



New Jersey Land Use/Land Cover Update: 2000-2001

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NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

Final Report

Project Title:

Land Use/Land Cover Update To Year 2000/2001

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Executive 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. There were three main objectives for this research: 1) to use medium scale satellite remotely sensed imagery (i.e., 10 meter spatial resolution SPOT Panchromatic imagery) to provide a consistent mapping of newly developed urban lands as of Year 2000/2001 across the state; 2) to use medium scale satellite remotely sensed imagery (i.e., 30 meter Landsat Enhanced Thematic Mapper) to provide a consistent mapping of land cover and impervious surface cover as of Year 2000/2001 across the state; and 3) evaluate the applicability of using less-costly satellite imagery as a means to update NJDEP's air-photo based Land Use/Land Cover (LULC) data in a cost-effective manner. In addition to this report, the digital LULC data sets (i.e., 2000 Land Use Update, 2001 Land Cover Update, 2001 Impervious Surface) discussed in this report are available for free public download at the Rutgers University Center for Remote Sensing and Spatial Analysis (CRSSA) website www.crssa.rutgers.edu/projects/lc/data/.

The LULC mapping standard currently employed by NJDEP is based upon aerial photography with a 1 meter resolution (i.e., every pixel or digital mapping unit represents 1 square meter of area). NJDEP's LULC system includes both land use and land cover categories: the way humans use the land is land use (LU), while land cover (LC) refers to the physical surface of the land. LULC classification evaluates features on the land within the context of the surrounding landscape. Therefore, a grassy or forested area less than an acre in size surrounded by residential lots would be classified and mapped as low density residential type using the NJDEP LULC system; whereas a similar grassy or forested parcel in a Land Cover only system (LC) would be classified grassland or forest.

The Year 2000 SPOT imagery was used to map generalized changes in LULC classes that were reconciled to the LULC classes currently used by NJDEP. The Year 2001 Landsat TM/ETM imagery was used to map Land Cover (LC) change, using the same LC classification scheme as that previously employed in CRSSA's 1972-1984-1995 LC change analysis (<http://crssa.rutgers.edu/projects/lc/>). Thus, the distinction between the LU vs LC classification schemes as well as the coarser scale of the SPOT (10x10m pixel or 100m²) and Landsat TM/ETM (30x30m pixel or 900m²) must be considered when evaluating the results presented.

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 positional 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 at the municipal to watershed scale. Our results show that the total area of new urban and transitional/barren land estimated from the SPOT interpreted maps is within +/- 5% of the land use change area estimated from the reference aerial photography. Similarly, the Landsat TM/ETM based approaches provide for lower cost updates of land cover and impervious surface cover for watershed scale monitoring.

The statistically adjusted estimate for the overall change in new urban land between 1995 and 2000 is approximately 77,950 (+/- 17,922 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 89,900 (+/- 16,528 acres). In the case of New Jersey's landscape, this new urban growth came at the cost of approximately 47,953 acres of forest, 25,911 acres of agricultural land, and 5,103 acres of natural wetlands. An additional 14,857 acres of existing barren lands were also converted to urban. 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.

The 2001 Land Cover Change data results show a continued growth in developed land cover with an increase of approximately 55,800 acres between 1995 and 2001. While at first blush there may appear to be an inconsistency between the approximately 73,200 acres of mapped new Urban land use estimated from the 2000 Land Use data as compared to the approximately 55,800 acres of Developed land cover estimated from the 2001 Land Cover Change data, one must remember that land use and land cover are two different ways of classifying the land surface. Within the mapped urban land use polygons in the Land Use Update, there may be areas of grassed lawn or remnant patches of forest/tree cover or wetlands that are classified as such in the Land Cover Update. Thus not all Urban land use is classified and mapped as Developed from a land cover perspective.

To summarize, my recommendations for future research are as follows:

- Continued research should be undertaken on refining sub-pixel analysis of Landsat TM/ETM scale imagery to estimate and map urban land use intensity (i.e., impervious surface cover but also managed lawn area).
- The utility of the NLCD and C-CAP land cover products to meet New Jersey state governments land cover monitoring and analysis needs should be explored.
- Newer object-oriented methods of computer-aided classification and change detection should be investigated to speed up the land use interpretation and mapping process.
- The feasibility of replacing digital ortho-photography with high spatial resolution satellite imagery or airborne digital camera technology should be explored.
- Once the NJDEP land use mapping for the 2002 imagery has been completed, 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) should be undertaken.

Introduction and Problem Statement

Land use and land cover are two approaches for describing land. **Land use** is a description of the way that humans are utilizing any particular piece of land for one or many purposes. **Land cover** is the physical material on the surface of any piece of land. Land use/land cover (LULC) mapping is a critical component of the geo-spatial infrastructure needed to support local to regional land use planning and management within the state of New Jersey. As continued human development is rapidly changing New Jersey's landscape, the need for updated LULC data to inform ongoing land use planning and management programs within NJDEP is critical. The goal of this project is to provide a consistent assessment of LULC as of Year 2000/2001 across the state as well as evaluate the utility of several types of satellite imagery sources and analysis techniques to undertake the above assessment in a cost effective manner.

There were three main objectives for this research: 1) to use medium scale satellite remotely sensed imagery (i.e., 10 meter spatial resolution SPOT Panchromatic imagery) to provide a consistent mapping of newly developed urban lands as of Year 2000/2001 across the state; 2) to use medium scale satellite remotely sensed imagery (i.e., 30 meter Landsat Enhanced Thematic Mapper) to provide a consistent mapping of land cover and impervious surface cover as of Year 2000/2001 across the state; and 3) evaluate the applicability of using less-costly satellite imagery as a means to update NJDEP's air-photo based land use/land cover data in a cost-effective manner.

Remote sensing technology is widely used at the Grant F. Walton Center for Remote Sensing and Spatial Analysis (CRSSA) at Rutgers University, The State University of New Jersey, to provide data for landscape, wildlife habitat and watershed planning, management and research. This LULC 2000/2001 Update report is part of a continuing investigation of New Jersey's changing landscape (for more information and public download of the LULC2000/2001 data products, see www.crssa.rutgers.edu/projects/lc). It is our hope that a better understanding of the spatial and temporal patterns of land use and land cover change will contribute to more informed land management policies and practices in New Jersey.

Project Design and 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 (Figure 1). The SPOT 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, its 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 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 development
- Recreational: developed parks, playing fields, 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 PI 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. For a nine county area of Atlantic, Burlington, Camden, Cape May, Cumberland, Gloucester, Mercer, Ocean and Salem counties, high resolution (approximately 1m GRC) panchromatic orthophotography acquired during the spring of 2000 by the Delaware Valley Regional Planning Commission was used as additional reference imagery. Only the appropriateness of interpreted land use change classification was assessed and not the spatial accuracy of the interpreted boundaries.

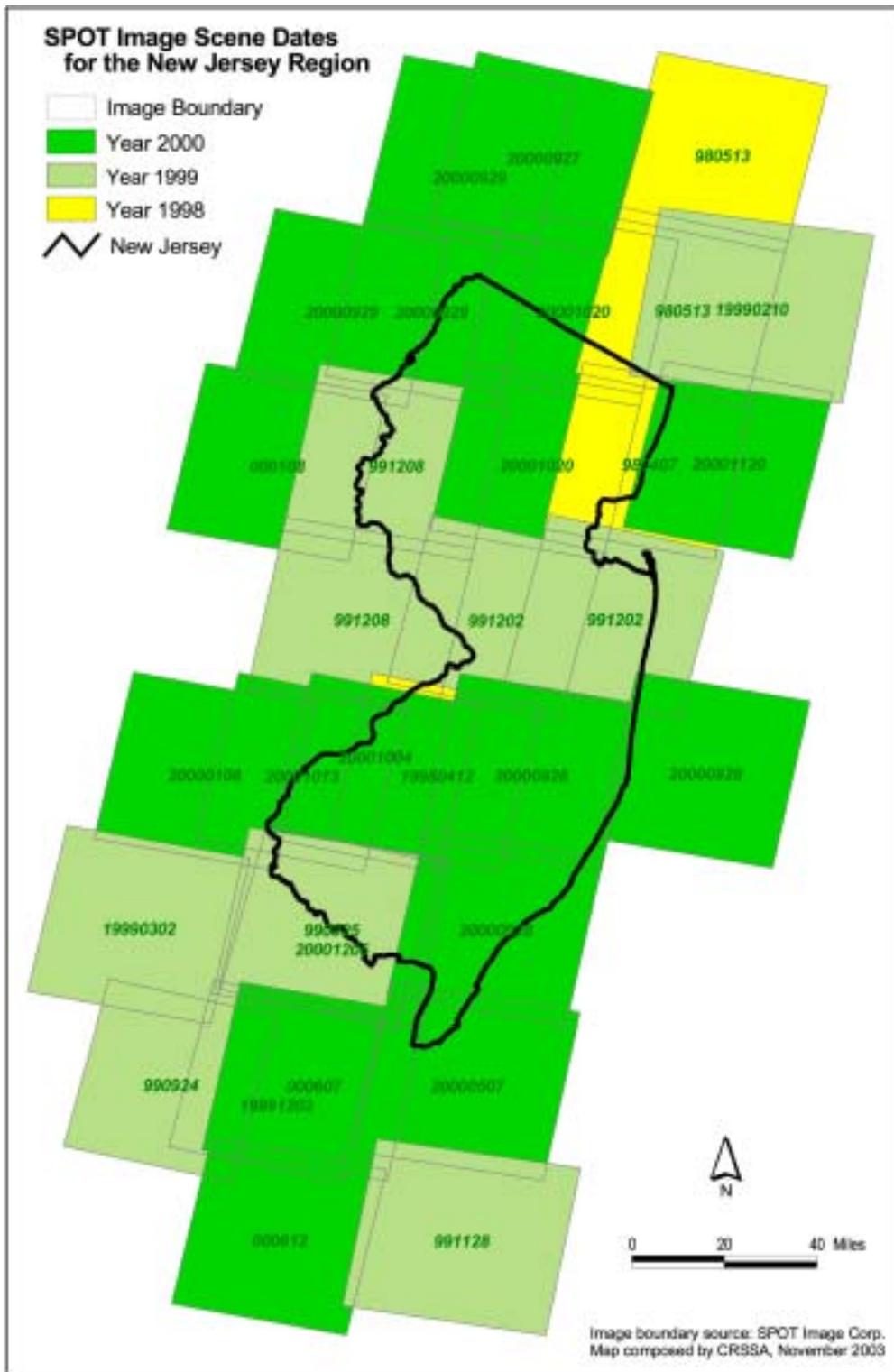


Figure 1. Date (Year/Month/Day) of individual SPOT scenes in New Jersey 2000 SPOT Mosaic.

Land Cover Classification

Enhanced Landsat Thematic Mapper (ETM+) satellite imagery was acquired for relatively cloud-free dates in 2001 (December 1, 2001 and September 12, 2001). Cloud covered areas in the September 12, 2001 imagery were replaced with image data from September 23, 1999 imagery. The December "leaf-off" imagery was taken after normal deciduous plant leaf fall, allowing the clearer differentiation of evergreen vs. deciduous forests and developed areas. The September "leaf-on" imagery permits the further discrimination of cultivated, wetland and developed areas. The LANDSAT image data sets were all orthorectified to a Universal Transverse Mercator (UTM) projection (UTM Zone 18; datum: NAD 83; spheroid: WGS84).

To try to correct for various scene to scene differences in brightness and spectral response (including atmospheric influences), an image-to-image empirical normalization procedure that compared invariant scene targets was used to normalize the 2001 ETM+ imagery to corresponding anniversary Landsat TM from 1994 and 1995. The 1994/1995 LANDSAT TM imagery data were used as a baseline (i.e., digital numbers left unchanged) while the 2001 image digital numbers were altered to more closely match the appropriate anniversary image (i.e. Sept. 2001 to Sept. 1995, Dec. 2001 to Nov 1994). Image bands 3, 4, 5 were subsetted from each normalized image and layer-stacked in to one 2001 leaf on-leaf-off composite image.

The land cover mapping was undertaken at one level of generalization: Level I, the most generalized with 8 classes.

Developed:

- 1) High Intensity (>75% IS), 2) Medium intensity (50-75% IS),
- 3) Low intensity (<50% IS) wooded, 4) Low intensity un-wooded

Cultivated/Grassland

Upland Forest

Barren

Marine/Estuarine Unconsolidated Shoreline

Estuarine Emergent Wetland

Palustrine Wetland

Water.

The Level I classification scheme was designed to meet the needs of the Endangered & Nongame Species Program of the NJDEP's Division of Fish & Wildlife, as well as match previous New Jersey land cover classification and mapping efforts undertaken by Rutgers Center for Remote Sensing & Spatial Analysis (Lathrop, 2000). The 2001 land cover classification employed several standard change detection/mapping techniques (Dobson et al., 1995). The Level 1 Developed land cover categories were further broken down into 4 Level 2 categories based on the % cover of impervious surface (IS): 1) High Intensity (>75% IS), 2) Medium intensity (50-75% IS), 3) Low intensity (<50% IS) wooded, 4) Low intensity (<50% IS) un-wooded.

To map upland land cover change due to urban growth and development, a "Multi-date Change Detection using Ancillary Data Sources" technique was employed using the 2000 Land Use product described above. To further update additional new development that may have occurred subsequent to the Year 2000 mapping, heads-up interpretation and digitizing was accomplished using the 2001 Landsat ETM+ imagery as the image backdrop. An additional 5,890 acres of urban and 4,004 acres of transitional land use change between the 2000 and 2001 image dates were mapped. The merged 2000/2001 land use was used to mask the 2001 ETM+ composite image and extract the image data for the developed change area. An unsupervised classification approach using 50 spectral clusters was conducted. These spectral clusters were then cross-referenced with the 2000 NY-NJ Highlands land cover data set (www.crssa.rutgers.edu/projects/highlands) for consistency. A GIS rules-based approach was employed to classify the spectral clusters into appropriate Level 1 land cover classes.

To update land cover changes in the coastal zone, a "Multiple-data Change Detection Using a Binary Change Mask" was employed. The normalized September 2001 ETM+ imagery was differenced from the September 1995 TM imagery. A binary change threshold was determined and the 2001 ETM+ imagery was masked and change data extracted. An unsupervised classification approach using 15 spectral clusters was

conducted. A GIS rules-based approach was employed to classify the spectral clusters into appropriate Level 1 land cover classes.

Impervious Surface Estimation

In related research funded by the NOAA Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET), we examined the utility of the several different techniques in the sub-pixel analysis of Landsat ETM to estimate impervious surface cover in an urban/suburban setting. Three different sub-pixel analysis methods were evaluated: Linear Mixture Modeling (LMM), supervised fuzzy c-means (FCM) and Self-Organizing Map (SOM)-Learning Vector Quantization (LVQ) neural network. A number of different accuracy assessments were undertaken across a range of conditions in our Mullica River basin study area. Overall, the SOM-LVQ method provided the best estimates of impervious surface cover with accuracies of $\pm 4 \sim 12\%$. Based on the results of this research, the SOM-LVQ neural network technique was adopted and applied to provide a statewide estimate of impervious surface cover to accompany the 2001 land cover map.

Below is an abbreviated description of the techniques employed; for greater detail on techniques and how they were implemented in this project, please refer to Lee (2003). The Self-Organizing Map (SOM) is a two-layer network that maps the n-dimensional input data into a regular two-dimensional array of nodes. While there are currently many different types of SOM available, we used the Kohonen SOM Neural Network (Kohonen 2001). In addition to the SOM, Learning-Vector Quantization (LVQ) was also adopted for a supervised classification (Kohonen 2001). For greater detail on the algorithm of SOM, refer to Ji (2000) and Kohonen (2001).

According to Kohonen (2001), the SOM-LVQ combined algorithm does not classify data by its posterior probability value, but by the class region defined around each codebook vector. This means that only hard classification is possible with the SOM-LVQ algorithm itself. Thus, to do soft classification of the land cover components of a mixed pixel (i.e., percent impervious surface,) an additional process was necessary to estimate

the posterior probability. A function of the distance between codebook vector and the data sample can be used as a fuzzy indicator of the data sample for the codebook vector:

$$r_i = \frac{1}{1 + \|x - m_i\|^2}, i = 1, \dots, N,$$

where m_i is the codebook vector node and N is the number of points in a data set.

But the probabilistic interpretation of the distance is not clear. Alternatively, the closeness of a data sample, x , to each codebook vector, i , can be defined using the Bayes' theorem:

$$p(c_k | x) = \frac{p(x | c_k) p(x)}{\sum p(x | c_k) p(x)}$$

To estimate the posterior probability using the Bayes' theorem, the prior probability, $P(i)$, and the conditional probability, $p(x|i)$, need to be estimated. To estimate the conditional probability, reduced kernel density estimation (RKDE) based on the SOM-LVQ codebook vector map is adopted.

The probability density estimation of the SOM is made possible by constructing the RKDE model using the codebook vector node as the kernel center. This method was originally proposed by Hämmäläinen (1995) and then slightly modified by Alhoniemi *et al.* (1999). The RKDE model of the SOM was initiated by constructing a Gaussian Mixture Model (GMM) based on a codebook vector map. A GMM requires a prior probability and the variance of cluster centers. The codebook vector node of the SOM is used as a cluster center for GMM and the variance of the cluster center is estimated based on the SOM. A prior probability is estimated by weighting the proportion of the total number of the best matched data for each codebook vector node in a data set with a neighborhood kernel. The simplest way to estimate the prior probability is ratio:

$$P(i) = \frac{\#(x_n \in m_i)}{\#x_n}, n = 1, \dots, M,$$

where m_i is the codebook vector node of the SOM and M is the number of samples. The conditional densities, $p(x/i)$, for each codebook vector node are estimated from the corresponding data set of which the best matching unit is m_i . But the estimation made in

this way results in a biased data set because no data units can lie outside the class region defined by its best matching codebook vector node.

Several SOM neural networks with different parameters were evaluated. Among the many parameters of the SOM, SOM map size is the most prominent and important parameter. Based on previous research (Ji 2000) and our pilot studies, we evaluated three different map size SOM neural networks thoroughly. The three map sizes were 15 x 15, 10 x 16, and 15 x 18. Besides map size, the neighborhood function is also important in SOM training and posterior probability estimation. Thus, Gaussian and bubble neighborhood functions were tested for each map size.

At first, each SOM model was trained in the SOM training process and was then refined by the LVQ training process. SOM training process has two separate steps: rough-tuning and fine-tuning. After the fine-tuning of SOM training, the SOM neural network was still not trained enough to do classification because the fine tuning of the SOM codebook vector map was carried out by the LVQ training process, which was for data classification. However, the final codebook vector map trained by the SOM-LVQ algorithm was well generalized and fine tuned enough to do accurate classification. SOM_PAK (Kohonen *et al.* 1996a) and LVQ_PAK (Kohonen *et al.* 1996b) were used to train the SOM_LVQ neural networks of the five different data sets.

The sub-pixel analysis of the Landsat ETM pixels was done by measuring the posterior probability of each pixel to the three land cover classes: impervious surface, grass and tree cover. The posterior probability was measured using a Gaussian mixture model based on the trained SOM codevector map (Alhoniemi *et al.* 1999). SOM TOOLBOX (Alhoniemi *et al.* 2000) was used to run the SOM_LVQ-based GMM method. To measure the posterior probability of test data for each land cover class, the posterior probabilities of neurons that were labeled as same land cover class were summed up, using a hard partition matrix based on the SOM neuron label.

For the accuracy assessment, high resolution (4m pixel size) IKONOS imagery was used as reference data. The IKONOS-based accuracy assessment measured the accuracy of the SOM-LVQ using regional scale estimations of the land cover composition as well as the accuracy of individual pixels. IKONOS images of two New Jersey study areas spanning a mix of urban and suburban land use/land covers were classified to measure the accuracy of the SOM-LVQ at both the Landsat pixel scale and regional scale. The regional scale accuracy of the LMM was measured by comparing the total estimated land cover class area of the SOM-LVQ and IKONOS for two urban/suburban study areas. For the accuracy assessment of the SOM-LVQ at the Landsat pixel scale, a polygon coverage with the Landsat ETM pixel boundaries was created and overlaid on the classified IKONOS map to measure the zonal mean values of the three land cover classes. Thus, the classified IKONOS map was compared to the composition of each Landsat pixel-size polygon.

Quality Assurance

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 2). 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%.

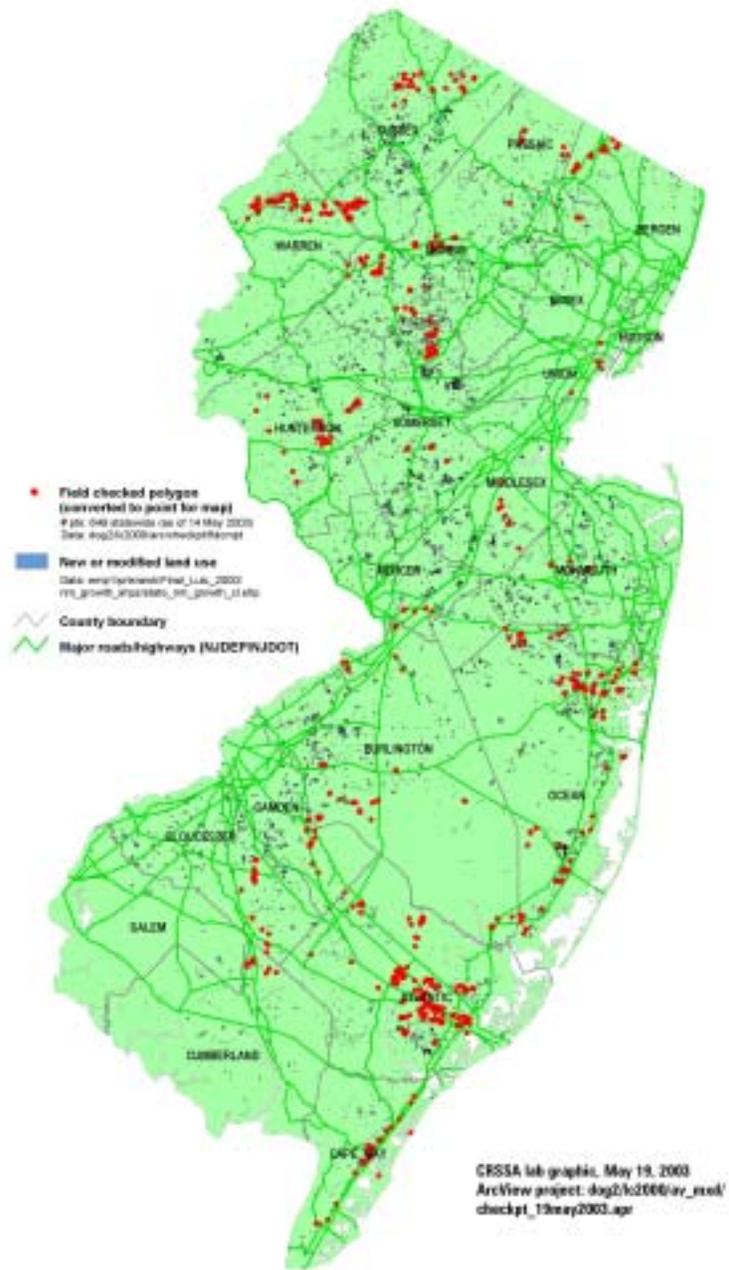


Figure 2. Field checked land use change polygons.

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 3a). The resulting aerial photo interpreted land use change estimates were then compared with the SPOT-derived estimates (Figure 3b). 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 4a 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 4b 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

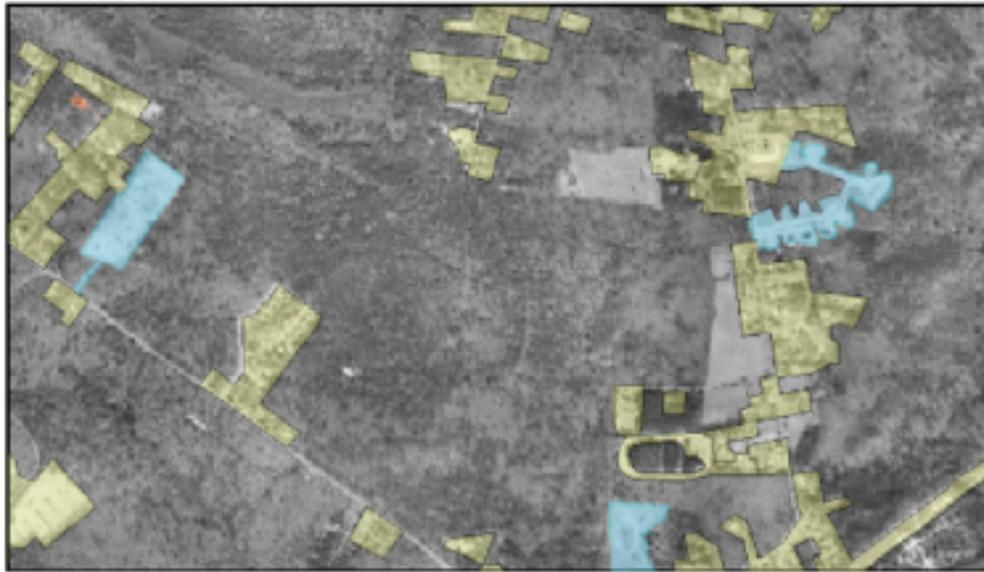


Figure 3a. B& W sub-meter DVRPC digital orthophotography with land use overlay:
1995 in yellow, 2000 in blue.

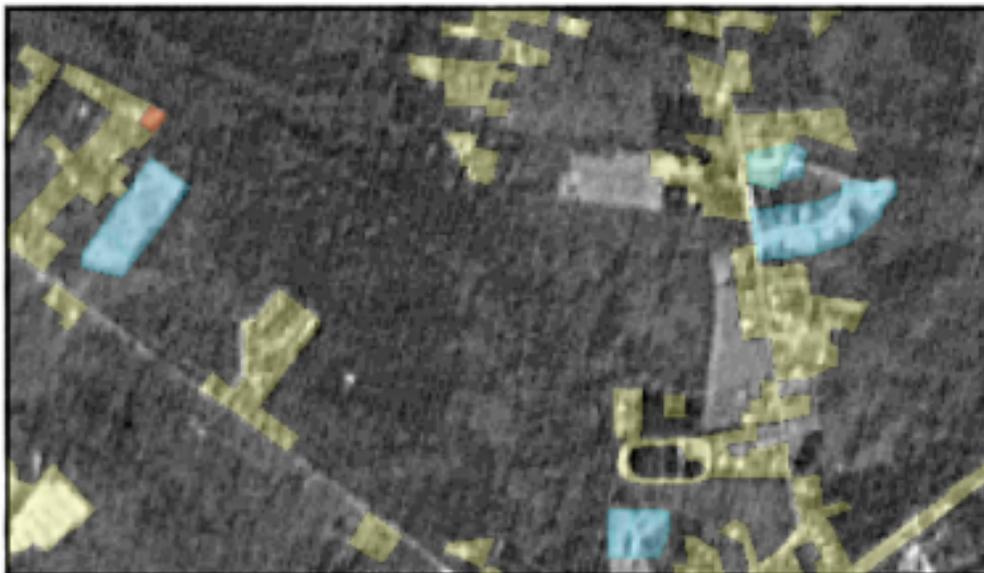


Figure 3b. 10 meter SPOT PAN imagery with land use overlay: 1995 in yellow, 2000 in
blue.

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 4c). 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. 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.

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.

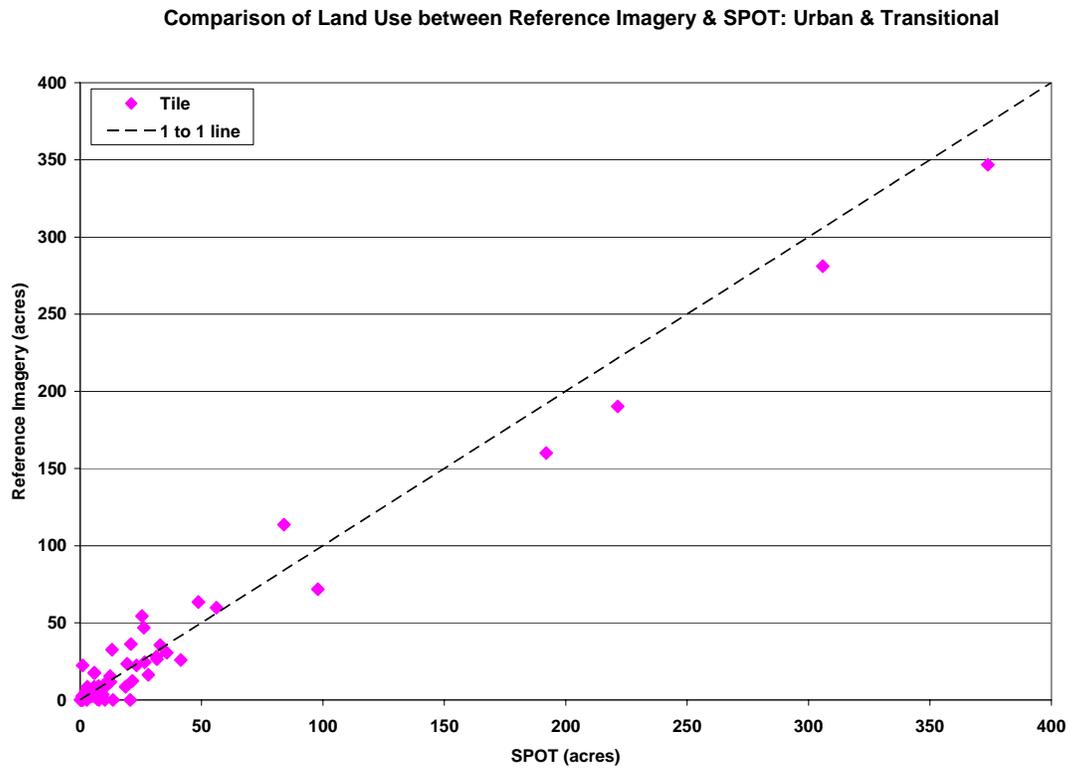


Figure 4a. Plot of Spot vs. DVRPC reference image estimates of Urban & Transitional Land Use change with 1:to:1 line.

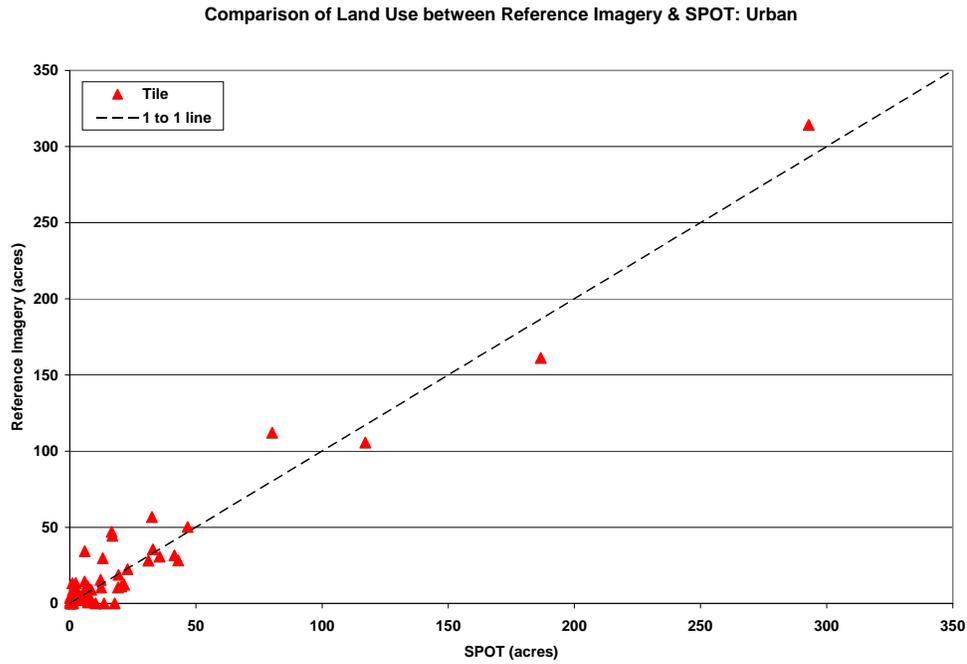


Figure 4b. Plot of Spot vs. DVRPC reference image estimates of Urban Land Use change with 1:to:1 line.

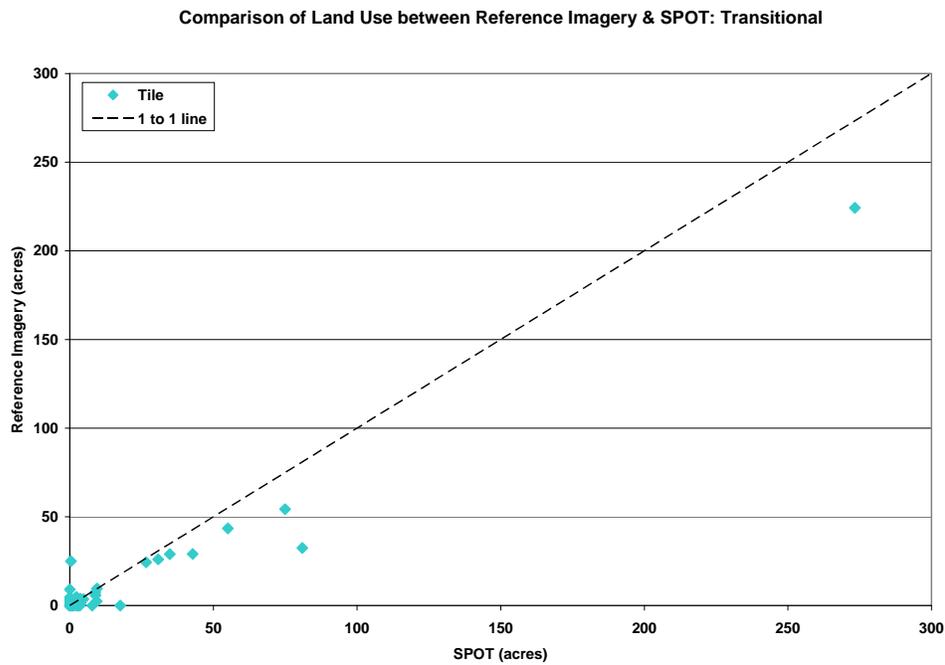


Figure 4c. Plot of Spot vs. DVRPC reference image estimates of Transitional Land Use change with 1:to:1 line.

Results and Discussion

Land Use Change

Over 100,000 acres were mapped by the 2000 Land Use Update as undergoing some form of land use change. 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). If we eliminate these "redeveloped" lands from consideration, we recorded approximately 73,191 acres of "new" urban land (Table 1). 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 95% Confidence Interval of +/- 1.3%.

An additional 22,000 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/water 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. 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. Combining the “newly altered” transitional and mining lands gives an estimate of 20,861 acres of new barren land (Table 1). 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).

Examining the 2000 LU Update mapped data in greater detail (see Figure 5, 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 22,050 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. For a more detailed analysis of the 2000 Land Use Update and land use change trends, consult the report “Measuring Land Use Change in New Jersey: Land Use Update To Year 2000” (Lathrop, 2004).

Table 1. Comparison of “newly developed” vs. redeveloped or altered lands (acres) for the urban and barren land use change categories for the 1995 to 2000 time period.

Land Use Change Category	Newly developed (acres)	Redeveloped or altered (acres)	Total land use change
Urban	73,191	1,959	75,150
<i>Transitional</i>	20,009	2,021	22,030
<i>Ext. Mining</i>	852	390	1,242
Total Barren	20,861	2,411	23,272
Total Urban & Barren	94,052	4,370	98,422

Table 2. Comparison of mapped vs. statistically adjusted estimate of 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
Overall	94,052	89,876 +/- 16,528

Table 3. Area amount (acres) of land use change by category.

Land Use Type	Area (acres)
Residential	57,072
Mixed Commercial/Service/Industrial	11,895
Recreation	6,196
Agriculture: Cropland	653
Agriculture: Other	453
Extractive	1,242
Water	280
Transitional	22,030
Unclassified	566
Total	100,387

Land Cover Change

A comprehensive analysis of the 2001 Land Cover Change data, similar to that accomplished for the 2000 Land Use Change data (as discussed above), was not undertaken. Rather the 2001 land cover data was compared with the 1972-1984-1995 land cover time series (Lathrop, 2000) and general trends in land cover were assessed (Table 4). The results show a continued growth in developed land cover with an increase of approximately 55,843 acres between 1995 and 2001. This represents a 3.9% increase in developed land cover over that mapped in 1995. New Jersey increased its developed land from approximately 25% of its total land area in 1984 to 31% of its total land area in 2001 (i.e., from approximately 1.20 million acres to 1.48 million acres). The amount of barren land cover (much of this in a transitional land use) showed a 29.5% increase over that mapped in 1995. Cultivated/Grassland and Upland Forest continued to decline with a percent change of 3.8 and 2.2%, respectively. Estuarine and Palustrine wetland continued to show declines but at a much lower percent change, 0.7 and 0.4% respectively, than the loss of upland farm or forest land.

Table 4. Land cover estimates for New Jersey for the years of 1972, 1984 and 1995, 2001.

Land Cover Description	1972	1984	1995	2001
Developed	888,520	1,204,920	1,427,315	1,483,158
Cultivated/Grassland	999,340	1,006,980	883,590	849,999
Forest/Scrub/Shrub	1,673,110	1,465,680	1,421,060	1,388,941
Barren	29,840	38,450	45,530	58,982
Estuarine Emergent Wetland	220,720	208,280	201,570	200,166
Palustrine Wetland: Emergent/Forested	925,300	788,870	737,010	734,028
Unconsolidated Shore	12,310	47,160	45,880	46,809
Water	517,700	516,570	514,960	514,843
Totals	5,266,840	5,276,910	5,276,915	5,276,926

While at first blush there may appear to be an inconsistency between the approximately 73,200 acres of new urban land use estimated from the 2000 Land Use data as compared to the approximately 55,800 acres of Developed land cover estimated from the 2001 Land Cover Change data, one must remember that land use and land cover are two different ways of classifying the land surface. Urban land uses span a range of impervious surface cover from the nearly 100% cover in centralized business districts to a comparatively minor percentage component in large lot suburban to exurban residential developments. The land cover mapping simplifies this complex gradient to 4 categories of developed land based on several thresholds of impervious surface cover. The breakdown of the amount of newly developed land cover at Level 2 categorization was: 1) High Intensity = 5,055 acres; 2) Medium intensity = 17,699 acres; 3) Low intensity wooded = 10,979 acres, 4) Low intensity un-wooded = 22,110 acres.

Note that there was approximately 80,199 acres of new urban/developed land uses mapped as part of the 2000/2001 Land Use Interpretation: 1) 73,200 acres of new urban land use estimated from the 2000 Land Use data; 2) 1,019 acres of miscellaneous developed land (e.g., other agriculture, other altered land) estimated from the 2000 Land Use data; and 3) 5,890 acres of new urban land mapped from the 2001 Landsat TM imagery. Approximately 70% of the total 80,199 acres of new/urban/developed land surface (55,843 / 80,199 acres) appears to be in some intensity of developed land surface (i.e., impervious surface) as classified in the 2001 Land Cover data.

To examine this issue of why an area mapped as Urban land use may be mapped as something other than a Developed land cover more closely, consider that a 1 acre minimum mapping unit will contain approximately 4.5 Landsat TM 30x30m pixels. Within the mapped Residential land use polygons in the Land Use Update, there may be extensive areas of grassed lawn or remnant patches of forest/tree cover or wetlands that are classified as such in the Land Cover Update. If a 30x30m Landsat TM pixel is showing up as pure grass or trees, it may be classified as Cultivated/Grassland or Forest. Thus a small stand (below the 1 acre minimum mapping unit but the size of a TM pixel or larger) of trees in a suburban neighborhood land use polygon can be classified as

Forest Land Cover, even though the Land Use says it is Urban. A large lawn surrounding a commercial development which would be considered an Urban land use but could be classified as Cultivated/Grassland land cover. In addition, the approximately 6,200 acres of new Recreational land considered Urban from a land use perspective, were primarily classified as Cultivated/Grassland or Forest from a land cover perspective. This distinction in land use vs. land cover, as well as other possible complications due to the coarser scale of the Landsat TM imagery accounts for the lower estimates of Developed land cover as compared to Urban land use. For a further examination of the comparison between land use and land cover data sets, please refer to Lathrop and Hasse, 2003.

Using the medium scale Landsat TM/ETM imagery it is feasible to more directly quantify impervious surface cover. Using the SOM algorithm, it is possible to estimate the impervious surface within plus or minus 4 ~ 6% as compared to the IKONOS estimate. Similarly, the SOM algorithm provides estimate of impervious surface that within approximately +/- 11% as compared to traditional aerial photo interpretation. For a greater discussion of the utility of medium scale Landsat TM/ETM imagery and the pros and cons of various algorithmic techniques, consult Lee (2003).

Conclusions and Recommendations for Future Research

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 77,940 +/- 17,920 acres, representing an increase of urban land of approximately 5.8% with a 95% Confidence Interval of +/- 1.3%. Adding in transitional/barren lands, the total developed land use change is 89,876 +/- 16,528 acres. 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 for forest, farmland, wetland and barren land conversion as enumerated in this report should be considered as best available 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 47,953 acres of forest, 25,911 acres of agricultural land, and 5,103 acres of natural wetlands. An additional 14,857 acres of existing barren lands were also converted to urban. The continued loss of forest land and wetland is of special concern due to the critical role these lands play in providing ecosystem services such as regulating reducing soil erosion, maintaining water quality, sequestering carbon, and providing wildlife habitat. It must be noted that the terms land use and land cover, while often used interchangeably, are not directly equivalent. These results show that of the approximately 73,000 acres per year of new urban land uses, approximately 3/4 was classified as a developed land surface (i.e., impervious surface) with the remaining area as either in grass, wetland or remnant forest/tree cover.

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 positional 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 at the municipal to watershed scale. Our results show that the total area of new urban and transitional/barren land estimated from the SPOT interpreted maps is within +/- 5% of the land use change area estimated from the reference aerial photography. Similarly, the Landsat TM/ETM based approaches provide for lower cost updates of land cover and impervious surface cover for watershed scale monitoring. However, the 30mx30m size of the Landsat TM/ETM provide a coarser view of the land surface and can not replicate the spatial or categorical detail provided by photointepreted 1 meter scale orthophotography. Continued research should be undertaken on refining sub-pixel analysis of Landsat TM/ETM scale imagery to estimate and map urban land use intensity (i.e., impervious surface cover but also managed lawn area).

Landsat-based land cover classification and mapping forms the basis of the U.S. Geological Survey's National Land Cover Data (NLCD). For more information on the NLCD go to <http://landcover.usgs.gov/nationallandcover.asp>. Twenty one classes of land cover were mapped, using consistent procedures across the entire U.S. The resulting land cover dataset is being used for a wide variety of national and regional applications. The USGS has mapped New Jersey as of 1992 and is developing a 2001 Update. The NOAA Coastal Change Analysis Program (C-CAP) is cooperating with the USGS NLCD 2001 efforts to complete a national baseline of land cover and change data for the nation's coastal zone. The entire state of New Jersey is contained within the NOAA C-CAP study region. C-CAP proposes to do land cover updates on a 5 year time interval rather than the 10 yr interval proposed for the rest of the country. For more information on the C-CAP go to <http://www.csc.noaa.gov/crs/lca/ccap.html>. The NLCD and C-CAP data sets are in the public domain and freely available for download. The utility of the NLCD and C-CAP land cover products to meet New Jersey state governments land cover monitoring and analysis needs should be explored. While there are definite advantages to working with a nationally consistent land cover product, there still may be instances where these national products do not meet NJDEP's specific needs.

While the Landsat-scale land **cover** data may have great utility for certain applications, given New Jersey's densely developed landscape, detailed land **use** will always be in great demand. The NJDEP has relied on digital ortho-photography as the basis for its 1986, 1995/97 and now 2002 land use mapping needs. Each iteration has provided consistently higher spatial resolution and better positional accuracy. However, the cost has also grown. Additional research on the feasibility of replacing digital orthophotography with high spatial resolution satellite imagery or airborne digital camera technology should be explored. Rather than complete wall-to-wall coverage for a single snapshot in time, new imagery could be acquired on a continually rotating basis to update particular hotspots of development or other land use/cover change. The coarser scale Landsat ETM imagery could be used to monitor and define those hotspots.

The NJDEP has also relied on visual interpretation of the aerial photographic imagery described above to map land use. While GIS-aided on-screen digitizing has greatly facilitated this approach, the land use interpretation/mapping phase is presently adding a one to two year delay in the release of an interpreted land use mapped product. Newer methods of computer-aided classification and change detection should be investigated to speed up this process. For example, object-oriented image segmentation and classification software provide new possibilities for identifying and detailed mapping of land use and land use change (e.g., eCognition software, for more information go to <http://www.definiens-imaging.com/>).

Subsequent to initiation of this research, NJDEP committed additional resources to updating its air-photo based data with sub-meter digital orthophotography acquired in 2002. This imagery, 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. 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. 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) should be undertaken.

To summarize, my recommendations for future research are as follows:

- Continued research should be undertaken on refining sub-pixel analysis of Landsat TM/ETM scale imagery to estimate and map urban land use intensity (i.e., impervious surface cover but also managed lawn area).
- The utility of the NLCD and C-CAP land cover products to meet New Jersey state governments land cover monitoring and analysis needs should be explored.
- Newer object-oriented methods of computer-aided classification and change detection should be investigated to speed up the land use interpretation and mapping process.

- The feasibility of replacing digital ortho-photography with high spatial resolution satellite imagery or airborne digital camera technology should be explored.
- Once the NJDEP land use mapping for the 2002 imagery has been completed, 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) should be undertaken.

This LULC 2000/2001 Update report is part of a continuing investigation of New Jersey's changing landscape (for more information, see www.crssa.rutgers.edu/projects/lc). It is our hope that a better understanding of the spatial and temporal patterns of land use and land cover change will contribute to more informed land management policies and practices in New Jersey in the coming years.

Recommendations and Application and use by NJDEP

Evaluation of the Utility of SPOT 10m Pan and Landsat ETM for LU/LC Mapping

An additional outcome of this study is our evaluation of the SPOT panchromatic statewide image mosaic as an alternative data source for New Jersey land use/land cover mapping/monitoring efforts. The SPOT image mosaic has several advantages as compared to aerial digital photo-based ortho-photography (i.e. similar to the 1995/97 NJ DOQQ's): 1) much lower cost at \$4,200 for a statewide mosaic; 2) reasonable turn around time of six months between final image acquisition and end-product delivery; and 3) the computer storage requirements (approximately 560 MB as compared to 70+ uncompressed GB) and display times for the entire statewide mosaic are not onerous. Some of the inherent drawbacks of the SPOT image mosaic (as compared to the NJ DOQQ's) are: 1) it is only panchromatic (single black & white band) rather than multispectral, thereby limiting image interpretation of some land use/land cover types; 2) its coarser spatial resolution (10m rather than 1m) also limits image interpretation of some land use/land cover types; 3) the stated ground positional accuracy of 12 meters or better with 90% confidence is lower than the typical USGS-derived DOQQs. Our

experience showed that the positional accuracy of that SPOT PAN image mosaic was variable across the study region with minimal spatial mis-registration in some locations to mis-registration of 10-30 meters in other locations.

Taking the inherent limitations of the SPOT NJ image mosaic into account, this data source does not provide the same level of categorical detail and accuracy in mapping land use/land cover as that possible with 1m color infrared DOQQ's. However, this study showed that the SPOT panchromatic statewide image mosaic (10m ground resolution cell) provides a useful alternative data source for New Jersey land use/land cover mapping/monitoring efforts. Only 4 major categories of urban growth could be reliably identified and interpreted (i.e., residential, commercial/industrial/mixed, recreational, and transitional) with a minimum mapping unit of 1 acre. The heads-up interpretation and digitizing for this project took approximately 2000 personnel hours. With a total project budget of under \$75,000 (which included a number of other tasks in addition to the land use mapping), the 2000 LU Update cost only a small fraction of the NJDEP 1995/97 LU/LC mapping project. The accuracy assessment shows that visual interpretation of the SPOT panchromatic imagery provided land use change areal estimates within 5-10% of that obtained with higher spatial resolution (1m) panchromatic ortho-photography. The one major caveat is the issue of the lower and variable positional accuracy which resulted in the delineated land use polygon boundaries to be offset up to 10-30m from their "true" location (as represented on the 1m DVRPC digital ortho-photography). Accordingly, the SPOT 10m Pan data and the 2000 LU Update data set must be used with caution at a site-specific scale (i.e., at the scale of the individual parcel or neighborhood).

The Landsat Enhanced Thematic Mapper provides statewide terrain-corrected imagery (30 m multispectral, 15m panchromatic) for an approximate cost of \$2,700. The utility of the Landsat ETM+ is greatly enhanced by first mapping polygonal areas of urban land use and including that information to constrain the subsequent land cover and impervious surface mapping and estimation. While the heads-up interpretation and digitizing of new urban growth is feasible based solely on the Landsat ETM+ imagery, higher resolution imagery (e.g., SPOT 10M and better) does provide for greater categorical detail, better

positional accuracy and a smaller minimum mapping unit. Within these interpreted urban land use “envelopes” the spectral information provided by the Landsat ETM is then useful for classifying the various land cover types and estimating the amount of impervious surface cover. As with the SPOT 10m Pan imagery, the medium scale resolution Landsat ETM+ provides high quality information on land cover and impervious surface useful at a municipal-wide or watershed scale on a cost effective basis.

Evaluation of the Utility of Landsat ETM for Impervious Surface Mapping

Percent impervious surface cover can be estimated from medium resolution satellite imagery (Landsat ETM) using mixed pixel analysis with similar accuracy as that obtainable from fine resolution satellite imagery (IKONOS) and traditional aerial photo interpretation. This means that environmental/ecological monitoring can be done cost effectively, as the price of Landsat ETM (\$600 per scene and 2¢ per Km^2) is much less expensive than IKONOS (\$270 per Km^2) allowing for more frequent updates in rapidly urbanizing areas. While we implemented the SOM-LVQ technique for sub-pixel estimates of impervious surface cover, the SOM-LVQ technique is quite complicated and requires a high level of training. A number of alternative methods for the estimation of impervious surface from Landsat scale imagery are being evaluated by various research groups around the country. A % Impervious Surface Cover thematic layer is being incorporated into the National Land Cover Data set (derived from Landsat TM/ETM imagery) and will be available for New Jersey in the near future. The NLCD Impervious Surface data will be free and in the public domain. The NJDEP should evaluate the utility of this NLCD Impervious Surface data to meet the department’s needs.

The sub-pixel analysis of medium resolution satellite image (e.g., Landsat TM/ETM) is especially appropriate for watershed level monitoring (i.e., basins of 100’s of km^2 in size). Accurate and frequently updated estimates of impervious surface cover at the landscape scale are extremely important for effective water quality monitoring and management. However, if the research or management purpose is site-specific where

fine detail is required over a small area extent (i.e., on the order of 10's of km²), than it may be more appropriate to use fine resolution satellite image or aerial photography.

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