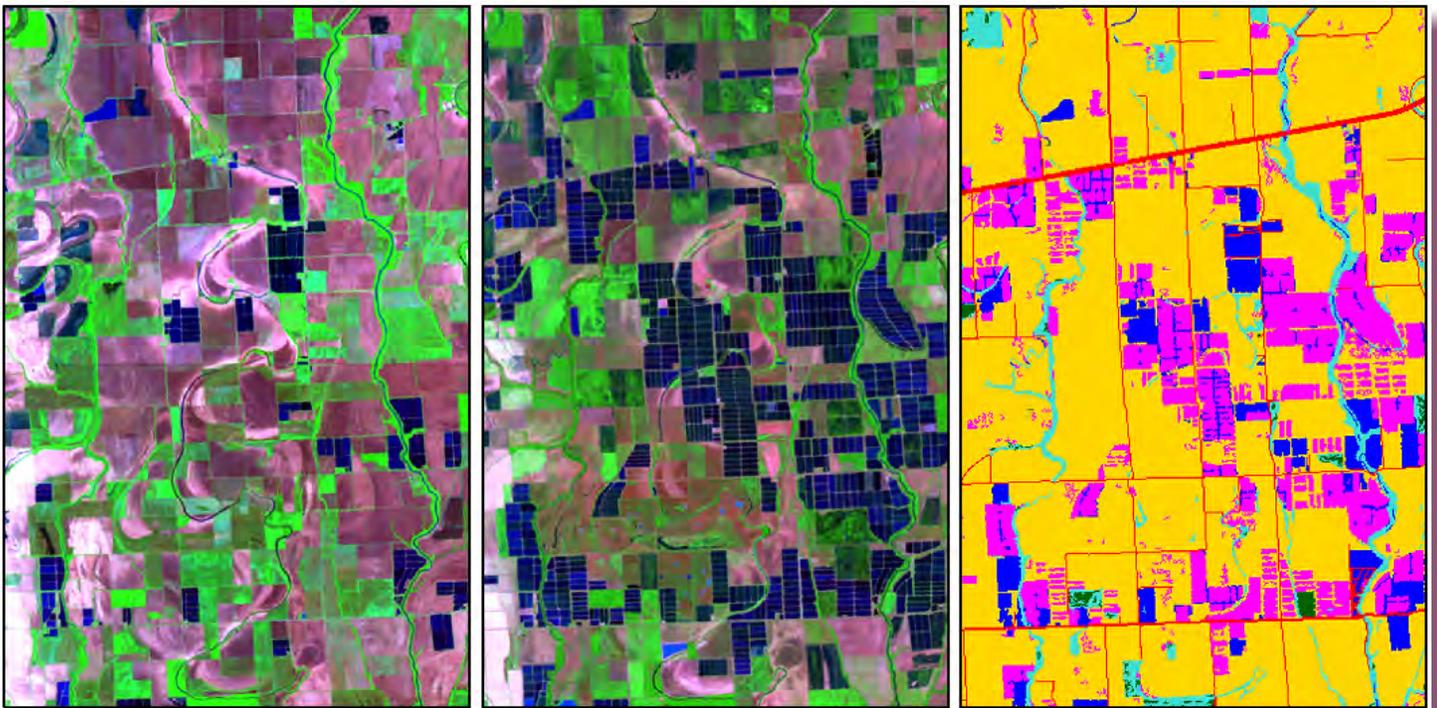


Completion of the National Land Cover Database (NLCD) 1992–2001 Land Cover Change Retrofit Product



Open-File Report 2008–1379

Front cover imagery: Agriculture to water change between 1992 and 2001 captured near Lake Village, Arkansas. Images from left to right: 1992 Landsat at-satellite reflectance, 2001 Landsat at-satellite reflectance, and the National Land Cover Database Land Cover Change Retrofit (NLCD-LCCR) product. Created December 5, 2008.

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By J.A. Fry, M.J. Coan, C.G. Homer, D.K. Meyer, and J.D. Wickham

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Conversion Factors

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
hectare (ha)	2.471	acre
square kilometer (km ²)	247.1	acre
square kilometer (km ²)	0.3861	square mile (mi ²)

Completion of the National Land Cover Database (NLCD) 1992–2001 Land Cover Change Retrofit Product

By J.A. Fry¹, M.J. Coan¹, C.G. Homer², D.K. Meyer¹, and J.D. Wickham³

Abstract

The Multi-Resolution Land Characteristics Consortium has supported the development of two national digital land cover products: the National Land Cover Dataset (NLCD) 1992 and National Land Cover Database (NLCD) 2001. Substantial differences in imagery, legends, and methods between these two land cover products must be overcome in order to support direct comparison. The NLCD 1992–2001 Land Cover Change Retrofit product was developed to provide more accurate and useful land cover change data than would be possible by direct comparison of NLCD 1992 and NLCD 2001. For the change analysis method to be both national in scale and timely, implementation required production across many Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) path/rows simultaneously. To meet these requirements, a hybrid change analysis process was developed to incorporate both post-classification comparison and specialized ratio differencing change analysis techniques.

At a resolution of 30 meters, the completed NLCD 1992–2001 Land Cover Change Retrofit product contains unchanged pixels from the NLCD 2001 land cover dataset that have been cross-walked to a modified Anderson Level I class code, and changed pixels labeled with a “from-to” class code. Analysis of the results for the conterminous United States indicated that about 3 percent of the land cover dataset changed between 1992 and 2001.

Introduction

The Multi-Resolution Land Characteristics Consortium (MRLC; <http://www.mrlc.gov>) has supported the development of two national land cover products including the National Land Cover Dataset 1992, and the National Land Cover Database (NLCD) 2001. Many users would like to

compare these two products to derive land cover change, but new improvements in mapping methodology, input data, and minor mapping legend modification for NLCD 2001 have made direct comparison between NLCD 1992 and NLCD 2001 inadvisable. Direct comparison of these two independently created land cover products is not recommended and will typically result in changes that are artifacts of different production methods rather than true change. Users that pursue direct comparison are likely to discover that differences in the methodology used to produce the two products overwhelm actual differences related to land cover change.

The NLCD design team has recognized that these legacy issues exist and developed a retrofit change product to accommodate direct comparison of NLCD 1992 and NLCD 2001. The goal of this project was to design and implement an operational solution to change analysis, based on 30-m resolution Landsat imagery that minimized error from direct comparison of the original land cover products (Vogelmann, and others, 2001; Homer and others, 2004; Homer and others, 2007), and provided invariant, standardized, and consistent land cover change information across all mapping zones in the conterminous United States. The essential design requirements were that the process was to be rigorous, automated, affordable, and fast. The product presented here, called the NLCD 1992–2001 Land Cover Change Retrofit (NLCD–LCCR) product, provides more accurate and tenable estimates of land cover change at the Anderson Level I classification scale (Anderson and others, 1976).

Background

Product Methodology Differences

For the NLCD 1992 land cover dataset, a 100-class unsupervised clustering algorithm was used to derive spectral classes (Vogelmann, and others, 1998; Vogelmann and others, 2001), which were then labeled using a hybrid classification system roughly equivalent to Anderson Level II (Anderson and others, 1976). Manual editing was used to refine the final product. Although this classification method was valid at the time and still widely used, improvements in technology and

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mapping protocols led to a decision to use a different mapping method for NLCD 2001 database products. The See5 decision tree method that was selected for NLCD 2001 (Breiman and others, 1984; Lawrence and Wright, 2001; Homer and others, 2004) had several advantages including: fast to train, objective, having a set of rules that allowed users access to classification parameters, and the option to create a classification confidence map allowing feedback on reliability. In addition, developed classes for the 2001 land cover map were modeled separately as percent imperviousness, with a threshold applied to define the different developed land cover classes. These differences in methodology used for NLCD 2001 have resulted in significantly different land cover datasets. For example, modeling imperviousness allowed the definition of many more road networks in the NLCD 2001 land cover map than was possible in the NLCD 1992 dataset.

Base Image Differences

Images selected for NLCD 1992 were chosen on the basis of brief, written, scene quality descriptions without an opportunity to examine the scenes prior to purchase. After purchase, the scenes were georegistered using image-to-image techniques and terrain corrected using Digital Terrain Elevation Data (DTED), a 3 arc-second digital terrain elevation dataset with a ground resolution of approximately 100 m (Vogelmann, and others, 1998). Scenes were then histogram matched to eliminate edge effects in adjacent images and, as a result, some spectral values in the matched areas were altered. In contrast, NLCD 2001 scenes were selected using a strategy to optimize seasonal phenology differences throughout the Nation and to provide a uniform spectral foundation for land cover mapping (Homer and Gallant, 2001; Yang and others, 2001). NLCD 2001 scenes were precision terrain corrected using 30-m digital elevation models (DEMs) from the National Elevation Dataset (NED, <http://eros.usgs.gov/products/elevation/ned.html>), through the National Landsat Archive Production System (NLAPS) and then preprocessed to at-satellite reflectance to improve compatibility of scenes collected on different dates without introducing random errors to the data (Huang and others, 2001). This resulted in differences in quality, georegistration, terrain correction, and spectral consistency between 1992 and 2001 that contributed to the substantial differences between the land cover datasets. For NLCD–LCCR, these differences were great enough to justify reprocessing 1992 era scenes with 2001 parameters to ensure consistency.

Legend Differences

Changes that were made in three NLCD 2001 legend definitions contributed to incompatibilities between the two land cover products for developed, agricultural, and barren classes. Developed classes were modeled in 2001 using an imperviousness layer threshold. Agricultural classes in 2001

were simplified to only hay/pasture and row crop (removing small grains, orchards/vineyards, and urban and recreational grasses). The barren class was simplified in 2001 to a single class. The urban and recreational grass class, included as one of the agricultural classes in 1992, was redefined as a developed open space class in the 2001 land cover legend. Also, the 1992 classification contained a transitional barren class that tended to rely on land-use interpretations. This class included forest clear-cut areas with a range of spectral values from different stages of succession that made it problematic to map accurately. However, most of these stated differences are significant only at the Anderson Level II class level and are minimized by collapsing the legend to Anderson Level I. This was one of the primary reasons NLCD–LCCR was designed to function at Anderson Level I.

Methods

Methods were developed to address known inconsistencies between the two land cover datasets. Four major steps were required for NLCD–LCCR production: (1) reclassifying both eras of land cover maps with a common legend using decision-tree mapping protocols to generate two new land cover products that were directly comparable, (2) post classification comparison and filtering, (3) spectral change analysis and change pixel labeling, and (4) final product compilation at a 5-pixel minimum mapping unit (fig. 1).

Land Cover Map Reclassification at Anderson Level I

Land cover maps were reclassified with a modified Anderson Level I (ALI) scheme (table 1) using the commercial decision tree software See5 (Quinlan, 1993).

Landsat 5 Thematic Mapper (TM) imagery used in generating mapping zone mosaics for the 1992 era was selected to match phenology of the corresponding 2001 era leaf-on mosaic as closely as possible and was pre-processed according to NLCD 2001 methods (Homer and others, 2004) to remove classification discrepancies resulting from image registration and processing differences. For the new land cover classifications, Landsat bands 1–5 and 7, processed to at-satellite reflectance, were used as input layers along with the date band, digital elevation model, slope, aspect, and positional index. In addition, special reflectance derivative data layers including a Green Normalized Difference Vegetation Index $[(\text{Band } 4 - \text{Band } 2) / (\text{Band } 4 + \text{Band } 2)]$ (Gitelson and others, 1996), a Normalized Difference Water Index $[(\text{Band } 4 - \text{Band } 5) / (\text{Band } 4 + \text{Band } 5)]$ (Gao, 1996), and a Specific Leaf Area Vegetation Index $[(\text{Band } 4) / (\text{Band } 3 + \text{Band } 7)]$ (Lymburner and others, 2000) were stacked into a 3-band image called the 3-ratio index, and included in the data model for a total of 14 input bands.

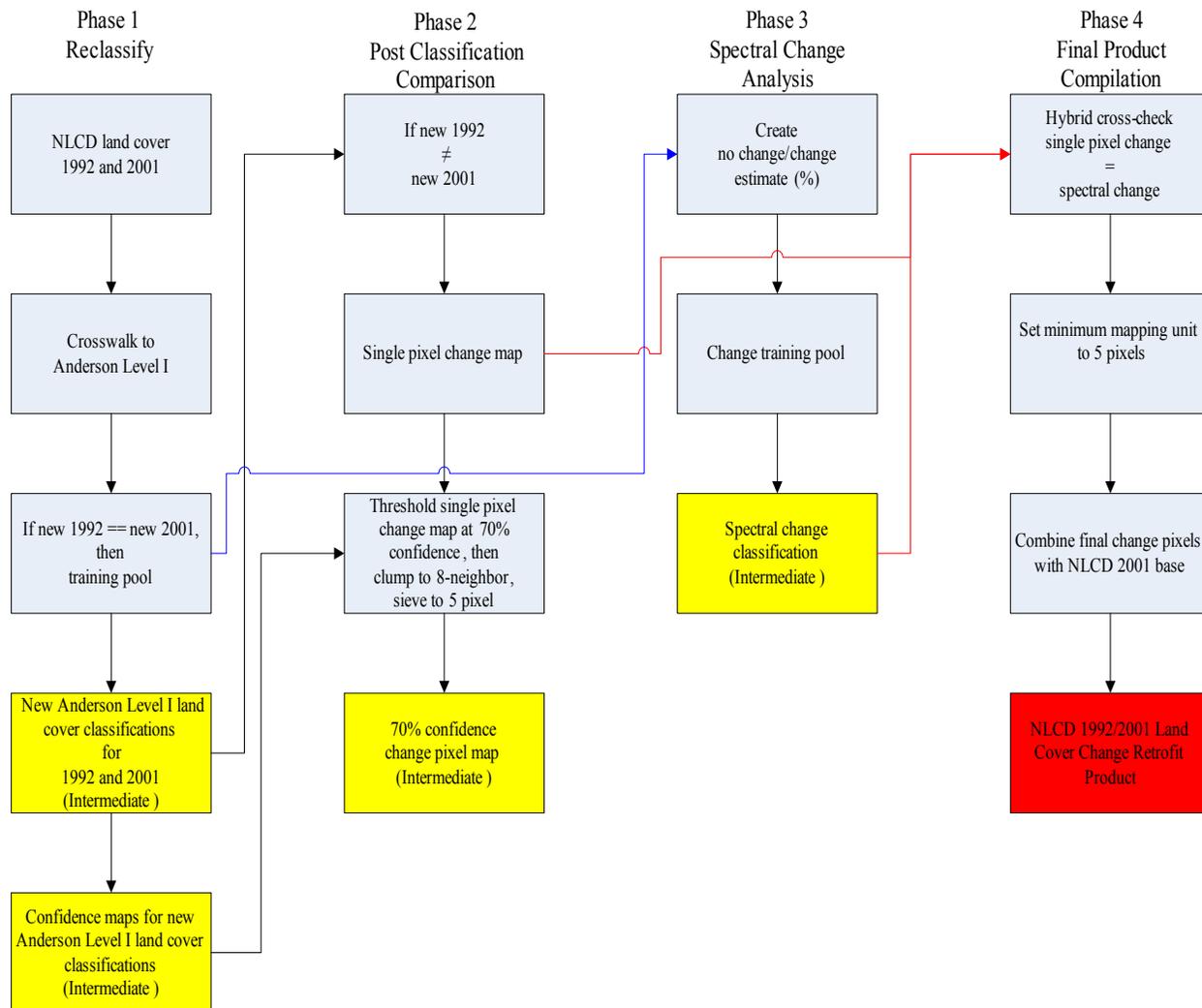


Figure 1. Generalized processing flow for the National Land Cover Database (NLCD)–Land Cover Change Retrofit (LCCR) product. The blue and red flow lines indicate additional use of the intermediate product in a later process step.

Model training data were derived from a comparison between the two cross-walked Anderson Level I (ALI) versions of the original land cover datasets. The same reasons that made post-classification comparison an inappropriate method for finding areas of change between the two native products made it a good method for finding areas of no change. If two, independent, land cover classifications, complete with all of the inherent differences in source image seasonality, georegistration, mapping methodologies, classification accuracy, and map legends, agreed on a land cover class code, then it was reasonable to assume that those pixels were classified appropriately and indicated areas of no change. The intent was to isolate areas of agreement in the two land cover datasets from areas that might represent actual land cover change or were misclassified in either NLCD 1992 or NLCD

2001. In this sense, the initial differencing acted to isolate unchanged pixels and heighten the quality of the training dataset for the decision tree. Using this reasoning, only those pixels that agreed were retained in the training pool. These like-classified (assumed to be unchanged) pixels served as the training pool for approximately 150,000–200,000 randomly selected points, stratified by population of each class.

Occasionally, rare classes were present in spatially small areas in one or both datasets. In these areas there were insufficient (if any) training points available for developing a valid decision tree model for that rare class, on either or both Level I classifications. In these cases, rare classes were absent from one or both of the new classifications. Boosted decision trees were developed to classify a new set of Level I land cover maps, and to generate their respective confidence maps.

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Table 1. Modified Anderson Level II and I land cover classification codes and brief descriptions. Class descriptions and codes for NLCD 1992 and NLCD 2001 were derived from components of Anderson Level I (ALI) and II (ALII) (Anderson, and others, 1976). To facilitate comparison, classes for NLCD 1992 and NLCD 2001 were cross-walked to the modified Anderson Level I class code. (More detail regarding the NLCD 1992, NLCD 2001 land cover classification legends is available from the Multi-Resolution Land Characteristics (MRLC) Consortium at: <http://www.mrlc.gov>)

Description	NLCD 1992 class code	NLCD 2001 class code	Modified Anderson Level 1 class code
Open water	11	11	1
Perennial ice, snow	12	12	8
Urban, recreational grasses	85	21	2
Low intensity residential	21	22	2
High intensity residential	22	23	2
Commercial, industrial, roads	23	24	2
Bare rock, sand	31	31	3
Quarry, strip mine, gravel pit	32	31	3
Transitional barren	33	31	3
Deciduous forest	41	41	4
Evergreen forest	42	42	4
Mixed forest	43	43	4
Shrubland	51	52	5
Orchards, vineyards, other	61	82	6
Grasslands, herbaceous	71	71	5
Pasture, hay	81	81	6
Row crops	82	82	6
Small grains	83	82	6
Fallow	84	82	6
Woody wetlands	91	90	7
Emergent, herbaceous wetland	92	95	7

Post Classification Comparison of Reclassified Land Cover Maps

The simplest change map was created by selecting pixels where the new Level I classifications did not agree, and writing out a code (table 2) corresponding to what these pixels were in the new 1992 Level I classification, and what they became in the new 2001 Level I classification (a “from-to” map). This intermediate single-pixel “change” product contained every pixel where the land cover classification did not agree between the new ALI classifications. While this could have been due to actual, meaningful change, it could also have been due to classification errors on one or more dates, or mixed pixels, commonly found around the edges of large homogeneous areas. This could be viewed as a “change product” that would have minimal omission errors. However, in an effort to reduce commission error a second generation

“change product” was made, incorporating the confidence maps from the boosted classification process. This was done by considering only those pixels that represented disagreement between the two new ALI classifications, confirming that the confidence level of both classifications was at least 70 percent, and then generating a binary mask of “confident” change.

The 70 percent confidence value was chosen after several trials as a reasonable threshold used to limit the number of change pixels. It was based on the typical multimodal shape of the histogram for Level I confidence maps (fig. 2). The multimode character of the histogram may be interpreted as representing the level of model uncertainty involved with determining a class for each pixel in terms of the number of other classes. For example, at 100 percent confidence, there was no confusion with respect to another class, at 95 percent confidence, there was confusion with one other class, at 85 percent there was confusion with two other classes, and so

Table 2. National Land Cover Database Land Cover Change Retrofit (NLCD–LCCR) “from-to” class code matrix. The first number in the code is the 1992 “from” retrofit land cover class code and the second number in the code is the 2001 “to” retrofit land cover class code. (More detail regarding NLCD–LCCR change class codes is available from the Multi-Resolution Land Characteristics (MRLC) Consortium at: <http://www.mrlc.gov>)

[ALI, Anderson Level I]

		2001 “to” class								
		Open water	Urban	Barren	Forest	Grass/shrub	Agriculture	Wetlands	Ice/snow	
		ALI	1	2	3	4	5	6	7	8
1992 “from” class	Open water	1		12	13	14	15	16	17	18
	Urban	2	21		23	24	25	26	27	28
	Barren	3	31	32		34	35	36	37	38
	Forest	4	41	42	43		45	46	47	48
	Grass/shrub	5	51	52	53	54		56	57	58
	Agriculture	6	61	62	63	64	65		67	68
	Wetland	7	71	72	73	74	75	76		78
	Ice/snow	8	81	82	83	84	85	86	87	

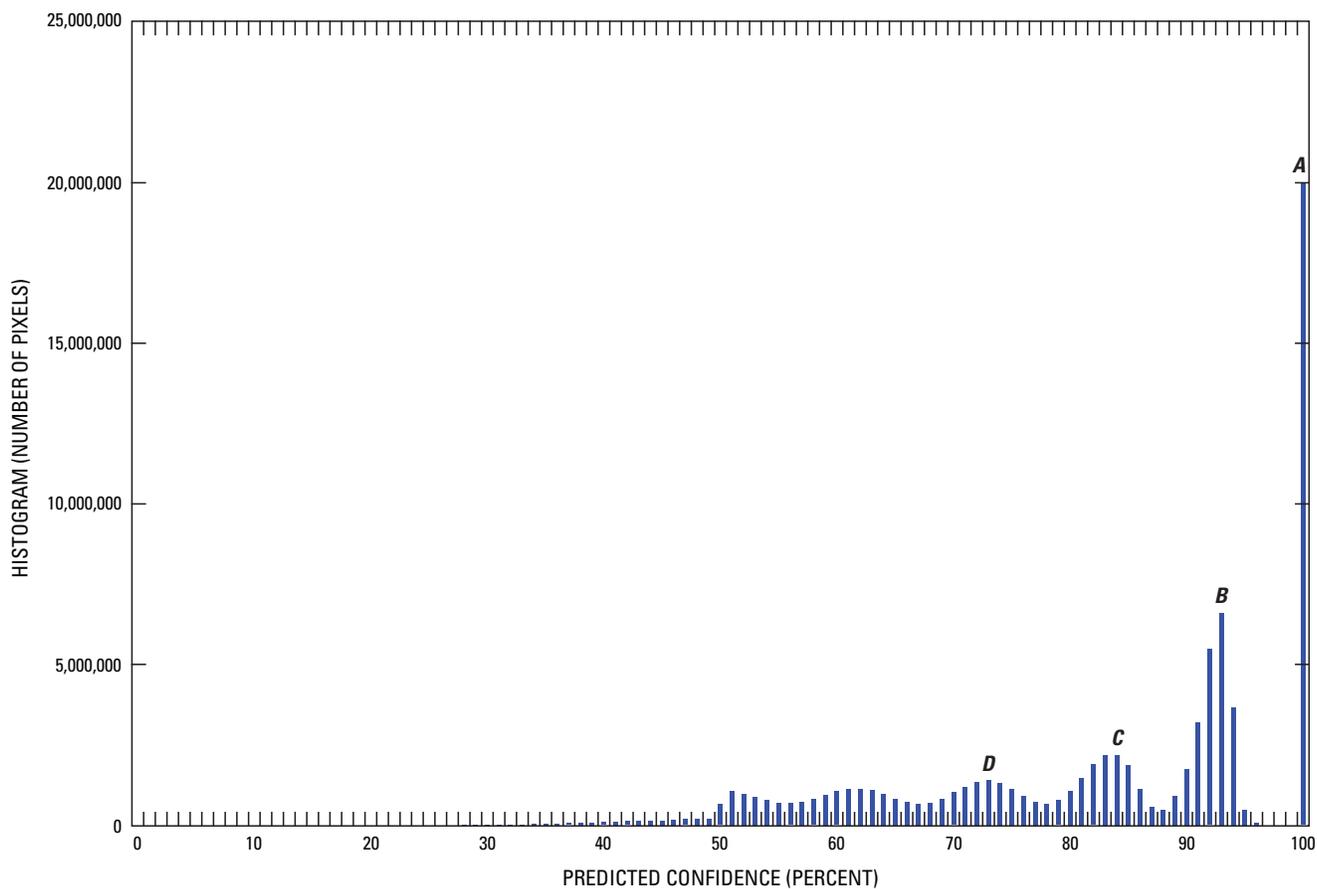


Figure 2. Example of generalized confidence map histogram. Pixels classified with A, 100 percent confidence; B, 95 percent confidence; C, 85 percent confidence; and D, 75 percent confidence.

on. The binary mask of 70 percent confidence was run through an 8-neighbor clump and 5-pixel sieve process, retaining only those contiguous areas of 5 pixels (about 0.4 hectare [1 acre]) or more regardless of the type of change. “From-to” class codes from the new post-classification comparison were used to label pixels in the spatially-filtered mask to create a more confident, less noisy “change” map at a 0.4 hectare (1-acre) minimum mapping unit level, that contained minimal commission errors. This second phase intermediate product, designated as the “70 percent change map” was used as the training data pool for spectral change analysis in the following step.

Spectral Change Analysis

To further refine the selection of pixels identified as changed, a method to analyze spectral change between the 1992 Landsat reflectance mosaic and the 2001 Landsat reflectance mosaic was developed. It was based on differencing of the three-ratio index derivative images from 1992 and 2001 and supplemented by the spatio-temporal thematic image. In this analysis, the ratio difference image served to represent a quantification of spectral change associated with the unique combinations of multiple path/rows across multiple dates. The spatio-temporal image, which represented the composite footprint of individual scene pairs, was used to supply a coded value for each unique segment. To differentiate pixels of probable no-change from probable change, a continuous no-change/change estimate was generated using commercial regression tree software called Cubist (Quinlan, 1993), which identified empirical relationships between the no change/change endpoints, the ratio difference image, and the spatio-temporal image. Training data for the no-change endpoints were randomly selected from the pool of unchanged pixels in the post-classification comparison of the new Level I land cover maps with the class value for each training point reset to a value of 1. Training data for the change endpoints were randomly selected from the “70 percent change map” pool of changed pixels with the class value for each training point reset to a value of 100. Input variables included the 3-layer ratio difference image and the spatio-temporal date image for a total of 4 layers. The no-change/change continuous estimate derived information from the spectral difference image to indicate the likelihood that the difference represented meaningful land cover classification change according to the Anderson Level I classes.

The no-change/change continuous estimate was used as input along with the ratio difference image and the spatio-temporal image in a decision tree model developed to segregate spectrally unchanged pixels from spectrally changed pixels, and at the same time, supplied a “from-to” label for the changed pixels. Training points for this model had the same coordinates as the training points used to generate the no-change/change continuous estimate, but the class value for the changed points was altered to reflect the “from-to” code where the new Level I 1992 and Level I 2001 land cover

maps did not agree. The resulting thematic image contained unchanged pixels with a class value of “1” and changed pixels labeled with a “from-to” class code.

Final Processing

In the first of two final processing steps, a mask was created to identify areas where cloud and cloud shadows may have influenced the classification in either Landsat mosaic. Images for both the 1992 and 2001 nominal date mosaics were selected to minimize clouds. However if clouds did occur, the change pixels that fell under a cloud or cloud shadow were reclassified as unchanged.

In the second final processing step, a single-pixel change product was derived from an intersection of the post-classification comparison of the new 1992 Level I land cover map with the new 2001 Level I land cover map, and the final spectral change image. Essentially, if the two independently processed intermediate products showed that a pixel had changed, it was retained as change and labeled with the “from-to” class code derived from the spectral analysis process described above. Isolated, single-pixel change, and small clusters of changed pixels that were below a 5-pixel minimum mapping unit were eliminated using the Smart Eliminate tool with a custom weight matrix (NLCD Mapping Tool, MacDonald Dettwiler and Associates (MDA) Federal, 2006 unpublished document). Then a final model placed the smart-eliminated change pixels on top of the NLCD 2001 base, cross-walked to Anderson Level I.

Results

National Results

Land cover change analysis results were generated by land cover class for the conterminous United States (table 3). A quantitative analysis of the change data obtained for the study period, based on nominal dates of the Landsat imagery used in the analysis, indicates that a total of 97.01 percent of the land cover mapped in the United States remained unchanged between 1992 and 2001, with 2.99 percent of the land cover mapped as changed. Flux among forest, grass/shrub, and agriculture classes accounted for the majority of mapped land cover change (table 3).

A second way to report land cover change was in terms of net gain or net loss in area by class (table 4 and fig. 3). Of the changed pixels, forest and agriculture classes encountered net loss in area, with losses of 61,945 km² and 7,461 km², respectively, while other classes showed variable net gains. Perennial ice and snow showed the least net change with a gain of 163 km². Overall, listed in increasing rank of net area gain were land cover classes barren, water, wetlands, urban, and grass/shrub (fig. 3).

The spatial distribution of total percent change results is illustrated in figure 4 by Landsat path/row boundaries. Although the processing was completed at a mapping zone scale (multiple Landsat path/rows), a summary of the results by path/row provided a more detailed illustration of the spatial distribution of change. Change in the path/row boxes, as a percentage of all pixels, ranged from less than 1 percent to approximately 16 percent.

Table 3. Change results matrix for the conterminous United States. Unchanged pixels are a percentage of all pixels, while changed pixels are a percentage of all changed pixels.

[%, percent]

		2001 "to" class								
		Open water (%)	Urban (%)	Barren (%)	Forest (%)	Grass/shrub (%)	Agriculture (%)	Wetlands (%)	Ice/snow (%)	Row totals (%)
1992 "from" class	Unchanged									
		5.03	4.86	1.13	25.22	34.48	21.79	4.48	0.02	97.01
	Changed									
	Open water		0.06	0.49	0.15	0.60	0.46	0.87	0	2.63
	Urban	0.13		.02	.17	.12	.48	.13	0	1.05
	Barren	.25	.04		.06	.34	.08	.06	.01	.84
	Forest	.42	3.53	.99		23.09	10.31	2.46	0	40.80
	Grass/shrub	1.30	1.54	.61	6.66		11.39	1.84	.12	23.46
	Agriculture	2.60	3.00	.26	7.16	10.87		3.03	0	26.92
	Wetland	.70	.38	.09	.97	.96	1.13		0	4.23
Ice/snow	0	.00	.02	0	.05	0	0		.07	
Column totals	5.40	8.55	2.48	15.17	36.03	23.85	8.39	.13	100.00	

Table 4. To and from class change statistics with net gain/loss expressed in pixels and square kilometers (km²). Changed pixel percentages are expressed as the percent of total changed pixels. The conversion factor used in calculating the land area was km² = number of pixels x 0.0009.

2001 "to" class	Number of pixels	Percent of total changed pixels	1992 "from" class	Number of pixels	Percent of total changed pixels	Net gain/loss pixels	Net gain/loss km ²
Forest	40,700,152	15.17	Forest	109,527,578	40.81	-68,827,426	-61,945
Agriculture	63,985,547	23.85	Agriculture	72,275,282	26.93	-8,289,735	-7,461
Ice/snow	364,637	0.13	Ice/snow	183,209	.07	181,428	163
Barren	6,634,927	2.48	Barren	2,253,008	.84	4,381,919	3,944
Open water	14,486,533	5.40	Open water	7,029,892	2.62	7,456,641	6,711
Wetlands	22,535,393	8.39	Wetlands	11,359,179	4.23	11,176,214	10,059
Urban	22,941,342	8.55	Urban	2,816,865	1.05	20,124,477	18,112
Grass/shrub	96,721,532	36.03	Grass/shrub	62,925,050	23.45	33,796,482	30,417

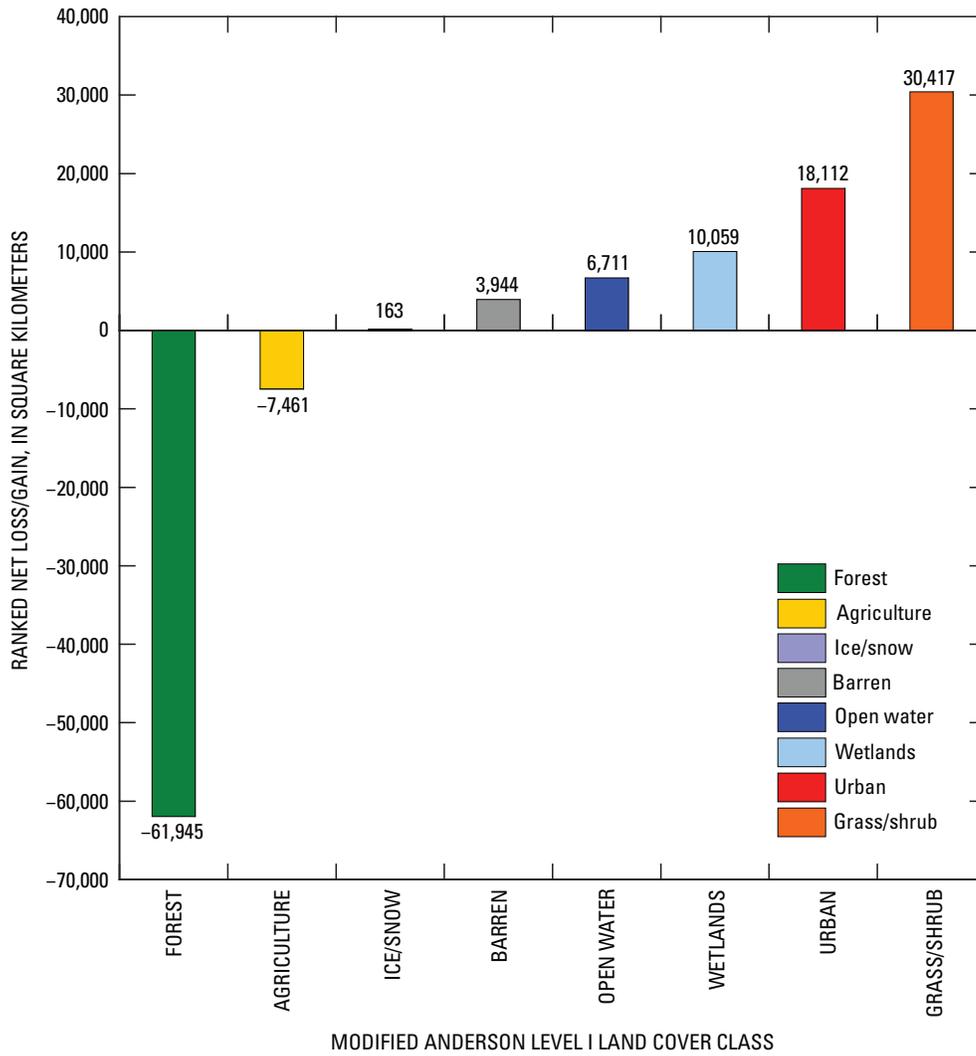


Figure 3. Ranked net loss or gain in land cover mapped by class for the conterminous United States. Forest and agriculture classes show a net loss in area and all other classes show a net gain in area.

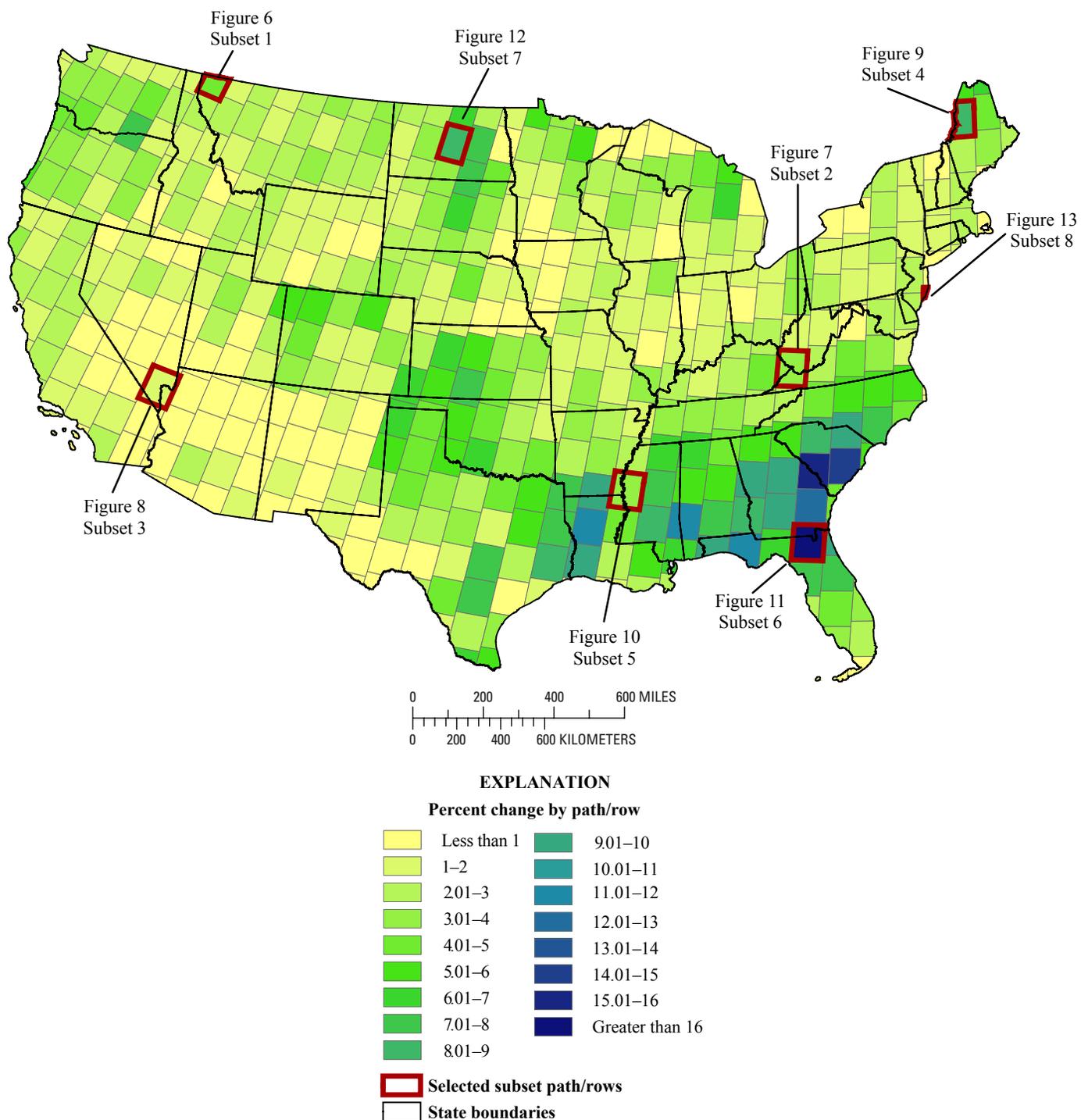


Figure 4. Land cover change summary map. Change from Multi-Resolution Land Characteristics Consortium (MRLC) zones is summarized by Landsat path/row boxes (image overlap areas omitted) with change as a percentage of all pixels. Numbered path/row boxes (highlighted in red) represent Landsat path/rows where a 20 kilometer x 20 kilometer subset was clipped to provide a closer look at change (figs. 6–13). Path/row box number 6 is Landsat Path 17, Row 39 with the highest percentage of change (16 percent) in the Nation. Reference information is provided for each subset area in table 5.

Model Performance

During the NLCD-LCCR research and design phase, methods were guided by a series of choices, incorporated into various models, to balance tradeoffs between implementation cost, speed, and accuracy. The highly automated nature of the decision-tree methodology provided a rigorous approach towards overcoming modeling challenges and for refining the spectral definition of changed pixels within project time and budget limits. Model performance, which varied from zone to zone, dictated the level of success in capturing spectral change and assigning an appropriate label. The success of this process was dependent upon the quality of the two primary input components: image mosaics, and training data.

Image Mosaics

Overall, the image quality in the mapping zone mosaics was excellent for both the 1992 and 2001 nominal dates. Pixels covered with substantial clouds, haze, smoke, and jet contrails were avoided in the mosaics so that they would not be included as candidates for change even though the possibility existed that change might have occurred in those areas. Restricting the imagery to only one season for each nominal date had the advantage of optimizing available funding and simplifying the change methodology. A problem with the image mosaic approach was the difficulty in matching yearly dates across the mosaic. As a result, mosaics contained a data range of several years that represented the nominal dates. The consequence of conducting change analysis for both nominal dates using satellite data from multiyear spans, rather than a bitemporal snapshot of change between two specific dates, was that the product represented a composite of multi-temporal change from each era. The Landsat image mosaics for Zone 23 provide a typical example of the range of image dates and the span of years used for change detection processing (fig. 5). While we recognize and describe this effect here, owing to image availability there was no practicable way to avoid this issue.

Training Data

To identify changed pixels, and then to supply an appropriate label for the type of change required training data from each possible change combination and each unique image-pair footprint. Assignment of the most appropriate “from-to”

label for spectral change would have required an adequate number of representative training points for all possible change combinations (in this case $n^2 - n = 56$) from each of the unique image pair footprints. The average number of training points used for land cover remapping for each zone was approximately 187,000 points. Although these points were randomly selected and stratified by class, each class from each of the unique segments may not have been sampled. Rare change combinations with less than 100 pixels in the filtered 70-percent change image histogram were not sampled, eliminating the possibility for some rare change combinations to be labeled. As a result, change labels for rare change classes, or changed pixels in relatively small, unique, image-segment pairs were underrepresented in the training data and had a higher probability of being inappropriately labeled or excluded from the classification. However, these issues with rare pixels were relatively uncommon and made up only a small percentage of the overall change amount.

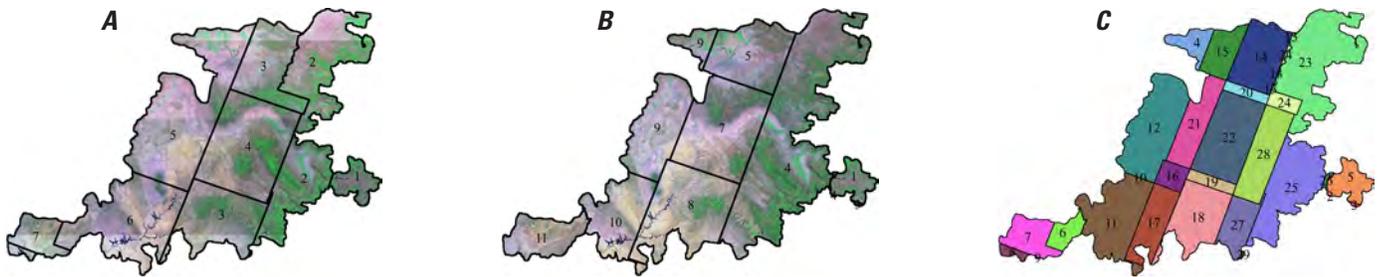
Urban Change

In order to account for every possible change combination in the change matrix, it was necessary to include the entire contingent of change including the “from” urban (classes 21 through 28, table 2). In the change matrix (tables 3 and 4), these pixels represented approximately 1.05 percent of all changed pixels, and approximately 0.00031 percent of all pixels in the conterminous United States. Even though it is fairly likely that these pixels did not change from urban to some other class, the fact that they survived as changed pixels indicates that either there was some kind of change, or that the model was provided with spurious urban training data at some point in the process.

Change Examples

No formal accuracy assessment has been completed for this product. The following examples are provided to create a bridge of understanding and to provide context for typical issues that may be encountered when using the product.

The NLCD-LCCR change product can best be understood by visual examination. Here, we present eight examples that include both dates of imagery and the change product at a scale of 1:100,000. These examples of land cover change from throughout the Nation provide context for some commonly encountered change situations (table 5).



1992/2001 Index	Histogram	Index 1992	Path 1992	Row 1992	Date 1992	Index 2001	1992/2001 Index	Path 2001	Row 2001	Date 2001
1	1,504	1	34	33	06/22/87	4	1	35	32	09/12/00
2	7,697	2	35	32	07/04/89	4	2	35	32	09/12/00
3	92,867	1	34	33	06/22/87	3	3	34	34	07/19/00
4	2,958,989	5	37	32	07/02/89	9	4	37	32	07/30/02
5	3,935,577	1	34	33	06/22/87	1	5	34	33	07/01/99
6	2,619,487	6	37	34	07/18/89	11	6	38	34	06/13/00
7	5,256,013	7	38	34	06/15/92	11	7	38	34	06/13/00
8	760,473	8	38	35	07/01/92	11	8	38	34	06/13/00
9	3,712	8	38	35	07/01/92	11	9	38	34	06/13/00
10	12,660	5	37	32	07/02/89	10	10	37	34	06/06/00
11	13,152,898	6	37	34	07/18/89	10	11	37	34	06/06/00
12	14,483,285	5	37	32	07/02/89	9	12	37	32	07/30/02
13	11,732	2	35	32	07/04/89	5	13	36	32	09/03/00
14	9,739,474	3	36	32	06/20/93	5	14	36	32	09/03/00
15	4,891,208	5	37	32	07/02/89	5	15	36	32	09/03/00
16	2,302,878	5	37	32	07/02/89	8	16	36	34	06/15/00
17	6,624,119	6	37	34	07/18/89	8	17	36	34	06/15/00
18	10,153,257	3	36	32	06/20/93	8	18	36	34	06/15/00
19	1,776,626	3	36	32	06/20/93	8	19	36	34	06/15/00
20	1,496,743	3	36	32	06/20/93	7	20	36	33	08/19/03
21	7,272,636	5	37	32	07/02/89	7	21	36	33	08/19/03
22	13,226,249	4	36	33	07/01/91	7	22	36	33	08/19/03
23	18,406,669	2	35	32	07/04/89	4	23	35	32	09/12/00
24	1,850,466	3	36	32	06/20/93	4	24	35	32	09/12/00
25	13,452,806	2	35	32	07/04/89	4	25	35	32	09/12/00
26	238,585	1	34	33	06/22/87	4	26	35	32	09/12/00
27	5,262,121	3	36	32	06/20/93	4	27	35	32	09/12/00
28	9,142,696	3	36	32	06/20/93	4	28	35	32	09/12/00
29	38,004	2	35	32	07/04/89	4	29	35	32	09/12/00

Figure 5. Landsat images and scene lists included in the 1992 and 2001 mosaics listed by path, row, and date for Multi-Resolution Land Characteristics (MRLC) Zone 23 in portions of Arizona, Colorado, and Utah. *A*, All of the 1992 scenes were Landsat 5 Thematic Mapper (TM). *B*, All of the 2001 scenes were Landsat 7 Enhanced Thematic Mapper Plus (ETM+), except for Path 36, Row 33 (August 19, 2003), which was a Landsat 5 TM scene. *C*, The composite footprint of individual scene pairs was created to capture the spatio-temporal combination for each unique scene pair. Scenes used in the 1992 era mosaic span a nearly 6-year interval (1987–1993) and the 2001 era mosaic spans slightly more than 4 years (1999–2003). For 1992, seasonal phenology was considered to be well matched with all scene dates for month and day falling within a 30-day period; for 2001, scene dates ranged from late June through mid-September, indicating a less than ideal phenology match. The complexity of scene pair footprints was unique for each zone, but the combination of 29 different scene pair segments illustrated in MRLC zone 23 was typical.

12 Completion of the National Land Cover Database (NLCD) 1992–2001 Land Cover Change Retrofit Product

Table 5. Eight 20 kilometer x 20 kilometer subsets of the seamless change product dataset were selected for a closer look at change (figs. 6–13). The small map subset boxes can be found in figure 4, outlined in red, and show the general location by Landsat path/row. This table provides additional location details and a brief description of the land cover map change highlighted in the subset area.

[MRLC, Multi-Resolution Land Characteristics]

Subset number	Path	Row	Approximate image chip upper left corner		MRLC zone	Town and State	Description
			Longitude	Latitude			
1	41	26	115°25'13.21"W	48°51'29.61"N	10	Libby, Montana	Fire scar and forest harvest.
2	18	34	81°36'24.03"W	38°04'23.41"N	53	Beckley, West Virginia	Mountaintop mining.
3	39	35	84°55'51.59"W	36°20'26.36"N	13	Las Vegas, Nevada	Urban change.
4	12	28	69°32'54.78"W	46°11'24.93"N	66	Jackman Station, Maine	Forest harvest cycle.
5	23	37	91°29'36.60"W	33°21'36.00"N	45	Lake Village, Arkansas	Agricultural change.
6	17	39	82°31'22.02"W	30°11'57.00"N	55	Lake Butler, Florida	Forest harvest cycle.
7	32	27	100°09'36.01"W	47°28'27.10"N	40	Hurdsfield, North Dakota	Wetland change.
8	13	33	74°26'38.00"W	39°37'24.06"N	60	Beach Haven, New Jersey	Barrier island erosion and accretion.

Subset 1

In this example, near Libby, Montana (fig. 6), the most common change was from forest to grass/shrub (change class 45), which resulted from fire in some places, and from the forest harvest cycle in others. In this area, not all change from fire was captured. The most severely burned area just east of the Kootenai River was captured and appropriately labeled as forest to grass/shrub (change class 45), but the burned area just west of the river remained in the unchanged forest class. The reason that the model missed this changed area was that

the western portion of the burn was classified as forest in both the original NLCD 2001 land cover product and the original 1992 land cover product, making “no-change” forest training data available in the training pool for the retrofit land cover classifications. In this case, the intermediate change product from phase 3 of the processing (fig. 1) identified the area as spectral change and labeled it properly as forest to grass/shrub, but in the final processing phase, these pixels were eliminated since they did not appear as change in both the post classification comparison of the new retrofit land cover maps and the spectral change intermediate product.

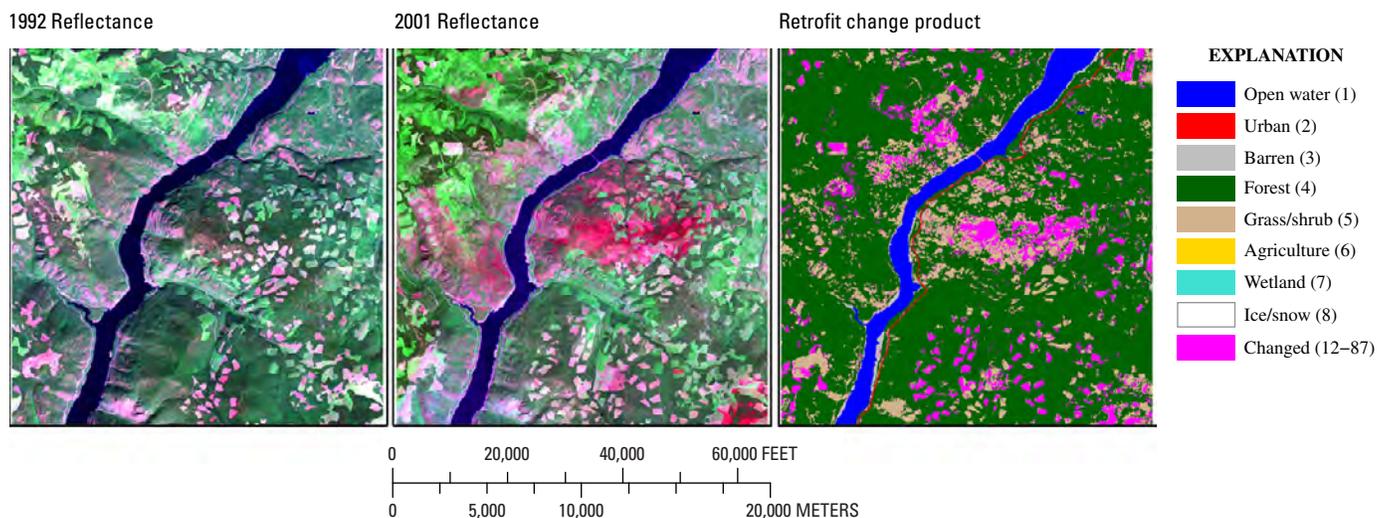


Figure 6. Subset 1. Fire scar and forest harvest cycle near Libby, Montana. Landsat images are displayed in a 6–4–2 band combination. Approximate image chip upper left corner: 115°25'13.21"W, 48°51'29.61"N.

Subset 2

Land cover change resulting from mountaintop mining was captured in this example from West Virginia (fig. 7). The majority of the change pixels represented change from forest to barren (change class 43) or forest to grass/shrub (change class 45) with nearly the same number of pixels in both categories. The change in this subset image covered slightly more than 40 km². The patch size in this example was relatively large in terms of contiguous change pixels. New quarry pit reservoirs represented slightly less than 1 km² of new water

cover (change classes 31, 41, and 61). This subset showed nearly 0.8 km² of forest to urban (change class 42) change located primarily along drainages that appear to correspond to new roadways and disturbance associated with road building. Slightly more than 1.25 km² of forest to agriculture change was scattered within the mined areas. These labels may represent additional forest to barren (change class 43) or forest to grass/shrub (change class 45) in confusion with the agriculture “to” class change since there were no obvious agricultural areas in the 2001 imagery.

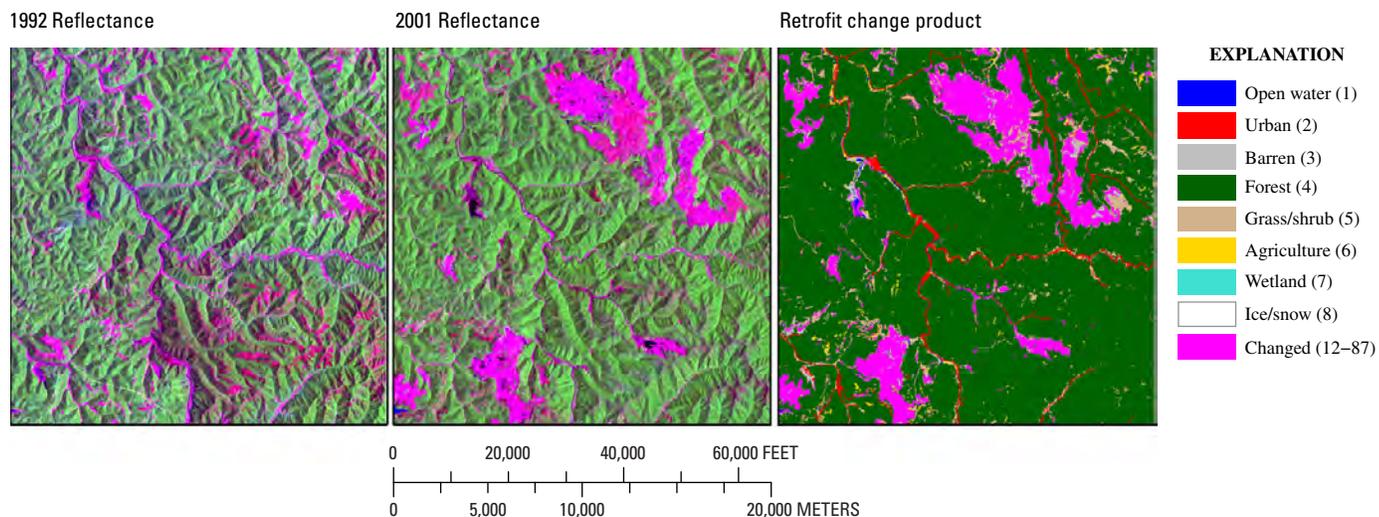


Figure 7. Subset 2. Mountaintop mining near Beckley, West Virginia. Landsat images are displayed in a 6–4–2 band combination. Approximate image chip upper left corner: 81°36'24.03"W, 38°04'23.41"N.

Subset 3

Rapid urban growth in suburban Las Vegas, Nevada (fig. 8), accounted for all of the change in this subset, with changed pixels covering slightly more than 20 percent of the subset area, or approximately 80 km². Two change classes

represented areas where urban development occurred. Grass/shrub to urban (change class 52) occurred in areas of new urban growth, and barren to urban (change class 32) represented areas that were already being prepared for development in the 1992 mosaic. Newly developed urban land cover included three new golf courses, complete with small water

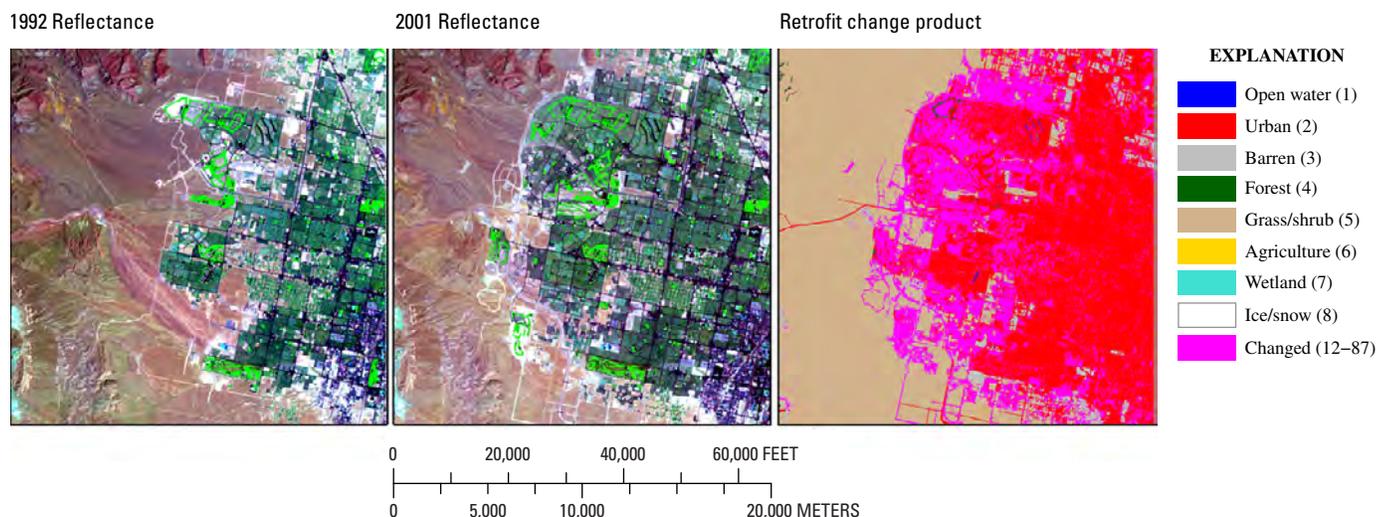


Figure 8. Subset 3. Urban growth near Las Vegas, Nevada. Landsat images are displayed in a 6–4–2 band combination. Approximate image chip upper left corner: 84°55'51.59"W, 36°20'26.36"N.

features, which accounted for a grass/shrub to water land cover change (change class 51) covering approximately 0.03 km². Grass/shrub to barren (change class 53), covering nearly 16 km² was shown in the 2001 mosaic as bright white areas where land was cleared to accommodate new roadways and continued development. A good example of an accurately modeled distinction between the change class labels grass/shrub to urban (change class 52) and grass/shrub to barren (change class 53) was located near the center of the southwestern quadrant of the image, where bright green portions of the newest golf course were identified as change and labeled as changing to grass/shrub to urban (change class 52), while bright white areas surrounding the golf course, also identified as change, were labeled as grass/shrub to barren (change class 53).

Subset 4

Changed land cover elements in this subset near Jackman Station, Maine (fig. 9), were related to the forest harvest cycle, a relatively drier 2001 season, and an anomalous legacy from the 2001 land cover classification. The forest harvest and regrowth cycle accounted for slightly less than 12 percent of the nearly 16 percent change in this subset. Change related to forest harvest occurred in solid, discretely spaced, geometric patterns (change classes 43 and 45) with regrowth (change class 54) distributed in more widespread, discontinuous patches. Change due to relatively lower water levels in the

2001 imagery affected 3.5 percent of the classified land cover in this subset and included water to barren (13), water to forest (14), water to grass/shrub (15), and water to wetland (17). These change areas formed a “rim” of varying width along the edges of existing water bodies and included nearly 14 km² around the Gero Island State Game Refuge in Chesuncook Lake, along Black Pond Stream, and on point bars on the West Branch Penobscot River. The anomalous legacy mentioned above is related to the narrow, unchanged border of barren classified land cover between the water and the changed rim pixels. It is clear from the 1992 and 2001 imagery used in change detection processing that those pixels are water cover in both mosaics, therefore unchanged. However, in a final processing step, all pixels with a “to” class different from the original 2001 land cover map are reset to the 2001 base. In the 2001 land cover base map, those pixels were classified as barren, and therefore reset to that class, even though doing so created an obvious misclassification based on the imagery used in this process. The NLCD 2001 base land cover map was processed using three seasons of imagery, and while it was possible that the 2001 land cover base map was misclassified, an alternative explanation is that one, or both, of the additional 2001 seasonal mosaics had even lower water levels than the leafon mosaic used here. This example emphasizes the critical need for a thorough understanding of the methods used to develop the retrofit product, and in-depth knowledge of derivation of the input layers used in modeling, prior to using the retrofit change product to reach reasonable and valid conclusions regarding change.

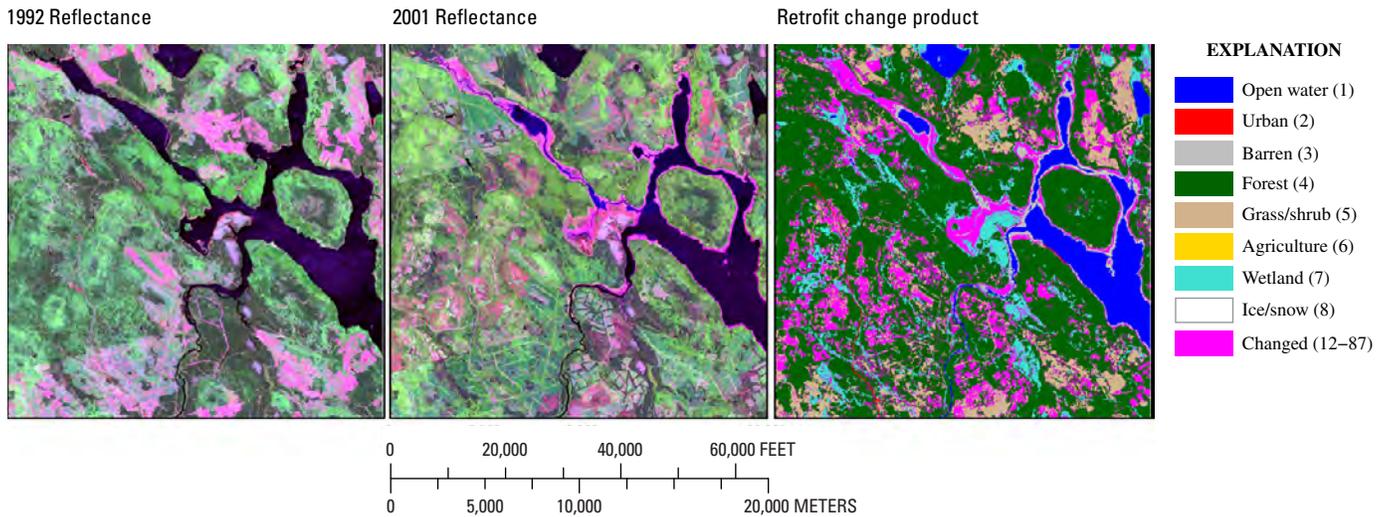


Figure 9. Subset 4. Forest harvest cycle and water level changes near Jackman Station, Maine. Landsat images are displayed in a 6–4–2 band combination. Approximate image chip upper left corner: 69°32'54.78"W, 46°11'24.93"N.

Subset 5

This example, near Lake Village, Arkansas (fig. 10), was selected to illustrate a relatively rare mapped land cover change from agriculture to water (change class 61) that represented less than one-half of one percent of changed pixels throughout the Nation. This subset demonstrates the ability of the model to differentiate between change and no change in agricultural areas where spectral differences due to seasonality, crop rotation, and planting cycles are common. This area, on the Mississippi flood plain, would be characterized as low-lying and featured several bayous and the Beouf River as part of the landscape. Slightly more than 10.7 percent of the pixels were identified as changed, with nearly 8.6 percent changing from agriculture to water or wetland to water, change classes 61 and 71 respectively. The area of water cover in this subset, located in Chicot County, Arkansas, increased from slightly more than 20 km² to almost 56 km². A majority of this water cover appeared to be new ponds, most likely used for catfish farming, which is a major contributor to the county's economy (Kaliba and others, 2004). Another 1.37 percent and 0.8 percent of the pixels were labeled as changed from wetland to agriculture (change class 76) and agriculture to wetland

(change class 67), respectively, with additional small amounts of change labeled as forest to agriculture (change class 46) or wetland to urban (change class 72). Agricultural land cover classes were appropriately labeled as unchanged, even though there were visible differences in spectral response throughout the subset image. The spatio-temporal mosaic for this area showed an index value of 13, corresponding to a segment of Path 23, Row 37. The 1992 image used in the mosaic was dated May 5, 1992, and the corresponding 2001 scene was dated June 18, 2002, a difference of 10 years and 34 days. With respect to agriculture, it is the 34-day difference in phenology that influenced the spectral information fed into the model. In 1992, the date was early in the growing season with imagery showing a mix of freshly plowed ground and early green-up in most of the cultivated fields. In contrast, the 2001 mosaic contained fewer freshly plowed fields and many cultivated areas displayed some evidence of green-up. A number of fields that were freshly plowed in 1992 imagery exhibited a different 2001 spectral signature with varying levels of bright green to dark green (Landsat band combination 7-4-2) indicative of more mature leaf-on vegetation. Agricultural areas, regardless of the difference in spectral signature, were, for the most part, appropriately identified as unchanged.

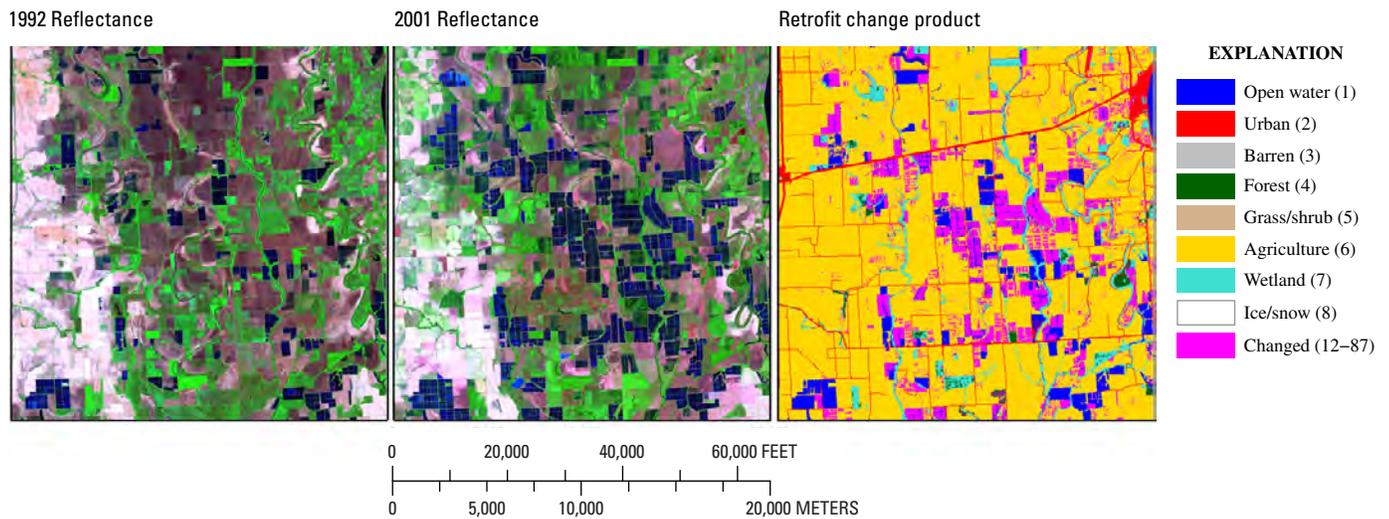


Figure 10. Subset 5. Agriculture to water change near Lake Village, Arkansas. Landsat images are displayed in a 6-4-2 band combination. Approximate image chip upper left corner: 91°29'36.60"W, 33°21'36.00"N.

Subset 6

This subset, Lake Butler, Florida (fig. 11), was included as a representative area in the most changed path/row in the Nation—Path 17, Row 39—with approximately 16.1 percent of all pixels in the path/row box identified as changed. Change in the subset area included just more than 21 percent of the total area, with approximately 79 percent of the pixels unchanged. Located in Union County, Florida, northwest of the city of Lake Butler, the majority of unchanged land cover mapped in the subset area was a mix of forest and wetlands, 45.4 percent and 20.1 percent respectively, with small amounts of urban, grass/shrub, and agricultural land cover mapped. Changed pixels with a label of forest to grass/shrub (change class 45) or grass/shrub to forest (change class 54) accounted for nearly 17 percent of the total pixels dispersed in spaced,

geometric patterns typical of the forest harvest cycle. There was the possibility that some change classes, including wetland to grass/shrub (change class 75) at approximately 0.5 percent, agriculture to forest (change class 64) at just over 0.1 percent, and forest to wetland (change class 47) just under 1 percent, might be mislabeled. Small patch sizes, similarity of spectral response between wetland and forest classes, and grass/shrub and agriculture classes, contribute to the likelihood of mislabeling. Unless each spectral variation associated with the label for each class was adequately sampled, there was the risk that the model might have assigned an inappropriate label. In the 2001 image mosaic, small scattered patches of unharvested wetland forest that appeared as inclusions in harvested areas are indicative of the degree to which habitats have been fragmented by the forest harvest cycle.

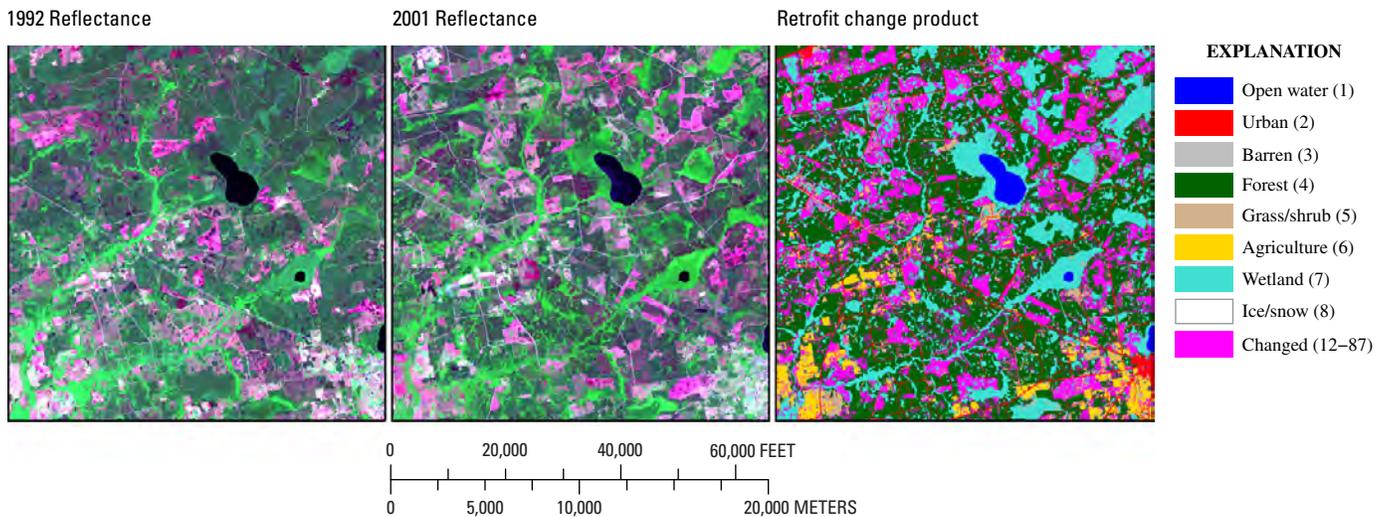


Figure 11. Subset 6. Most changed Landsat path/row near Lake Butler, Florida. Landsat images are displayed in a 6–4–2 band combination. Approximate image chip upper left corner: 82°31'22.02"W, 30°11'57.00"N.

Subset 7

This subset, near Hurdsfield, North Dakota (fig. 12), is located in the west central portion of the prairie pothole region. Unchanged land cover mapped in this subset consisted chiefly of grass/shrub and agriculture, covering nearly 47 percent and 25 percent of the land, respectively. In contrast to reduced water levels indicated by exposed lakeshore sediments and river banks in Subset 4, this subset exhibited a relatively wetter landscape in 2001 than in 1992. Unchanged water cover, distributed in the distinctive pattern characteristic of the prairie pothole region, accounted for slightly less than 5 percent of the pixels (approximately 19 km²). Pixels changed to water represented slightly less than 13 percent of the pixels

(nearly 52 km²). This magnitude of change, an increase in water cover of greater than 270 percent, was related to a severe drought in the area between 1988 and 1992 (Williams-Sether and others, 1994). In this subset area the retrofit change product provided an additional spatial component of change captured between the two scene dates for Landsat Path 32, Row 27 (July 31, 1989, and July 03, 2002), allowing a more comprehensive view of the consequences of drought on the landscape and providing a way to quantify changes in water cover area. In this case, it was critically important to know the scene pair dates in order to appropriately interpret and understand the change. Also, the range of dates used in the mosaics would have had an impact on the amount of change identified in any single unique footprint segment.

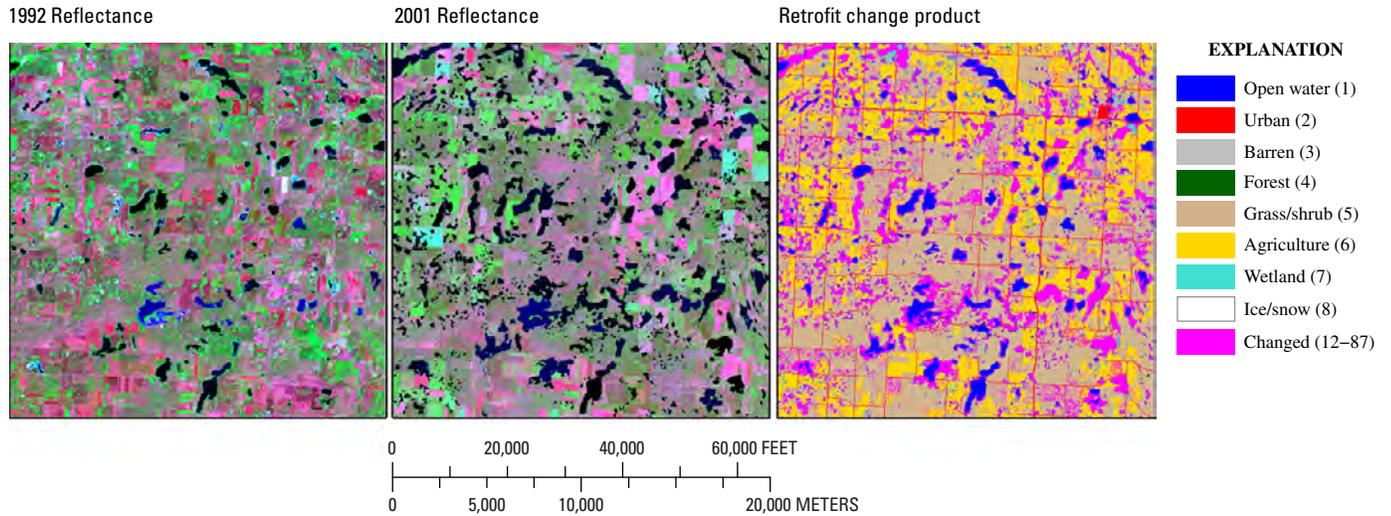


Figure 12. Subset 7. Drought recovery near Hurdsfield, North Dakota. Landsat images are displayed in a 6–4–2 band combination. Approximate image chip upper left corner: 100°09'36.01"W, 47°28'27.10"N.

Subset 8

The final subset was located on the New Jersey shoreline near Beach Haven (fig. 13) and contained small, but notable changes in the barrier island complex due to wave action. About 1.67 percent of all pixels in this subset were identified as changed. Land cover shifts from water to barren (change class 13) and barren to water (change class 31) made up 0.42 percent (nearly 1.7 km²) and 0.15 percent (slightly

more than 0.61 km²) of land cover change that was associated with the barrier islands. Water to wetland (change class 17) accounted for 0.27 percent of the change (nearly 1.1 km²) and was located in back-barrier marshes. Forest to agriculture change was mislabeled since most of these pixels appeared in the newly developed urban areas near Absecon Heights, Parkers Landing, and Mystic Islands, New Jersey, that also included some light industrial areas. These pixels occurred in the same vicinity as other pixels that were appropriately labeled as forest to urban (change class 42).

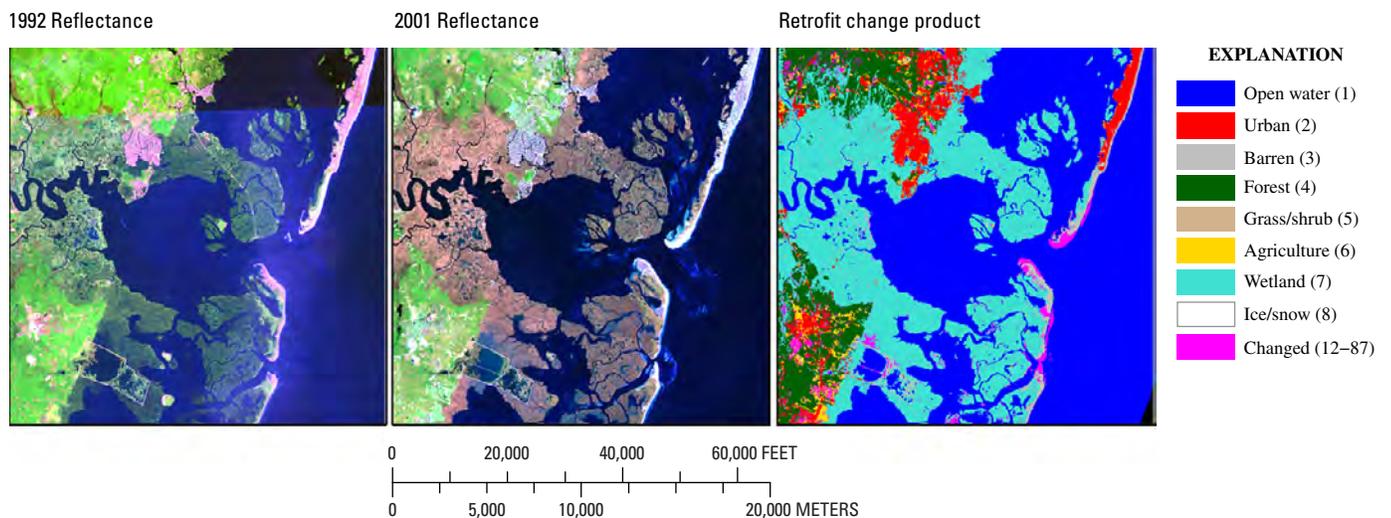


Figure 13. Subset 8. Barrier island erosion and accretion near Beach Haven, New Jersey. Landsat images are displayed in a 6–4–2 band combination. Approximate image chip upper left corner: 74°26'38.00"W, 39°37'24.06"N.

Conclusions

Successful land cover change detection must overcome issues related to temporal phenology, spectral discrimination, classification definitions, methodological artifacts, and spatial scale differences. The NLCD–LCCR described here provides an intermediate bridge product so that users can understand the mapped land cover differences between NLCD 1992 and NLCD 2001. This product relies on several key steps to complete the land cover change analysis. First, it identifies spectral change between nominal date 1992 and 2001 across Landsat image mosaics assembled by mapping zone. Second, it provides a solution that addresses the differences between the two originally published land cover datasets by reclassifying the land cover map for both eras at an Anderson Level I. Third, using a hybrid, multiphase, processing design, spectral change is identified and labeled with a “from-to” land cover change code (table 2).

This and other NLCD products are Web enabled for http download from the MRLC Web site at <http://www.mrlc.gov>.

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