Measuring Land Use Change in New Jersey:

Land Use Update to Year 2000

A Report on Recent Development Patterns 1995 to 2000

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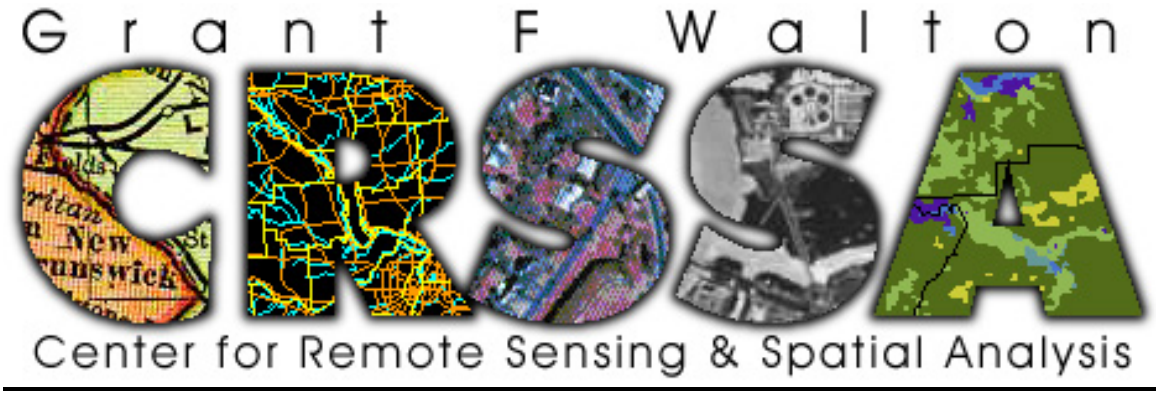
May 2004



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May 6, 2004

This report is CRSSA Publication # 17-2004-1.

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Introduction and Summary

As reflected in Year 2000 Census data, New Jersey continues to increase in population. Accompanying that population growth has been significant changes to New Jersey's landscape. To accommodate this growth, housing developments and shopping malls encroach on lands that were formerly farm fields and forests. The rapid pace of development and land use change has resulted in a high demand for updated land use/land cover data to inform ongoing land use planning and growth management programs within New Jersey Department of Environmental Protection (NJDEP) and other state and local agencies. The objective of this research was to use medium scale satellite imagery to provide a consistent mapping of land use and land cover change as of Year 2000/2001 across the state, while exploring the applicability of using less-costly satellite imagery as a means to update NJDEP's air-photo based land use data (Lathrop, 2004). As a supplement to the research, this report is an assessment of the major trends in the land use changes occurring between 1995/1997 and Year 2000. This project provides an update to earlier work examining urban growth and land use change occurring between 1986 and 1995/1997 which was based on air-photo interpreted data for both time periods (Hasse and Lathrop, 2001).

The overall trends revealed in the 2000 Land Use Update show that New Jersey's urban development continues at a pace comparable with the 1986 to 1995 time period. The statistically adjusted estimate for the overall change in new urban land between 1995 and 2000 is approximately 77,940 (+/- 17,920 acres), representing an increase of urban land of approximately 5.8%. Adding in new transitional and barren lands, the total developed land change is approximately 89,880 (+/- 16,530 acres). Taken on an annual basis (based on unadjusted figures from the map analysis), New Jersey adds approximately 14,640 acres of new urban land use and 4,170 acres in transition to future development or mining while losing approximately 9,590 acres of forest, 5,180 acres of farmland, and 1,020 acres of natural wetlands. These results suggest for the 1995 to 2000 time period that the annual rate of forest loss to development has remained relatively steady, while the rate of farmland and wetland loss has declined.

Although this update compares data generated by different imaging technologies (higher resolution aerial photo-based data from 1995/97 with lower resolution satellite imagery from 2000), this analysis focuses on the relative patterns of change in New Jersey over time. Thus, results are provided taking error among the data sets into account. While the accuracy of the overall urban and transitional change area estimates was statistically evaluated, the statistical confidence in the conversion of specific categories of land (e.g., forest, farmland or wetland) was not separately evaluated. Thus the total acreage amounts or change rates for forest, farmland and wetland conversion as enumerated in this report should be considered as initial estimates. Subsequent to initiation of this research, NJDEP committed additional resources to updating its air-photo based data with 2002 aerial photography. Upon completion of aerial-photo interpretation and land use/land cover classification, we expect to conduct further analyses to ascertain additional and more refined rates of land use change for New Jersey.

Methods

Land Use Interpretation and Mapping

A combination of satellite imagery, digital orthophotography, and existing (LU/LC) data sets were used to map land use change. Our focus in this respect was identifying and mapping land areas that have gone from a non-developed to a developed or transitional state subsequent to the New Jersey statewide LU/LC mapping previously undertaken for the 1995/1997 time period. SPOTView 10m PAN USA Select imagery acquired during the 1999-2000 time period was used as the primary data source to map this change. The SPOTView imagery was a mosaic of multiple terrain-corrected scenes acquired over the 1999 to 2000 time period with a majority of the imagery from 2000. While the SPOT 2000 imagery does not have the same high spatial and spectral resolution as the original 1995/1997 digital orthophotography, it's comparatively low cost and ready availability made a Year 2000 LU/LC update economically feasible.

The 1995/1997 NJDEP Land Use/Land Cover data (NJDEP, 2000) was overlaid on the above imagery and areas of change (subsequent to 1995/1997) were interpreted and digitized on-screen using the ArcView and ERDAS Imagine geographic information system (GIS) software. Areas of change include those areas that have gone from a natural land cover to developed land use or transitional to developed. Areas of change were classified into the following categories:

Residential
Mixed: Commercial/Service/Industrial
Recreational: developed parks, playing field, golf courses, etc.
Extractive Mining
Transitional: (cleared and in transition towards development)
Agriculture (new cultivated fields).
Other Agriculture (new structures, other land use changes)
Water
Unclassified

Due to the panchromatic nature and limited spatial resolution of the SPOT imagery (i.e., i.e. black and white, rather than the color IR and 10 x 10 m grid cell resolution rather than the 1 x 1 m resolution provided by the 1995/1997 digital orthophotography) only these generalized categories of developed land uses could be interpreted. Not all possible land use changes were mapped. For example, the abandonment of agricultural fields to scrub/shrub or forest was not mapped. In addition, there was an Unclassified category, i.e., the land use appeared to change but the category of that change could not be discerned. A minimum mapping unit of approximately 1 acre was imposed (i.e. a tract of new development had to be at least 1 acre in size to be interpreted and mapped).

The photo interpretation was undertaken by trained staff, graduate and post-baccalaureate students. The resulting SPOT-based interpretation was then quality checked by the Principal Investigator, R. Lathrop, using additional imagery for reference. Leaf-on and leaf-off Landsat Thematic Mapper imagery (September 12, 2001 and December 1, 2001, respectively) were used for additional reference in checking omission and commission errors in the interpretation.

To assess the accuracy of the satellite image interpretation and LU mapping, an extensive statewide field campaign was conducted. 638 locations interpreted as undergoing a classifiable land use change (i.e., one of the 8 land use change categories above, not Unclassified) were field checked. Of these 638 locations, 581 were correctly interpreted as undergoing the right category of land use change (i.e. new residential land use), giving an accuracy of 91%. In addition to the field checking, a separate accuracy assessment was conducted using high resolution (approximately 1m GRC) panchromatic orthophotography acquired for a nine county area of Atlantic, Burlington, Camden, Cape May, Cumberland, Gloucester, Mercer, Ocean and Salem counties, during the spring of 2000 by the Delaware Valley Regional Planning Commission. Only the appropriateness of interpreted land use change classification was assessed and not the spatial accuracy of the interpreted boundaries. For more details on the accuracy assessment refer to Appendix A.

Results

Urban Land Use Change

Over 100,000 acres were mapped by the 2000 Land Use Update as undergoing some form of land use change (Figure 1). While all the scope and impact of all these various land use changes are potentially of interest, of particular concern to New Jersey's public officials and citizenry alike are the multi-faceted consequences of urban growth and sprawl. Thus a major objective of the Land Use/Land Cover 2000 Update was to quantify the amount and spatial distribution of lands converted to urban uses (i.e., residential, mixed commercial/service/industrial, and recreational), redeveloped (i.e., changed urban land use type) or transitional to urban uses. Transitional lands are those lands that have been cleared often with preliminary infrastructure (e.g., roadways and foundations) in place. Based on the more detailed comparison of the medium resolution satellite vs. high resolution aerial imagery, a statistical adjustment was developed to help correct for any inaccuracy in the coarser scale satellite-based estimates.

Approximately 75,150 acres were mapped as urban land use change (i.e., residential, mixed commercial/service/industrial and recreation combined). Approximately 1,960 of these acres can be categorized as redevelopment (i.e., it was mapped as urban in 1995 but under a different urban land use category in 2000) (Table 1). If we eliminate these "redeveloped" lands from consideration, we recorded approximately 73,190 acres of "new" urban land (Table 1). Our quality assurance procedures showed that our mapping procedures slightly underestimated the amount of new Urban land uses. Using a ratio estimation technique the total urban land use change estimates were statistically adjusted upward (See Appendix A). The adjusted estimate for the overall change in new urban land is 77,941 acres with a 95% Confidence Interval of +/- 17,922 acres (Table 2). Comparing this figure with the 1,342,250 acres of existing urban land mapped in 1995/1997, our results show an increase of urban land of approximately 5.8% with a margin of error of +/- 1.3%.

An additional 22,030 acres of lands appeared to have been cleared or altered between 1995/97 and 2000 and are in likely transition to future urban land area. Some areas mapped as transitional in 2000 can be further categorized as altered (i.e., the land was initially mapped as transitional, altered, mining, water or urban in 1995 but underwent further alteration during the 1995 to 2000 time period and was mapped as transitional in 2000) rather than "new" transitional lands (i.e., forest, agricultural or wetland converted to transitional). If we exclude the 2,021 acres that fall into this altered category, we tallied approximately 20,009 acres of "new" transitional land (Table 1). Of the 1,242 acres mapped as extractive mining, 390 acres can be considered as already altered (i.e., land that was originally mapped as other barren, water or urban in 1995) and only 852 acres as originally forest, agricultural or wetland (Table 1). Combining the "newly altered" transitional and mining lands gives an estimate of 20,861 acres of new barren land (Table 1). Our quality assurance procedures showed that our mapping procedures slightly overestimated the amount of Transitional land uses. Using a ratio estimation technique the transitional land use change estimates were statistically adjusted downward (See Appendix A). The adjusted estimate for the increase in new transitional land is 16,082 acres with a 95% Confidence Interval of +/- 7,053 acres (Table 2). Combining

the urban and transitional land use categories, the land mapped as urbanized and/or undergoing transition to urban during the five year 1995 to 2000 period of this analysis was approximately 94,050 acres in area. The statistically adjusted estimate for this overall change in new urban and transitional land is 89,876 acres with a 95% Confidence Interval of +/- 16,528 acres (Table 2).

Table 1. Comparison of mapped newly developed vs. redeveloped or altered land area for 1995/1997 to 2000 time period.

	Newly Developed (acres)*	**Redeveloped or Altered (acres)***	**Total Land Use Change (acres)***
Urban	73,191	1,959	75,150
Transitional	20,009	2,021	22,030
Ext. Mining	852	390	1,242
Subtotal Barren	20,861	2,411	23,272
Total Urban & Barren	94,052	4,370	98,422

*Note: these are estimated area amounts derived from the GIS analysis, see Appendix A for further discussion on Error Analysis

Table 2. Comparison of mapped vs. statistically adjusted estimate of new urban and transitional/barren land use change between 1995 and 2000.

Land Use Change Category	**Mapped Estimate (Acres)**	**Statistically Adjusted Estimate (acres)**
Urban	73,191	77,941 +/- 17,922
Transitional/Barren	20,861	16,082 +/- 7,053
Total Urban & Barren	94,052	89,876 +/- 16,528

Examining the 2000 LU Update mapped data in greater detail (see Figure 1, Table 3) reveals that the major category of change was the increase in residential land use, which accounted for over 57,050 acres or approximately 59% of the mapped change. The second highest category of change was transitional at approximately 22,030 acres. The third largest category was mixed commercial/service/industrial land uses at approximately 11,900 acres. Over 6,150 acres of new recreational lands (e.g., golf courses, ball fields and other active recreational areas) were mapped. In addition comparatively small amounts of new agricultural (e.g., cultivated fields), other agricultural land use changes (e.g., replacement of cropland with greenhouses or other intensive agricultural production), new water bodies and extractive mining lands were mapped. An additional 580 acres of land use change was also mapped that could not be specifically classified into any of the above categories.

The overall new urban and barren (i.e., both transitional and extractive mining) land use change was enumerated by county (Table 4). Four counties lead the change with each over 9,000 acres of new developed growth, (in descending order): Ocean, Somerset, Monmouth, and Morris. The next five highest counties, each with over 5,000 acres in new development, were (in descending order): Burlington, Sussex, Hunterdon, Middlesex, and Atlantic.

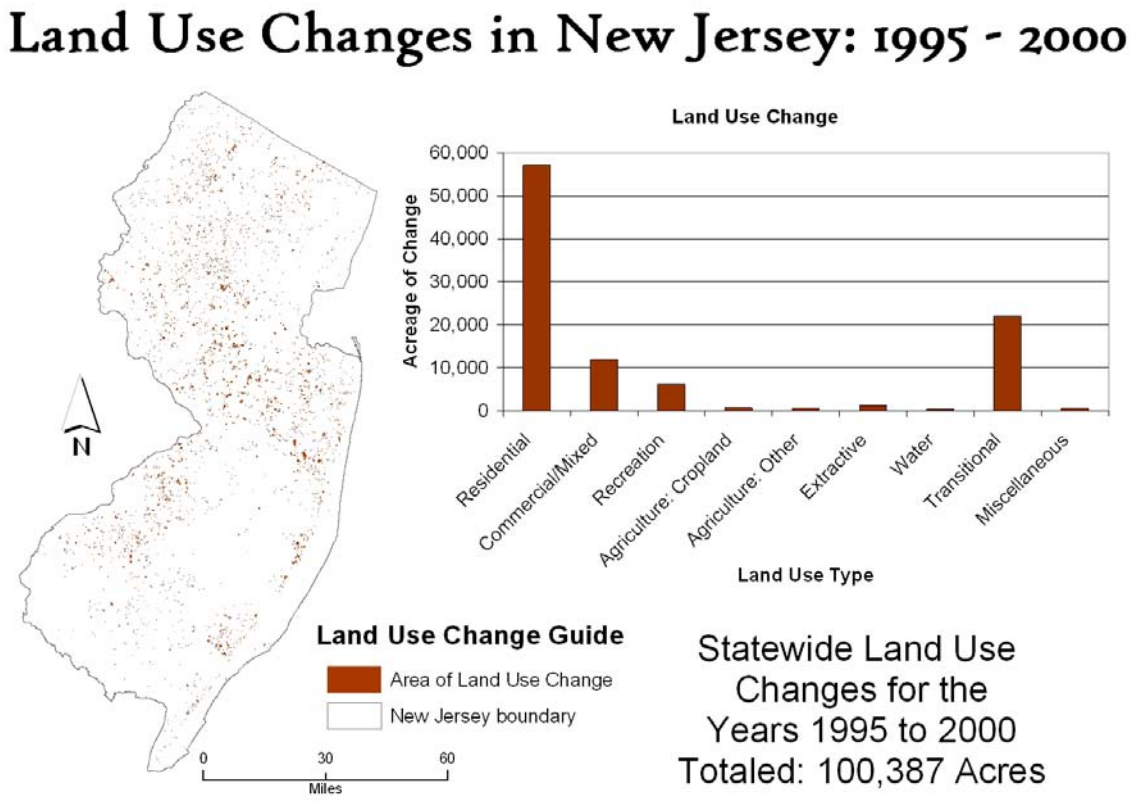

Figure 1. Overall mapped land use change for 1995/1997 to 2000.

Table 3. Mapped area amount (acres) of 1995 to 2000 land use change by 2000 land use type. Note: includes both newly developed as well as altered lands.

Land Use Type	**Area (acres)***
Residential	57,064
Mixed Commercial/Service/Industrial	11,890
Recreation	6,196
Agriculture: Cropland	653
Agriculture: Other	453
Extractive	1,242
Water	280
Transitional	22,030
Unclassified	579
Total	100,387

*Note: these are estimated area amounts derived from the GIS analysis, see Appendix A for further discussion on Error Analysis.

Table 4. Mapped new urban growth (i.e. new urban and transitional/barren land) enumerated by county for 1995/1997 to 2000 time period.

County	New Urban (acres)*	New Barren (acres)*	Total New Urban & Barren (acres)*
Ocean	6,720	3,905	10,625
Somerset	8,332	1,370	9,703
Monmouth	7,216	2,435	9,650
Morris	8,042	999	9,041
Burlington	5,276	2,270	7,547
Sussex	6,274	1,001	7,275
Hunterdon	5,702	833	6,535
Middlesex	3,709	1,680	5,389
Atlantic	3,959	1,196	5,155
Gloucester	3,868	1,077	4,946
Mercer	3,314	1,261	4,575
Warren	2,763	262	3,026
Camden	1,948	478	2,426
Passaic	1,645	198	1,843
Bergen	1,075	626	1,701
Cape May	1,242	233	1,474
Cumberland	614	605	1,220
Essex	471	157	628
Salem	555	68	623
Union	303	178	481
Hudson	169	41	210
Total**	73,199	20,873	94,072

*Note: these are estimated area amounts derived from the GIS analysis, see Appendix A for further discussion on Error Analysis.
** Note: that due to rounding error, totals will not exactly match figures in Table 2.

Urban Growth Rate

Further analysis of the mapped land use change data was undertaken to highlight the major land use transitions (i.e., change from one type to another type of land use) and the overall conversion of undeveloped lands to new urban or transitional land uses. This analysis worked with the original mapped data rather than the statistically adjusted

estimates. The overall estimated rate of urbanization (i.e., conversion of forest, agricultural, wetland/water or transitional/barren lands to urban) during the 1995 to 2000 time period was 73,191 acres/5 yrs or approximately 14,640 acres/yr (Table 5). During the same time period another 20,861 acres of undeveloped lands (i.e., including forest, wetland, and agricultural lands) were converted to transitional/barren at a rate of approximately 4,170 acres/yr (Table 5). The overall conversion of forest, agricultural and wetland/water to new urban and transitional/barren lands was estimated at approximately 15,840 acres/yr (Table 5) (note that the water to transitional/barren change was excluded due to the seasonally temporary nature of this change). However, determining the rate of new development as an acreage amount per year is not straightforward because there were not two simple Time 1 and Time 2 endpoints in time. Due to the geographic variation in the Time 1 and 2 endpoints, one must recognize the uncertainty in the rate estimates (See Appendix A for greater detail).

The change rates for the 1995 to 2000 time period discussed above were compared with change estimates made for the 1986 to 1995 time period (Hasse and Lathrop, 2001). The urban land use growth rate (other categories to Urban) appears to have decreased from the approximately 16,660 acres/yr between 1986 and 1995 to the 14,640 acres/yr change recorded between 1995 and 2000 (Table 5). Conversely, the rate of change of forest/farm/wetland to transitional or barren land appears to have increased from an estimated rate of approximately 3,160 acres/yr rate between 1986 and 1995 to approximately 4,170 acres/yr between 1995 and 2000 (Table 5). During the 1995 to 2000 time period, the rate of change of transitional to urban land was approximately 2,970 acres/yr, a significant percentage increase over the approximately 1,570 acres/yr rate estimated between 1986 and 1995 (Table 5). Examination of the overall conversion of lands to new urban or barren land uses, shows a slight decline from an estimated rate of approximately 19,810 acres/year between 1986 to 1995 to approximately 18,810 acres/year between 1995 and 2000 (Table 5); a 5% decline in conversion rate and within the estimated margin of error.

Table 5. Comparison of from-to land use transitions between the 1986 to 1995 and 1995 to 2000 time periods. Note that in qualifying whether a change in the annual rate was relatively unchanged (↔) or significantly higher (↑) or lower (↓), a change threshold of +/- 25% was used to account for a margin of error.

Land Use Conversion	From → To 1986 1995 *(Acres)* Annual rate	From → To 1995 2000 (*Acres)* Annual rate	Change in Rate Percent Trend
Forest → Urban	*(67,108)* 7,456	*(35,645)* 7,129	-4.4% ↔
Forest → Barren	*(10,536)* 1,171	*(12,308)* 2,462	+110.2% ↑
Forest → Urban/Barren Subtotal	*(77,644)* 8,627	*(47,953)* 9,591	+11.2% ↔
Agriculture → Urban	*(57,552)* 6,391	*(18,774)* 3,755	-41.2% ↓
Agriculture → Barren	*(9,637)* 1,071	*(7,137)* 1,427	+33.2% ↑
Agriculture → Urban/Barren Subtotal	*(67,189)* 7,465	*(25,911)* 5,182	-30.6% ↓
Wetland → Urban	*(10,979)* 1,220	*(3,687)* 737	-39.6% ↓
Wetland → Barren	*(8,222)* 914	*(1,416)* 283	-69.0% ↓
Wetland → Urban/Barren Subtotal	*(19,201)* 2,133	*(5,103)* 1,021	-52.1% ↓
Water → Urban	*(153)* 17	*(228)* 46	+170.6% ↑
Water → Barren	*(2,238)* 249	*(143)* 29	-88.4% ↓
Forest/Agric/Wetland/Water → Urban	*(135,792)* 15,088	*(58,334)* 11,667	-22.7% ↔
Barren → Urban	*(14,112)* 1,568	*(14,857)* 2,971	+89.5% ↑
Forest/Agric/Wetland/Water → Urban + Barren → Urban Subtotal	*(149,904)* 16,656	*(73,191)* 14,638	-12.1% ↔
Forest/Agric/Wetland → Barren Subtotal	*(28,395)* 3,155	*(20,861)* 4,172	+32.2% ↑
Forest/Agric/Wetland/Water → Urban + Forest/Agric/Wetland* → Barren Subtotal	*(164,187)* 18,243	*(79,195)* 15,839	-13.1% ↔
Forest/Agric/Wetland/Water/Barren → Urban + Forest/Agric/Wetland* → Barren	*(178,299)* 19,811	*(94,052)* 18,810	-5.0% ↔

* Excludes Water → Barren Transition due to the seasonal nature of this change
Note: these are estimated area amounts derived from the GIS analysis, see Appendix A for further discussion on Error Analysis.

Forest Land Conversion

Over 48,600 acres of forest land were converted to other land uses during the 1995/1997 to 1999/2000 time period (Figure 2). This amount of forest loss approximately equals the area of Stokes State Forest, High Point and Wawayanda State Parks combined. Comparing this amount with the 1,602,869 acres of forest land mapped in 1995/1997, the Year 2000 data represents a decrease of forest land of approximately 3%. It must be noted, that in 2000 Update study, areas of *new* forest (i.e., abandoned farmlands that may have re-grown into forest during the 1995/97 to 2000 time period) were not mapped.

An estimated 47,953 acres of forest were converted to development (i.e., urban and transitional/barren land uses) between 1995 and 2000, which equates to an annual rate of approximately 9,590 acres/yr (Table 5). In comparison, an estimated 77,644 acres of forest were converted to development during the 1986 to 1995/97 time period, representing a rate of approximately 8,630 acres/yr lost (Hasse and Lathrop, 2001) (Table 5). While there was a slight decrease in the amount of forest converted to urban land, there was a substantial percentage increase in the amount converted to transitional/barren land (Table 5). Overall, the rate of forest converted to urban growth over the 1995 to 2000 time period registered a 11% increase over that experienced during the 1986 to 1995 time period , representing a non-significant change in trend (Table 5).

Much of this forest loss is attributable to suburban and/or exurban growth with approximately 27,700 acres converted to residential development and another 11,500 acres converted to transitional. Over 3,000 acres were cleared for recreational land uses such as golf courses and ball fields. The top five counties of forest conversion were (in descending order): Ocean, Morris, Atlantic, Sussex and Somerset (Figure 3). The high forest loss counties include areas in the Coastal Plain (but outside of the core areas of the Pinelands Reserve) and the Highlands/Skylands areas of Morris, Sussex and northern Somerset counties. Such exurban development can lead to forest core area reduction and forest fragmentation, which may have significant implications for wildlife habitat

sustainability and forest land management. Forest loss also has implications for soil erosion, flooding, non-point source pollution, carbon sequestration and air quality.

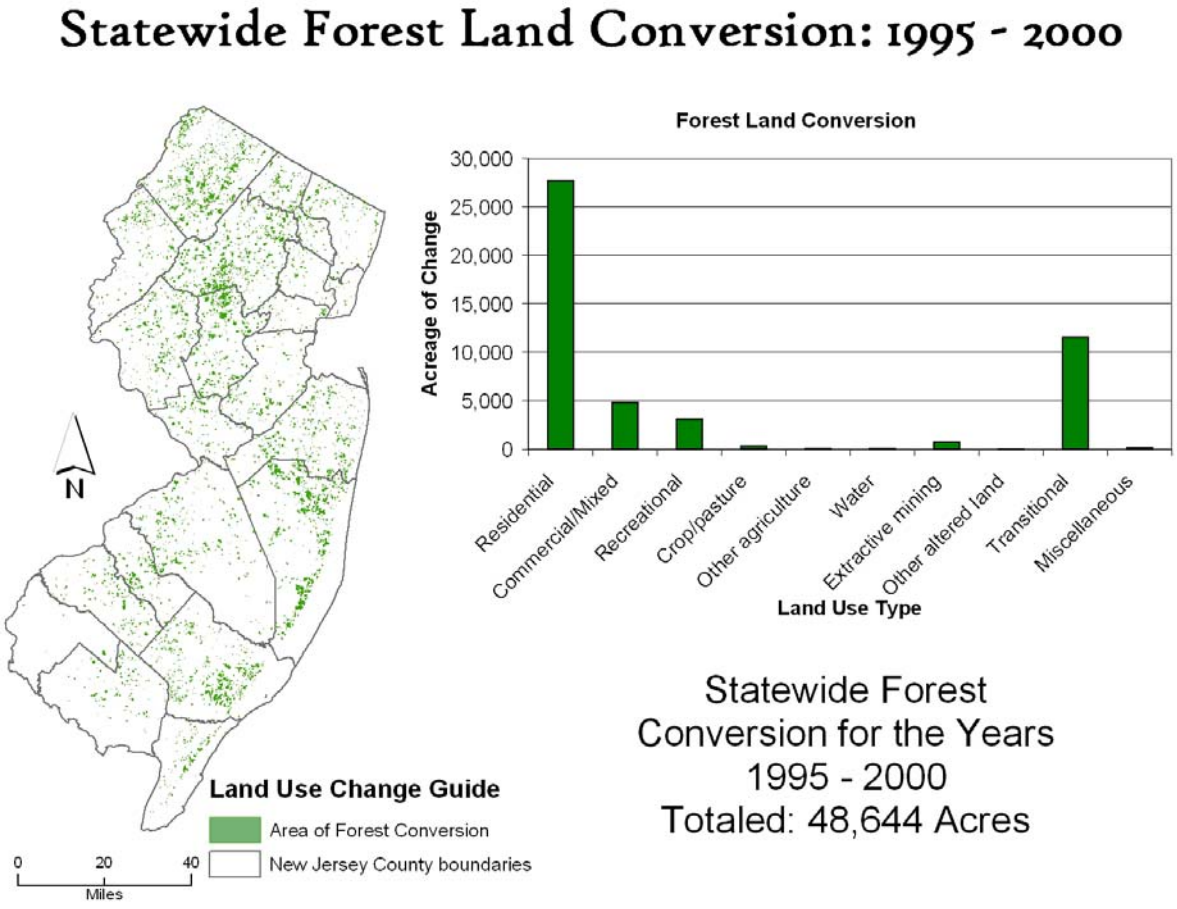

Figure 2. Forest land converted to other land uses.

Note: these are estimated area amounts derived from the GIS analysis, see Appendix A for further discussion on Error Analysis. Also note that the map scale and small graphic size accentuate the geographic extent of land use change in the map above.

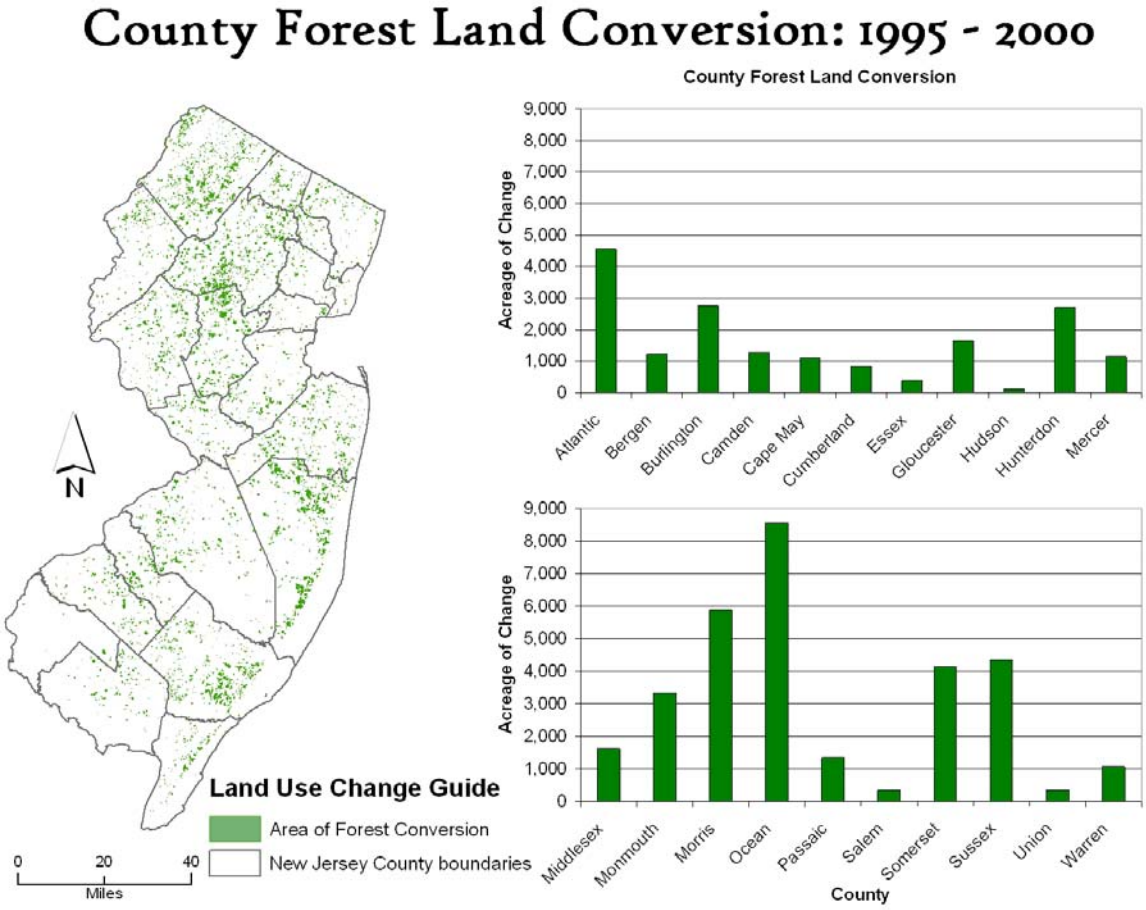

Figure 3. Forest land converted to other land uses broken down by county.

Note: these are estimated area amounts derived from the GIS analysis, see Appendix A for further discussion on Error Analysis. Also note that the map scale and small graphic size accentuate the geographic extent of land use change in the map above.

Agricultural Land Conversion

Approximately 26,000 acres of cultivated land were converted to other non-agricultural uses during the 1995 to 2000 time period (Figure 4). Of this loss, over 50% (approximately 14,000 acres) were converted to residential land use and another 25% (approximately, 7,100 acres) converted to transitional. Comparing this with the 659,018 acres of agricultural land mapped in 1995/1997, the Year 2000 data represents a decrease of cultivated agricultural land of approximately 4.0%. To put this in context, this amount of farmland loss well exceeds all the farmland currently remaining in Middlesex County. The top five counties of agricultural land use change were (in descending order): Monmouth, Burlington, Somerset, Hunterdon, and Mercer (Figure 5).

The estimated rate of agricultural conversion to developed land uses (i.e., urban or barren/transitional) is 25,911/5 yr or approximately 5,180 acres/yr (Table 5). In comparison, an estimated 67,189 acres of agricultural land were converted to developed land uses (i.e. urban or barren/transitional) during the period between 1986 and 1995 (Hasse and Lathrop, 2001) at a rate of approximately 7,460 acres/yr (Table 5). While there was a significant decrease in the amount of agricultural land converted to urban, there was a significant percentage increase in the amount converted to transitional/barren land (Table 5). Overall, the rate of agricultural land converted to urban growth over the 1995 to 2000 time period registered a 30% decrease over that experienced during the 1986 to 1995 time period, representing a significant change in trend (Table 5).

Agriculture is still an important component of the Garden State's economy with cash sales of farm products estimated at $829.5 million (NJDA, 2000). While the 2000 Land Use Update shows that New Jersey is still losing the farmland that supports this economic base, the rate of loss appears to have slowed compared to the 1986 to 1995 time period (Table 5). It should be noted that over the same 1995 to 2000 time period nearly 40,000 acres of farmland were enrolled in New Jersey's Farmland Preservation Program (Hamill and Sturm, 2003).

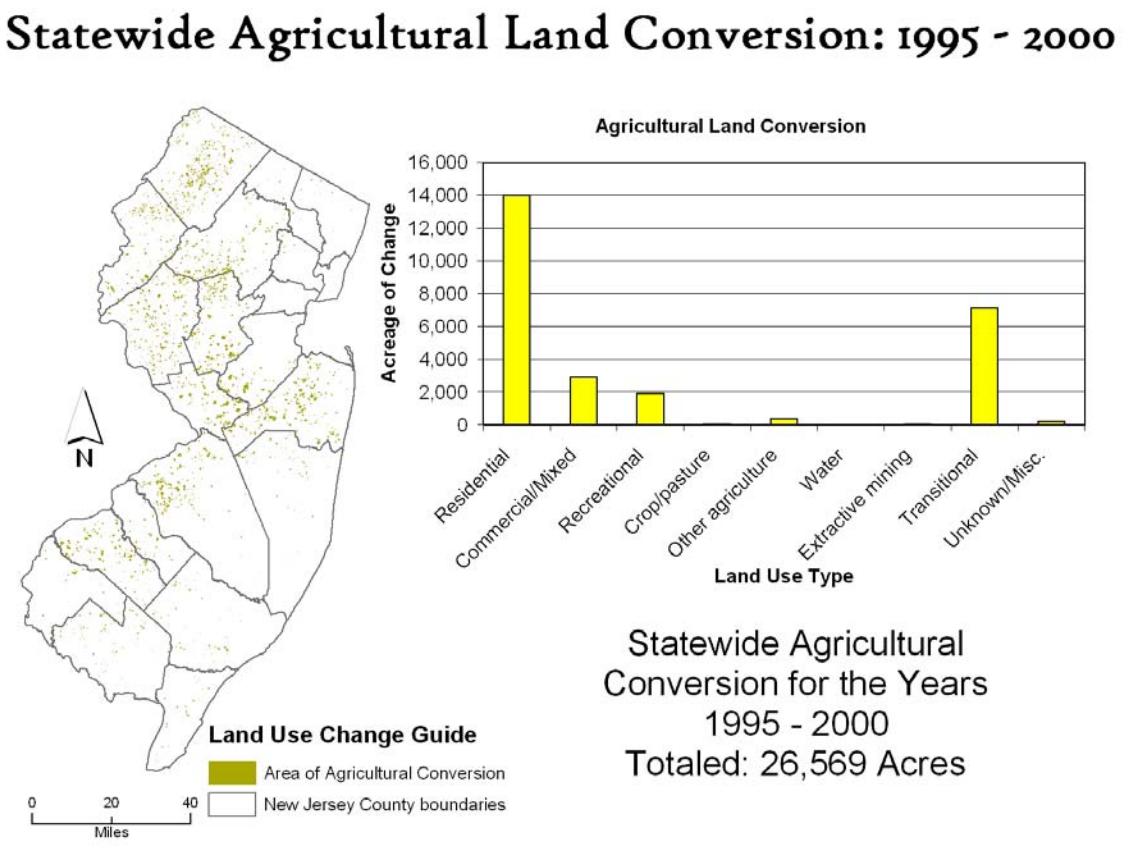

Figure 4. Agricultural land converted to other land uses. This acreage estimate does not include cultivated land that may have been abandoned and is no longer in productive cultivation. While overall, New Jersey showed a net loss of agricultural lands, there was approximately 400 acres gain in agricultural land from other land uses (e.g., forest or wetland) not reflected in the above figure.

Note: these are estimated area amounts derived from the GIS analysis, see Appendix A for further discussion on Error Analysis. Also note that the map scale and small graphic size accentuate the geographic extent of land use change in the map above.

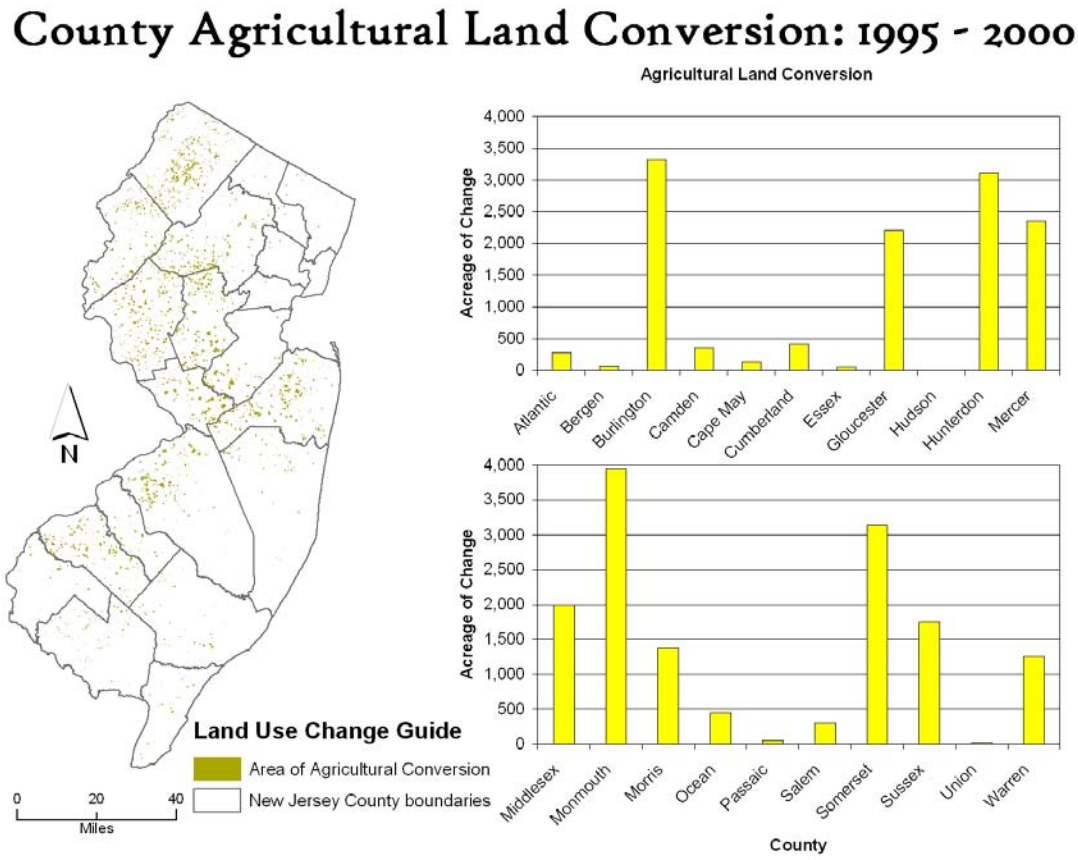

Figure 5. Agricultural land converted to other land uses broken down by county.

Note: these are estimated area amounts derived from the GIS analysis, see Appendix A for further discussion on Error Analysis. Also note that the map scale and small graphic size accentuate the geographic extent of land use change in the map above.

Wetlands Conversion

Comprising one fifth of the state's land, natural wetlands are a vital component of the New Jersey landscape. Natural wetlands are defined as those wetlands that have comparatively intact natural wetland vegetation communities and have not been directly modified by urban, agricultural or other altered land uses. Over 5,200 acres of natural wetlands were converted to other land uses (Figure 6). This amount of wetland loss equates to an area approximately two-thirds the size of the Great Swamp National Wildlife Refuge. Comparing this with the 917,368 acres of wetland mapped in 1995/1997, the Year 2000 data represents a decrease of wetland of approximately 0.6%. Of these 5,200 acres, over 50% (approximately 2,800 acres) were converted to residential land use and another 25% (approximately 1,400 acres) were converted to transitional. The top five counties of natural wetlands loss were (in descending order): Monmouth, Somerset, Ocean, Middlesex and Morris (Figure 7).

In addition to these natural wetlands, approximately 4,230 acres of additional urban, agricultural or disturbed wetlands were converted to urban or transitional land uses (i.e., 82; 2,199; and 1,949 acres, respectively). Wetlands mapped under an urban or transitional/barren land use in 1995 that underwent further development by 2000 were considered redeveloped/altered land use change and not included in the analysis of natural wetlands conversion. Agricultural wetlands were considered an agricultural land use and included in the Agriculture Conversion section discussed above.

The estimated rate of natural wetland conversion to developed land uses (i.e., urban and transitional/barren) is 5,103/5 yr or approximately 1,020 acres/yr (Table 5). In comparison, there was a estimated net loss of 19,201 acres of wetland to urban development during the period between 1986 and 1995 (Hasse and Lathrop, 2001) at a rate of approximately 2,130 acres/yr (Table 5). Overall, the rate of natural wetland converted to urban and transitional/barren land uses over the 1995 to 2000 time period registered a 52% decrease compared to the 1986 to 1995 time period, representing a significant decline in trend (Table 5). It should be noted that the amount of wetland

converted to agricultural land uses declined significantly as well (i.e., 2,289 acres between 1986 and 1995 vs. 149 acres between 1995 and 2000).

Wetlands are important for wildlife habitat, flood mitigation, and water purification. Coastal wetlands have been protected since 1970. Disturbance of fresh water wetlands has been regulated since the 1987 New Jersey Freshwater Protection Act. While this regulation appears to have been successful in reducing the magnitude of wetlands loss compared to pre-regulatory days, the LU 2000 Update shows that there is still a nontrivial loss of wetlands.

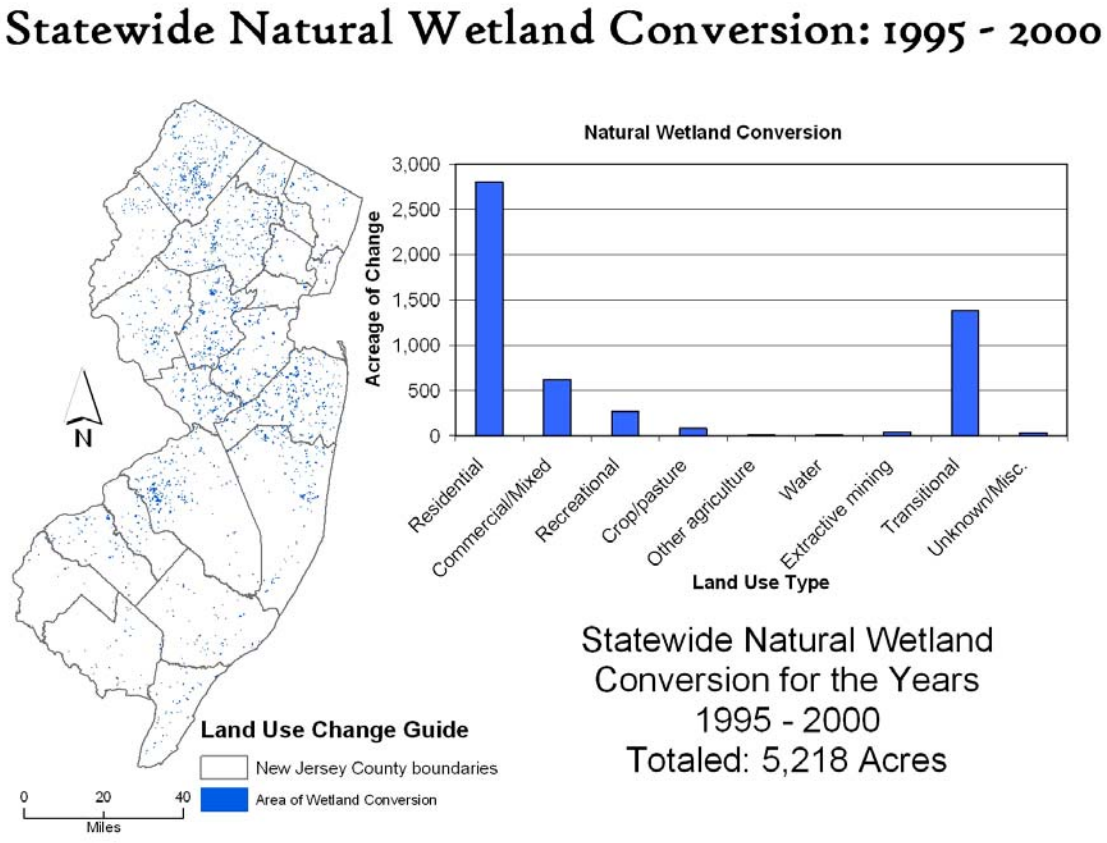

Figure 6. Wetlands converted to other land uses.

Note: these are estimated area amounts derived from the GIS analysis, see Appendix A for further discussion on Error Analysis. Also note that the map scale and small graphic size accentuate the geographic extent of land use change in the map above.

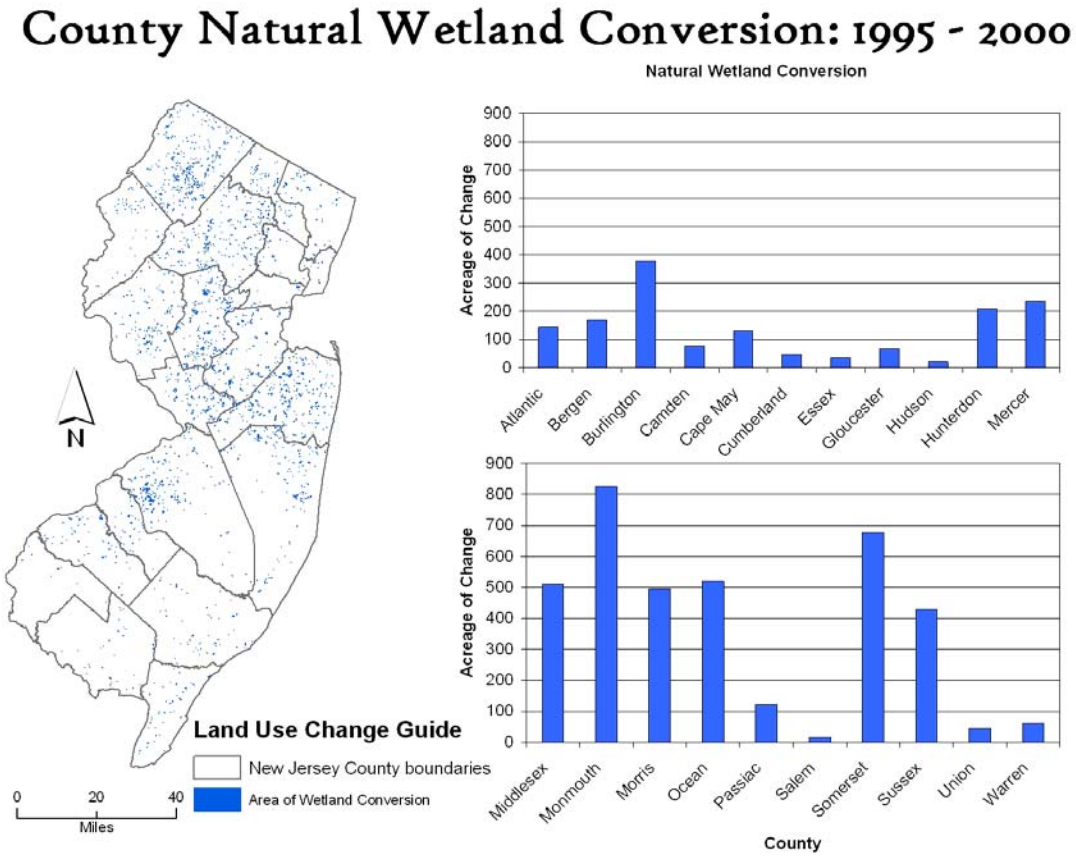

Figure 7. Wetlands converted to other land uses broken down by county.

Note: these are estimated area amounts derived from the GIS analysis, see Appendix A for further discussion on Error Analysis. Also note that the map scale and small graphic size accentuate the geographic extent of land use change in the map above.

Conclusions

The trends revealed in the 2000 Land Use Update show that New Jersey's urban development continues apace. The statistically adjusted estimate for the overall change in new urban land between 1995 and 2000 is approximately 77,940 +/- 17,920 acres (Table 2), representing an increase of urban land of approximately 5.8% with a margin of error of +/- 1.3%. Adding in new transitional/barren lands, the statistically adjusted estimate of total developed land use change is approximately 89,880 +/- 16,530 acres (Table 2). While the accuracy of the overall urban and transitional change area estimates was statistically evaluated, the statistical confidence intervals for the conversion of specific categories of land (e.g., forest, farmland or wetland) were not separately evaluated. Thus the total acreage amounts and annual rates for forest, farmland, wetland and barren land conversion as enumerated in this report should be considered as best available estimates.

Taken on an annual basis, New Jersey added approximately 14,640 acres of new urban land use and an additional 4,170 acres in transition to future development or mining per year (based on the map analysis, rather than the statistically adjusted estimate (Table 5)). This annual rate of change is slightly less than the 16,660 acres of new urban and 3,160 acres in new barren land use recorded for the 1986 to 1995 time period but within the estimated margin of error (Table 5). The overall urban/barren land conversion rate has remained relatively steady with an estimated rate of approximately19,810 and 18,810 acres/year between 1986-1995 and between 1995-2000, respectively (Table 5). This 5% decline in conversion rate is within the estimated margin of error. Due to the geographic variation in the Time 1 and 2 endpoints, one must recognize the uncertainty in the annual rate estimates.

Land use change is a zero sum game. Gain in any one category must come at the loss of another. In the case of New Jersey's landscape, this new urban growth came at the cost of approximately 9,590 acres of forest, 5,180 acres of agricultural land, and 1,020 acres of natural wetlands per year. An additional 2,970 acres of previously cleared forest, farm

and wetland were also developed each year. These results suggest for the 1995 to 2000 time period that the rate of forest loss was slightly higher (+11.2%), while the rate of agricultural land and wetland conversion was substantially lower (-30.6% and -52.1% respectively) as compared to the 1986 to 1995 time period. The forest loss trend to urban development has remained relatively steady (i.e., a non-significant change in trend), while the farmland and wetland loss trend has experienced a significant decline as compared to the 1986 to 1995 time period. The continued loss of forest land is of special concern due to the critical role these lands play in providing ecosystem services such regulating reducing soil erosion, maintaining water quality, sequestering carbon, and providing wildlife habitat. The declining rate of loss of wetlands suggests that New Jersey's strict wetlands protection laws are having the intended effect, though continued diligence is clearly warranted given the critical ecosystem services that these lands provide.

This LU 2000 Update report is part of a continuing investigation of New Jersey's changing landscape (for more information and download of the 2000 Land Use Update digital GIS data, go to www.crssa.rutgers.edu/projects/lc). Taking the inherent limitations of the 10 meter Panchromatic SPOTView NJ image mosaic into account, this image data source does not provide the same level of categorical detail and accuracy in mapping land use/land cover as that possible with meter scale color infrared digital orthophotography. However, the SPOT statewide image mosaic does provide a cost-effective alternative for the mapping and monitoring of broader trends in urban growth and land use change. The sub-meter digital orthophotography acquired by the NJDEP in 2002 and scheduled to be made available in 2004 will provide a more current and higher resolution image data source for a more detailed mapping of recent land use change. Once these image data are interpreted and digitized (scheduled for completion in 2005-2006), a more comprehensive analysis of urban growth and land use change comparable to that undertaken for the change between 1986 and 1995/1997 (e.g., Hasse and Lathrop, 2001) will be undertaken. It is our hope that a better understanding of the land development patterns will contribute to more informed land management policies and practices in New Jersey in the coming years.

Acknowledgements

This bulk of this work was funded by the New Jersey Department of Environmental Protection. Additional funding was provided by the U.S. Forest Service, the Jacques Cousteau National Estuarine Research Reserve and the New Jersey Agricultural Experiment Station. Special thanks go to Chris Dugan, who performed the bulk of the photo-interpretation and mapping. John Bognar provided invaluable assistance in data processing and analysis. Paul Montesano undertook the image interpretation for the accuracy assessment. Scott Haag, Jennifer Daniels, Joe Geib, Christine Giordano, Dave Gwynn, Paul Montesano and Jim Myers also contributed in photo-interpretation, mapping and data processing. Dr. Ed Green provided statistical consulting for the accuracy assessment. The long time collaboration of Dr. John Hasse, Dr. Marjorie Kaplan and John Tyrawski in New Jersey land use change-related research is also gratefully acknowledged.

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Appendix A. Error Analysis

To assess the accuracy of the satellite image interpretation and LU mapping, an extensive statewide field campaign was conducted. A sample of 684 polygonal areas identified in the mapping as LU change were visited in the field to verify their status (Figure 8). The sites were located in the field using a laptop computer linked with a Global Positioning System (GPS) receiver. Field notes and digital ground photos were taken for each field reference point. 638 locations interpreted as undergoing a classifiable land use change (i.e., one of the 8 land use change categories above, not Unclassified) were field checked. Of these 638 locations, 581 were correctly interpreted as undergoing the right category of land use change (i.e. new residential land use), giving an accuracy of 91%. An additional 46 field checked polygons interpreted as "unclassified" land use change type were also field checked. Of these 46 locations, 38 were correctly interpreted as undergoing land use change (in that the land use had changed from 1995/97), giving an accuracy of 83%.

In addition to the field checking, a separate accuracy assessment was conducted using high resolution (approximately 1m GRC) panchromatic orthophotography acquired during the spring of 2000 by the Delaware Valley Regional Planning Commission. Imagery was available for the counties of Atlantic, Burlington, Camden, Cape May, Cumberland, Gloucester, Mercer, Ocean and Salem counties, representing approximately one half of the state's land area. This digital imagery was loaned to CRSSA for this accuracy assessment purpose. 62 orthophotographic tiles (each tile was approximately 1,015 acres in size) were selected using a stratified random sampling design, representing slightly more than 2% of the DVRPC imaged area. The SPOT-derived land use map was stratified into low, medium, high and highest change areas and an approximately equal number of tiles were randomly from each class. Each tile was then interpreted by a skilled photo-interpreter using this same methods and classification scheme as that used for the SPOT imagery (Figure 9a). The resulting aerial photo interpreted land use change estimates were then compared with the SPOT-derived estimates (Figure 9b). Due to differences in the dates of the SPOT vs. DVRPC imagery, some areas of change show up in one set of imagery and not the other. For example, land use change that occurred

subsequent to Spring 2000 (the date of DVRPC imagery) is apparent in the SPOT imagery acquired several months later in 2000. These areas were identified and excluded from the comparison.

The total area of new urban and transitional/barren land estimated from the SPOT interpreted maps was 1983 acres as compared to 1895 acres estimated from the reference aerial photography which equates to an overestimate of slightly below 5%. Figure 10a shows the close correspondence between the two estimates. The relative accuracy of the estimation of urban vs. transitional land was evaluated separately. The total area of new urban land estimated from the SPOT interpreted maps was 1263 acres as compared to 1345 acres estimated from the reference aerial photography which equates to an underestimate of approximately 9%. Figure 10b shows the correspondence between the two estimates. Accurate interpretation and detailed delineation of transitional lands in agricultural land settings can be difficult with the SPOT imagery. Due to this difficulty in interpretation, there appeared to be an overestimation of transitional land. The total area of new transitional land estimated from the SPOT interpreted maps was 719 acres as compared to 554 acres estimated from the reference aerial photography which equates to an overestimate of slightly below 30%. Approximately one half of the difference between the two estimates was due to the over/under estimate of transitional land in three tiles (as can be noted that in Figure 10c). Some discrepancy in the individual Urban and Transitional assessments is due to the interpretation of newly developing areas that were classified as urban in the DVRPC and transitional in the SPOT imagery and vice versa. Thus the larger discrepancies in the individual Urban and Transitional assessments are balanced out in the combined assessment, resulting in an overall lower error.

Based on the above comparison between the SPOT and the DVRPC reference imagery land use estimates, a ratio estimation technique (Shiver and Border, 1996) was applied to determine a 95% confidence interval around the overall estimated land use change. The ratio estimation and confidence intervals were calibrated for the nine county accuracy assessment sub-area and then extrapolated to the state-wide land use change estimates. Overall, the 2000 LU Update was deemed to be sufficiently accurate for us to be

confident in the estimates of land use change based on these mapped data for use in analyzing county to regional trends. The above accuracy assessment only examined the attribute accuracy of the interpretation and not the spatial accuracy of the mapped boundaries. Due to the coarser spatial resolution of the SPOT imagery, there is error in the mapped land use change polygon boundaries. The stated positional accuracy of the SPOTView Imagery is 12 meters or better with 90% confidence. Comparison of the SPOT-digitized boundaries with the higher resolution DVRPC reference imagery showed discrepancies on the order of up to 20 to 30 meters in a horizontal direction, thus caution should be employed in using the 2000 Land Use Update GIS data for more site-specific assessments.

While the accuracy of the overall urban and transitional change area estimates were statistically evaluated, the statistical confidence in the conversion of specific categories of land (e.g., forest, farmland or wetland) were not separately evaluated. Thus the total acreage amounts or change rates for forest, farmland and wetland conversion as enumerated in this report should be considered as initial estimates. Once the sub-meter statewide digital orthophotography acquired in 2002 are interpreted and digitized (scheduled for completion in 2005-2006), a more comprehensive and detailed analysis will be undertaken and more refined estimates of urban growth and land use change will be feasible.

Determining the rate of new development as an acreage amount per year is not straightforward because there were not two simple Time 1 and Time 2 endpoints in time. For the Time 1 endpoint (i.e. the NJDEP LU/LC), part of the state was mapped in 1995 and part in 1997 (Figure 11). Approximately, 11,000 acres (or 10.9%) of the changed land use area and 8,400 acres (or 11.1%) of new urban is for the 1997 DOQ mapped area; so instead of a 5 year figure in the denominator, 3 years could be used instead, thereby increasing the rate of change for those areas of the state. The SPOT imagery ranged in date from 4/071998 to 12/05/2000. As the majority of the imagery was from year 2000 (Figure 12), a 2000 date was used as the Time 2 endpoint. Due to the geographic variation in the Time 1 and 2 endpoints, one must recognize the uncertainty in the rate

estimates that is difficult to quantify. Due to this uncertainty a change threshold of +/- 25% was used to account for a margin of error in ascertaining whether a trend in the annual conversion rate was relatively unchanged (↔) or significantly higher (↑) or lower (↓),

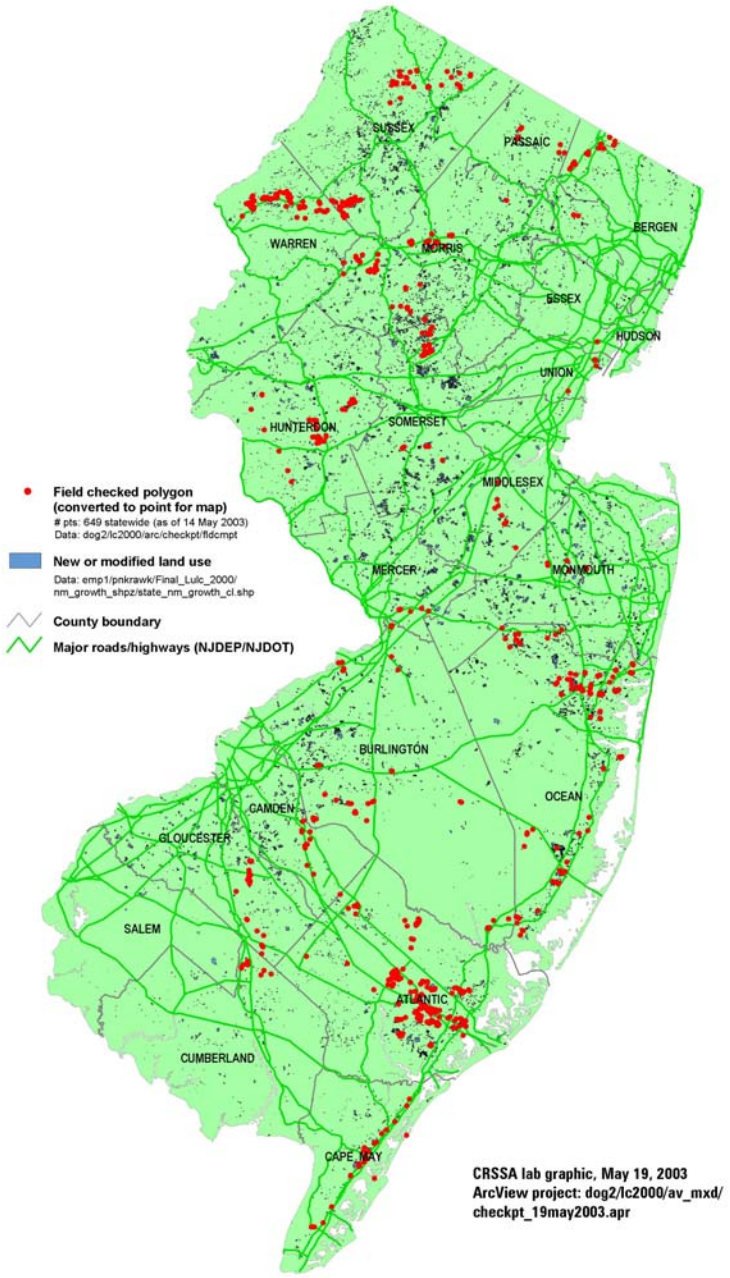

Figure 8. Field checked land use change polygons.

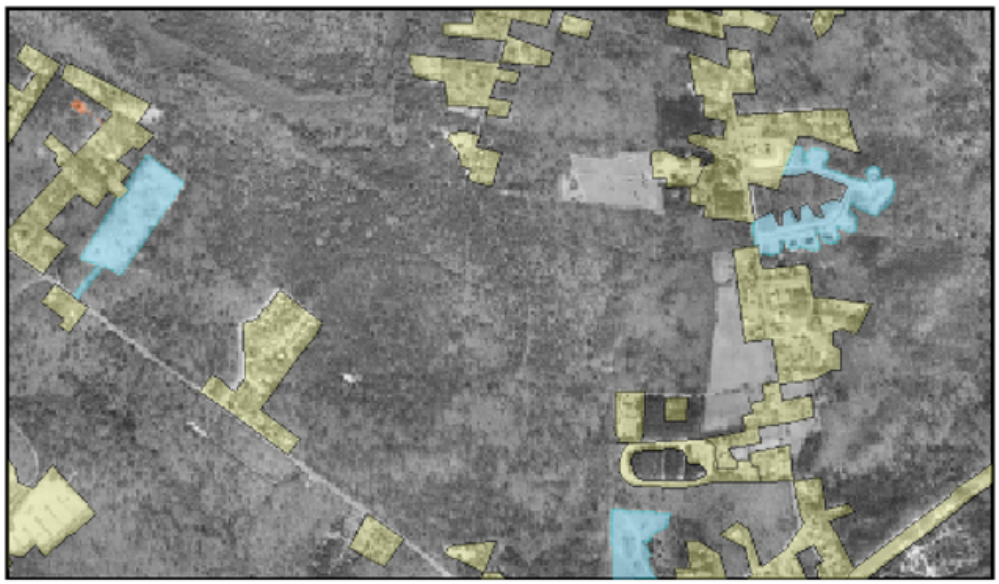

Figure 9a. B& W sub-meter DVRPC digital orthophotography with land use overlay: 1995 in yellow, 2000 in blue.

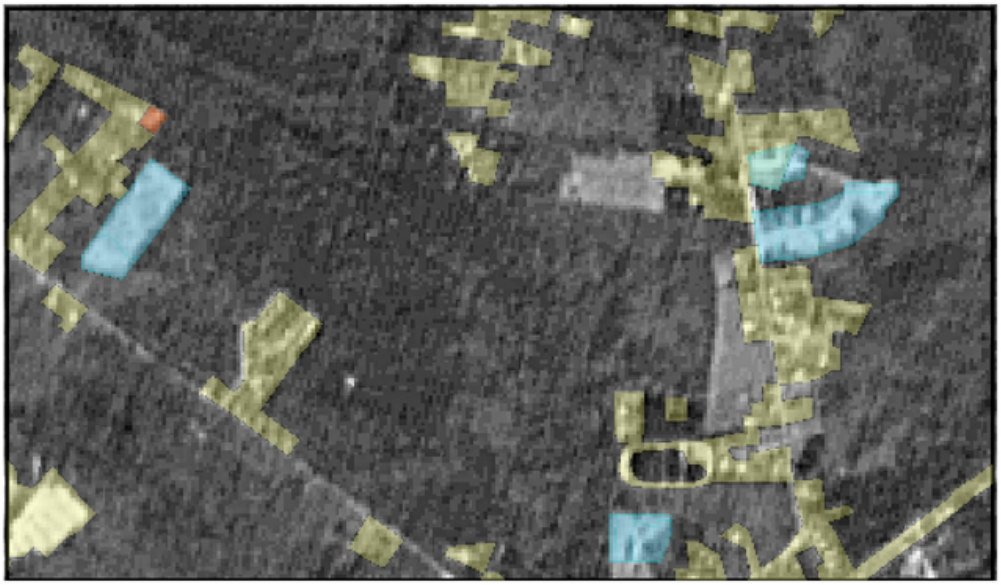

Figure 9b. 10 meter SPOT PAN imagery with land use overlay: 1995 in yellow, 2000 in blue.

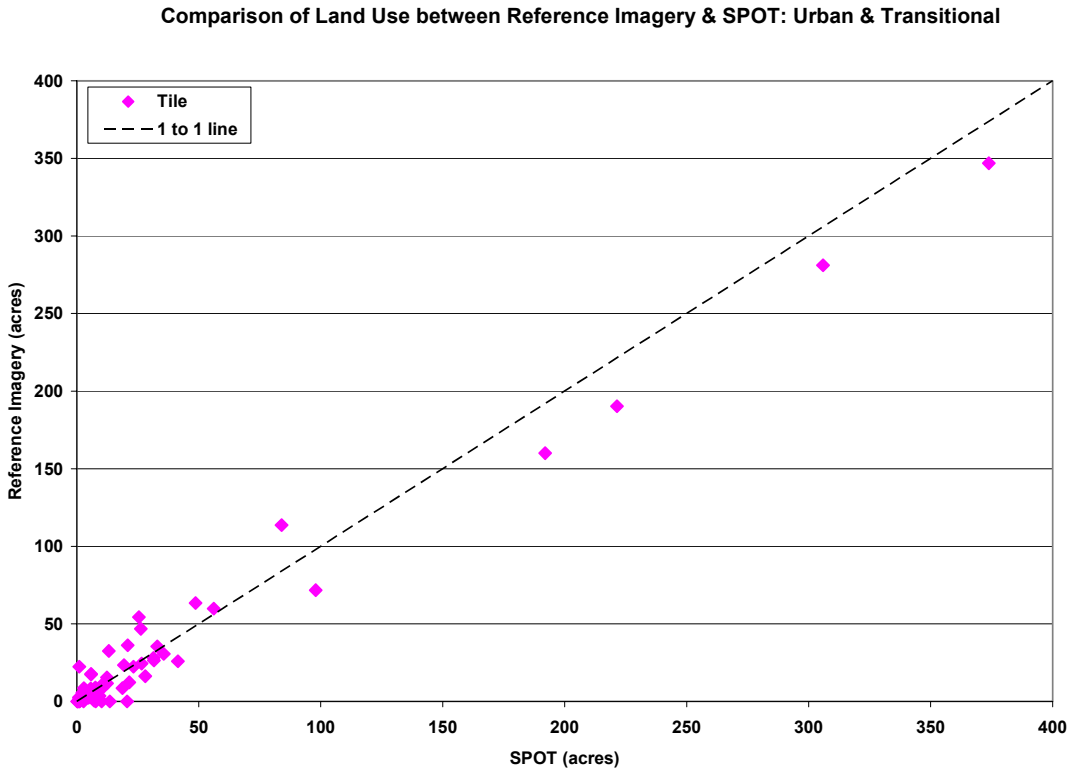

Figure 10a. Plot of Spot vs. DVRPC reference image estimates of Urban & Transitional Land Use change with 1:to:1 line.

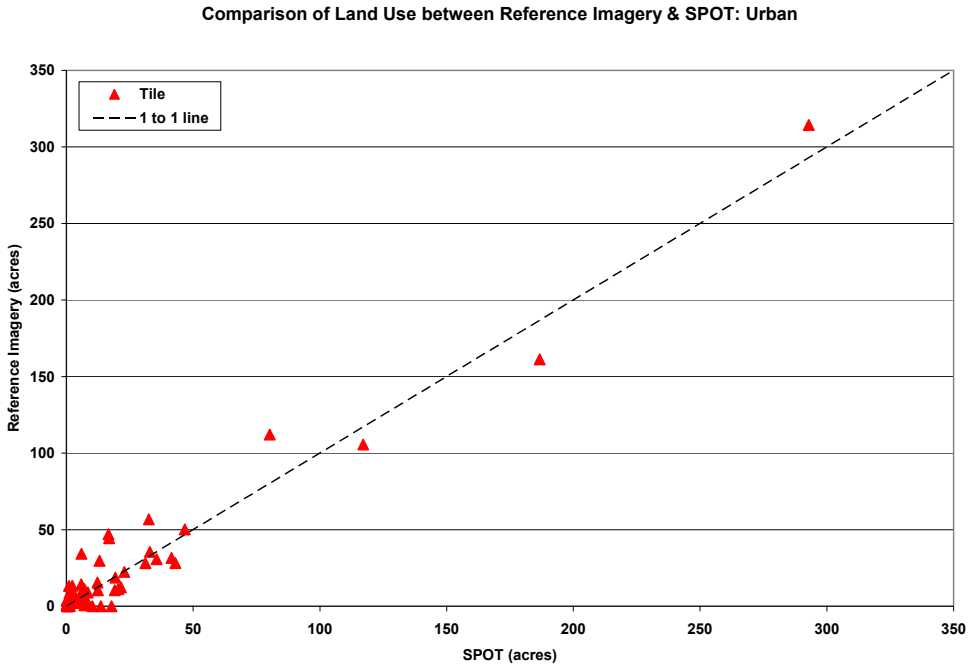

Figure 10b. Plot of Spot vs. DVRPC reference image estimates of Urban Land Use change with 1:to:1 line.

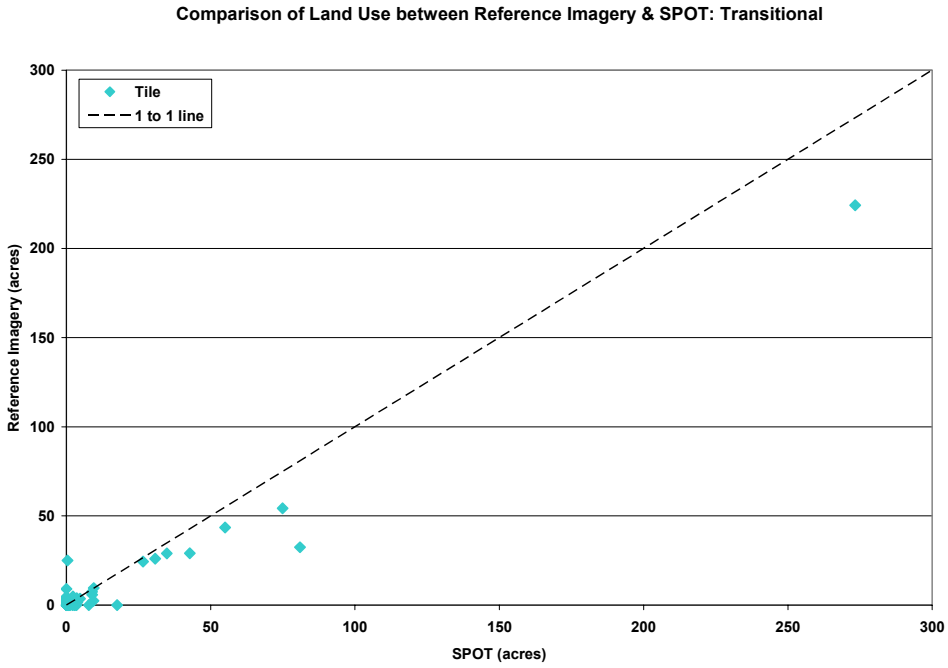

Figure 10c. Plot of Spot vs. DVRPC reference image estimates of Transitional Land Use change with 1:to:1 line.

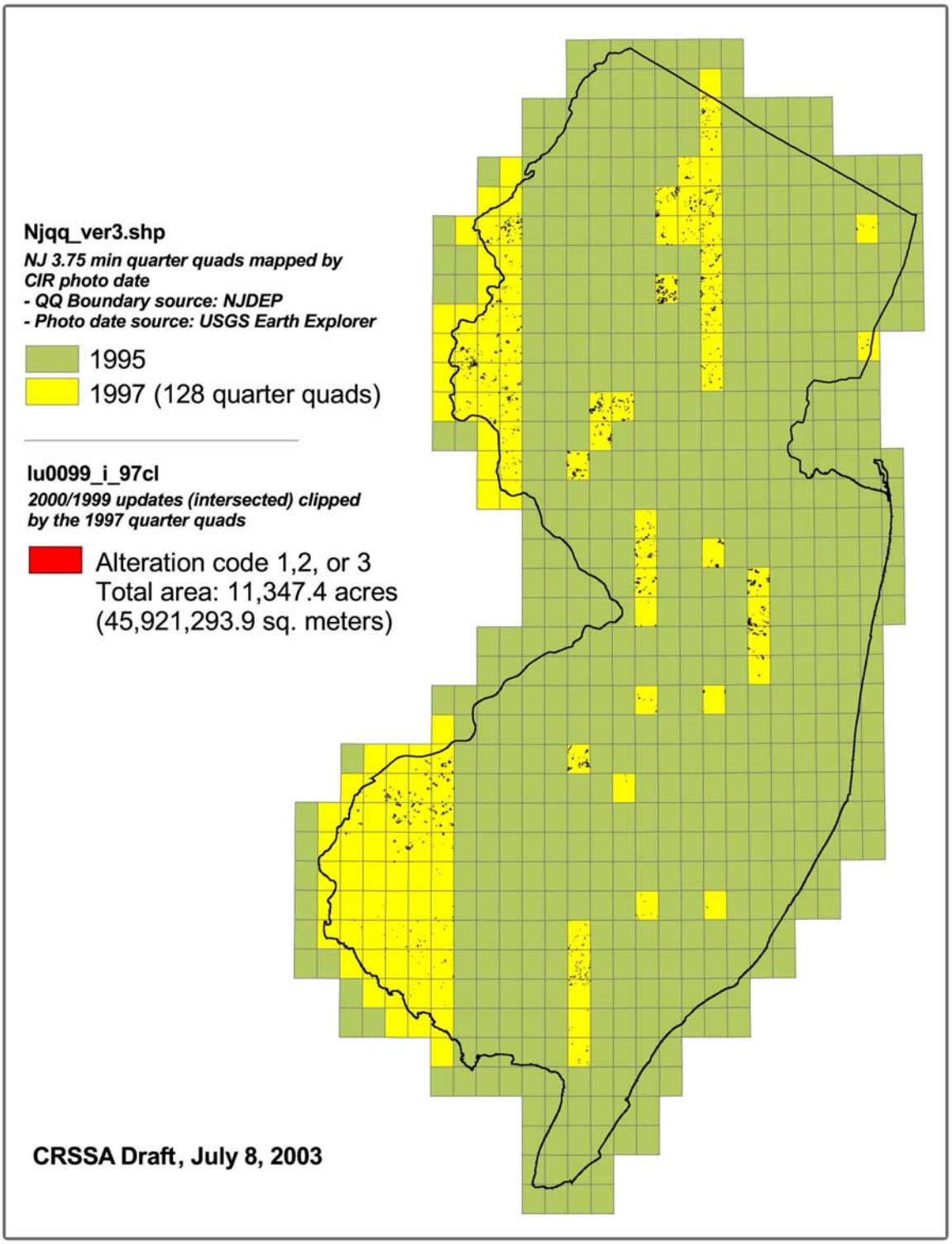

Figure 11. Year 2000 land use change vs. 1997/1995 Digital orthophotographic coverage.

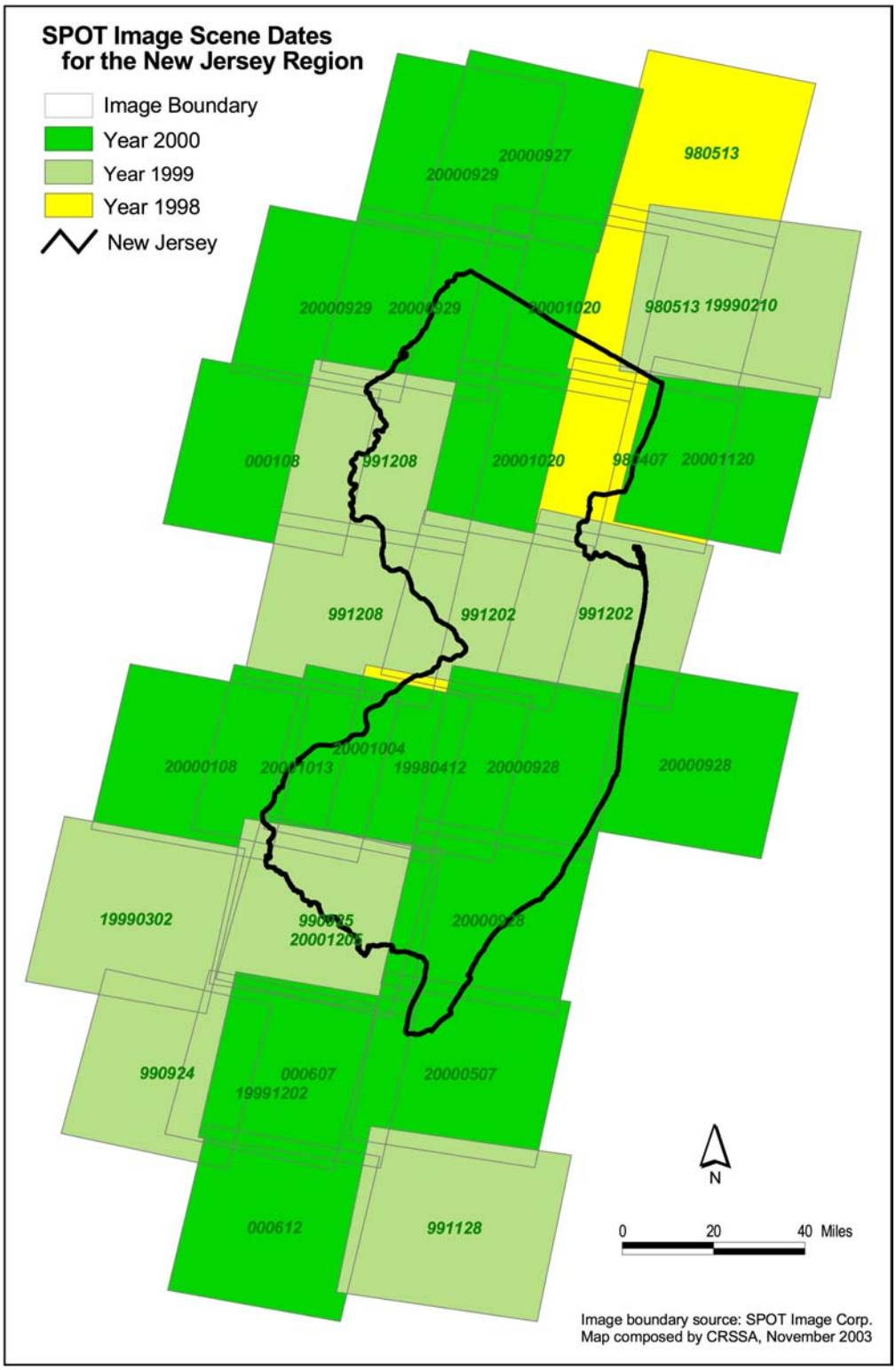

Figure 12. Date (Year/Month/Day) of individual SPOT scenes in New Jersey 2000 SPOT Mosaic.