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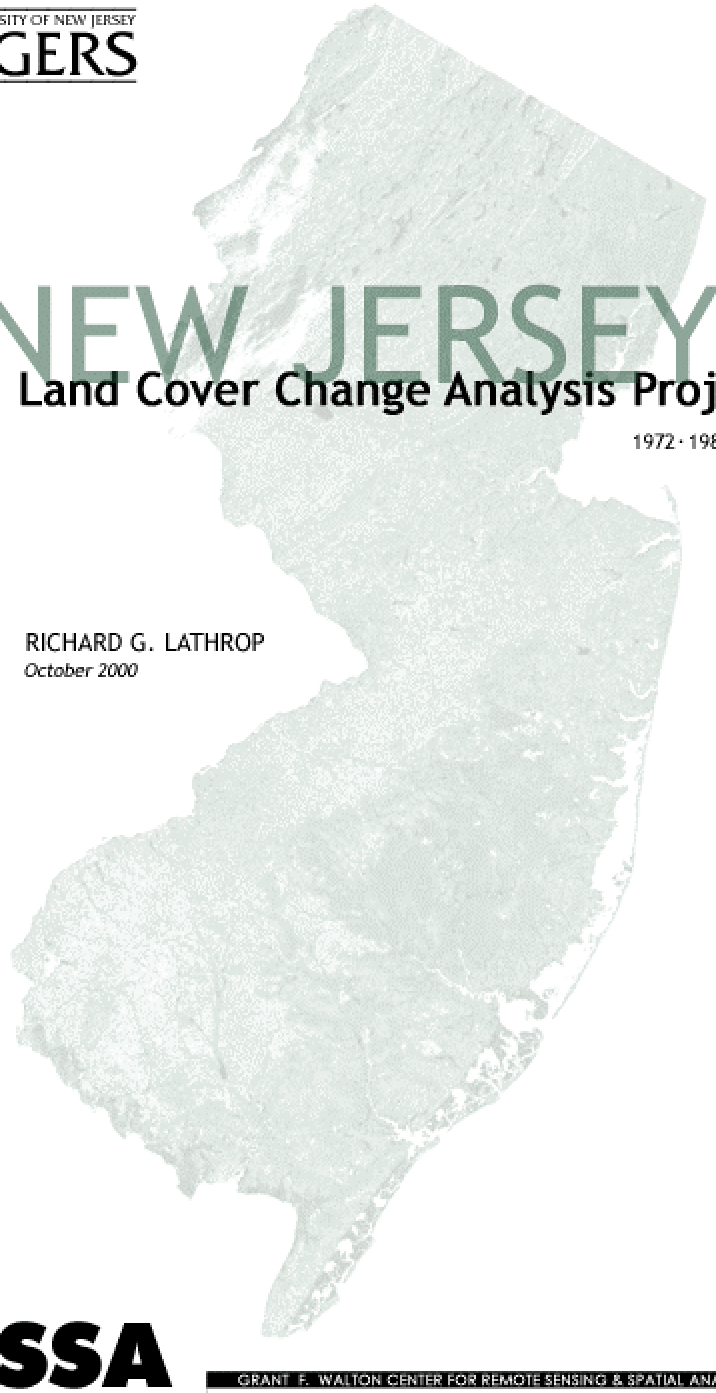

NEW JERSEY
Land Cover Change Analysis Project

1972 · 1984 · 1995

RICHARD G. LATHROP

October 2000

CRSSA
GRANT F. WALTON CENTER FOR REMOTE SENSING & SPATIAL ANALYSIS

New Jersey Land Cover Change Analysis Project

by

Richard G. Lathrop

Center for Remote Sensing & Spatial Analysis
Cook College - Rutgers University
14 College Farm Road
New Brunswick NJ 08901-8551

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New Jersey Land Cover Change Analysis (NJLCCA) Project

Introduction

In cooperation with the New Jersey Department of Environmental Protection (NJDEP) and the National Oceanic & Atmospheric Administration (NOAA), the Rutgers University Center for Remote Sensing and Spatial Analysis (CRSSA) has completed a Land Cover Change Analysis Project for the state of New Jersey. This project is one component of CRSSA's New Jersey Landscape Change research program (http://www.crssa.rutgers.edu/projects/lc/). The goal of the program is to monitor New Jersey's changing landscape and provide feedback to the various local, state and federal agencies concerned with the success or failure of land use and habitat management policies in New Jersey. The more immediate objective of this project was to develop a standardized information base on the present land cover of New Jersey and to map trends in land cover change during the 1970-1980-1990's time period.

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 bio-physical material covering the earth's surface at any particular location. For example an area that has a land cover of 'grass' may have a number of possible land uses. For example in a land use map, that same grass area could be labeled a recreational park or a cemetery or a corporate office park. Together land use and land cover information provide a good indication of the landscape condition and processes that are occurring at a particular place. Landscape change research is important for many scientific, ecological and land management purposes. Time series of land use/land cover maps tell us how much of the landscape is changing, as well as what changes have occurred and where the changes are taking place. Accurate and timely mapping of land use/land cover provides vital information on the state of the environment, development trends and wildlife habitat among others.

One of the most effective ways to map land use/land cover is through the use of remote sensing imagery collected from satellites and aircraft. Remote sensing satellites orbit at hundreds of miles above the earth continually imaging the surface and transmitting the images back to ground stations for use by the research community. This technology is an excellent medium for monitoring the condition of land throughout the globe. Photography taken from airplanes is also useful, especially where greater detail of the land surface is needed. New satellite sensors are now approaching the detail once provided exclusively by aerial photography. Advanced computer processing techniques allow the images to be combined with other environmental data sets to map land cover. Mapping land use requires visual interpretation by experienced image interpreters and is a time consuming labor intensive process. Remote sensing technology is widely used at the Grant F. Walton Center for Remote Sensing and Spatial Analysis at Rutgers University, The State University of New Jersey, to provide data for landscape change, wildlife habitat and watershed planning, management and research.

Land Cover Mapping Methods

Due to the broad state-wide scope of the project and the desire to produce standardized land cover information consistent with CCAP mapping efforts conducted elsewhere, satellite remote sensing imagery were used as the basis for the New Jersey Land Cover Change Analysis (NJLCCA) Project. See Appendix 1 for more documentation of the land cover mapping methodology used.

Landsat Thematic Mapper (TM) satellite imagery were acquired for relatively cloud-free dates in 1994 and 1995 (November 4, 1994 and September 4, 1995). Cloud covered areas were replaced with December 22, 1994 imagery. The November "leaf-off" imagery was taken after normal deciduous plant leaf fall, allowing the clearer differentiation of evergreen vs. deciduous forests and developed areas (see Figure 1). The September "leaf-on" imagery permits the further discrimination of cultivated, wetland and developed areas. For the change detection efforts, corresponding images from November 8, 1984 and September 21, 1984 were acquired. These "anniversary" images allow us to quantify the change in land cover that has occurred during the 10-year interval between 1984 and 1994/95. To extend comparisons further back in time though at a coarser spatial resolution and more generalized level of categorization, earlier generation Landsat Multi-spectral Scanner (MSS) imagery from October 10, 1972 was also acquired for analysis.

The land cover mapping was undertaken at three levels of generalization: Level I, the most generalized with 8 classes; Level 2, with 15 classes; Level III, the most detailed with 40 classes. The Level I and Level II classification schemes were designed to follow the NOAA Coastal Land Cover Classification System. The Level III classification scheme was designed to meet the needs of the Endangered & Nongame Species Program of the NJDEP's Division of Fish & Wildlife. The more generalized Level I classification scheme was used for the 1972 Landsat MSS-derived classification and for comparison purposes for the 1984 and 95 classifications.

Standard NOAA Coastal Change Analysis Program (CCAP) protocols including the land cover classification scheme were used to provide for a land cover data base consistent with those developed in CCAP projects in other states. A combination of digital image analysis techniques were used to classify the Landsat TM and MSS images into land cover maps. Incorporation of additional mapped data sets in the context of a geographic information system (GIS) was used to provide further classification improvement. Existing digital data sets such as U.S. Fish and Wildlife Service National Wetland Inventory (NWI), New Jersey Department of Environmental Protection (NJDEP) Freshwater Wetlands, NJDEP Integrated Terrain Unit (ITU) and U.S. Geological Survey Land Use/Land Cover were incorporated into the classification process as either pre-classification stratification or post-classification modification. To provide for updated land use information for the 1995 time period, CRSSA created a statewide coverage of 1995 color infrared digital orthophoto quarter-quads (DOQQ's) at 5 meter grid cell resolution. Areas of new development (subsequent to 1986) were then interpreted and digitized on-screen.

To assist in the post-classification accuracy assessment of the 1994/1995 mapping effort, a "ground-truthing" field campaign was undertaken. Over 300 field sites were visited during the fall of 1994 and winter/spring months of 1995, simultaneous with the image acquisition and prior to any classification activities. Over 1,400 field sites were visited in the Spring of 1997 and 2000 to serve as additional post-classification accuracy assessment ground reference sites. Results of the accuracy assessment suggests that the Level I land cover map is approximately 93% correct, while the more detailed Level II land cover map is correct approximately 85% of the time. No attempt was made to independently assess the accuracy of the 1972 or 1984 time period image maps due to the absence of appropriate field reference data for those time periods.

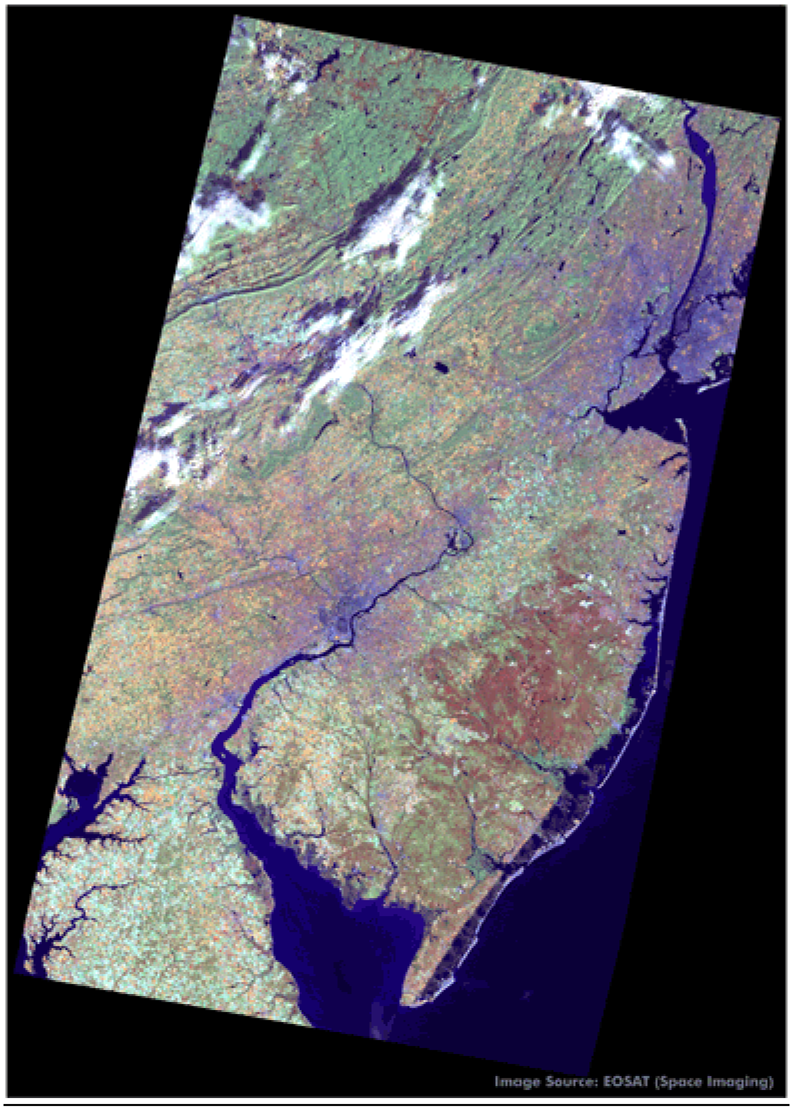

Figure 1. Landsat Thematic Mapper satellite image (November 4, 1994) of New Jersey. Image shown as false-color infrared (near infrared, mid infrared and red).

Statewide Land Cover Change Analysis

Comparison of the 1972, 1984 and 1995 land cover maps show the types of landscape change that occurred during the period of analysis. Figure 2 represents a combined map highlighting the spatial patterns of development over the time period. Due to the cruder technology of the Landsat Multispectral Scanner, the 1972 land cover map provides a coarser view of land cover during this earlier time period. Our qualitative accuracy assessment for the 1972 land cover map suggests that due to the larger minimum mapping unit (coarser scale) of the data, the amount of area mapped as Developed land cover is significantly underestimated. While good for a visual analysis of the general spatial patterns of land cover change, a numerical comparison of the 1972 and the 1984 data sets overestimates the amount of new development occurring during this time interval. As the 1984 and 1995 land cover sets were both created from the Landsat Thematic Mapper satellite sensor and comparable auxiliary data sets, they provide a good estimate of land cover change during this latter time period. The analysis below highlights those landscape changes that have occurred over this 1984 to 1995 time period.

Suburban sprawl is alive and well in New Jersey. The changes occurring to New Jersey's landscape are largely the result of human activities, namely residential, commercial and to a lesser extent industrial development. New Jersey increased its developed land by 17% from approximately 1.20 million acres (25% of the total land area) in 1984 to approximately 1.43 million acres (30 % of the total land area) in 1995 (see Table 1). This represents an increase in developed land area of approximately 222,400 acres or 20,200 acres per year. Much of this new development can be characterized as suburban sprawl with approximately 80% of the developed land in 1995 in low to moderate intensity development (i.e., suburban land uses). Another significant land cover category that increased due to human land use activities are bare land areas due principally to sand and gravel mining or other land clearing activities (i.e., prior to development). Bare land areas increased by approximately 7,000 acres between 1984 and 1995.

Open space areas of farmland, forest and wetlands declined proportionately to the increase in development and land clearing (see Table 1). New Jersey is fast losing the garden in the Garden State. Approximately 123,500 acres of non-forested open space, much of this farmland, were converted to other land cover types during the 1984 to 1995 time period. The 74,700 acres of cultivated land and 48,700 acres of grassland lost during this time interval represents a loss of 12% as compared to 1984. Upland forested areas declined by approximately 44,500 acres (3% loss of forest area from 1984). Estuarine emergent wetlands (e.g., coastal salt marshes) remained relatively stable in area. Some of the estimated loss is due to human development impacts and some due to natural processes of erosion and tidal flooding. Palustrine wetlands (e.g., freshwater marshes, swamps and riparian forests) showed a more significant decline in area of approximately 52,000 acres or a 6% loss. A large majority of this wetlands decline was due to the loss of forested wetlands. Some of the changes in the combined shoreline and water land cover category are due primarily to new reservoirs such as Merrill Creek and Monksville Reservoirs and surface mining activities as well as natural accretion/erosion in beaches and other shoreline areas.

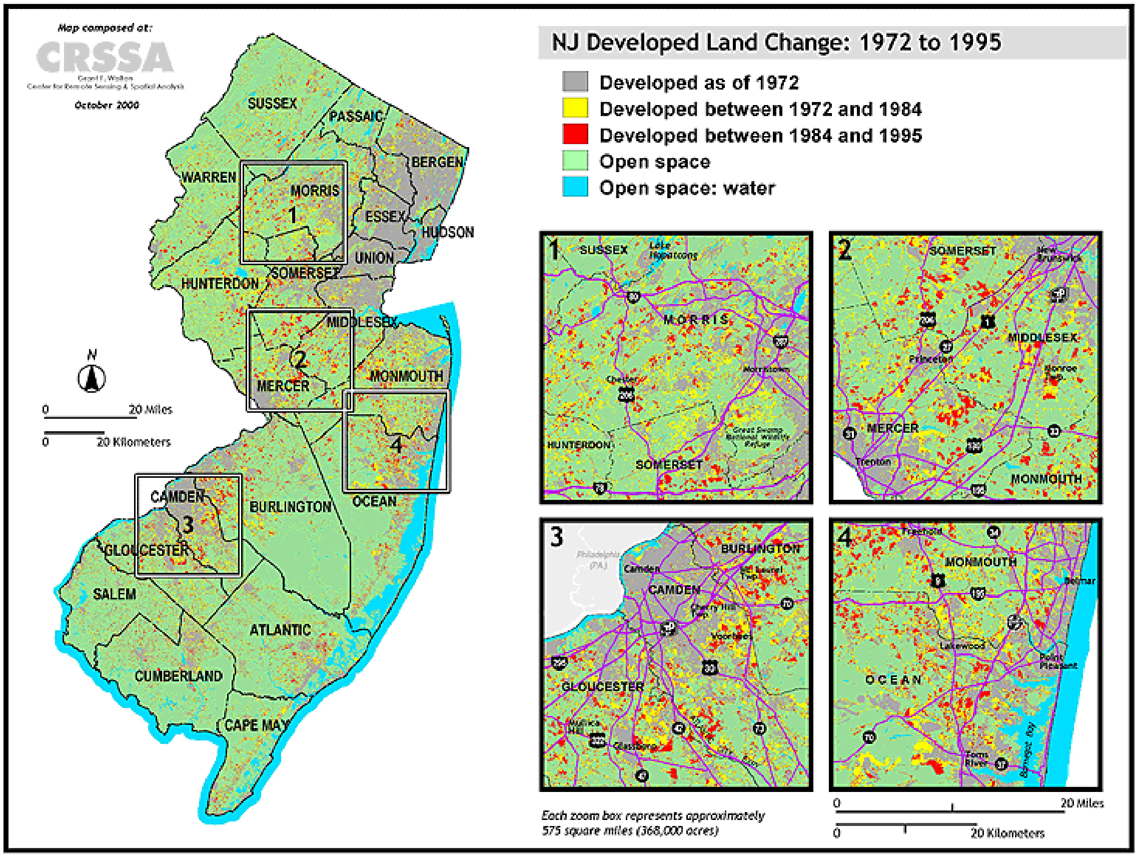

Figure 2. New Jersey land cover change map highlighting changes in developed land between 1972 and 1995.

Table 1. Land cover estimates for New Jersey for the years of 1972, 1984 and 1995.

Land Cover Description	1972 (acres)	1984 (acres)	1995 (acres)
Developed	888,520	1,204,920	1,427,310
Cultivated/Grassland	999,340	1,006,980	883,590
Forest/Scrub/Shrub	1,673,110	1,465,680	1,421,060
Barren	29,840	38,450	45,530
Estuarine Emergent Wetland	220,720	208,280	201,570
Palustrine Wetland: Emergent/Forested	925,300	788,870	737,010
Unconsolidated Shore	12,310	47,160	45,880
Water	517,700	516,570	514,960
Totals	5,266,840	5,276,910	5,276,910

County Level Land Cover Change Analysis

While most New Jersey counties received substantial levels of new development between 1984 and 1995, three major hotspots stand out: the Jersey Shore counties; the suburban fringe of the Philadelphia metro area in south Jersey; and the outer fringes of the New York metro area in central Jersey (see Figure 2). Table 2 details the area amounts (in acres) of land cover change by type. Table 3 shows the percentage of the county land area (excludes water) that was in a developed land cover in 1984 and 1995 and the change over the time period. The Jersey Shore counties of Monmouth, Ocean and Atlantic account for over a quarter of the state's growth (approx. 59,500 acres). This pattern follows a broader nationwide trend of increasingly concentrated development in the coastal zone. The Philadelphia suburban counties of Burlington, Camden and Gloucester accounted for approximately another quarter (52,450 acres) of New Jersey's new development. Each of these counties have increased the percentage of the county land area developed by 5% or more. Most of this development occurred in the 'outer ring' counties of Burlington and Gloucester, with the 'inner ring' county of Camden receiving comparatively modest absolute growth but still high relative growth. Another growth area follows the interstate highway corridors of Routes 78, 80 and 287 in the central Jersey counties of Morris, Somerset and Hunterdon (39,800 acres or 18% of new development). Other central Jersey counties of Mercer and Middlesex showed more modest levels of absolute growth but still relatively high % change.

In contrast, the highly urbanized northeastern counties of Essex, Hudson and Union are close to a mature 'built-out' state showing little to no growth in developed area. Approximately 80% of the land area of these counties was in developed land covers by 1995. The counties of Cumberland and Salem in the south and Sussex and Warren in the north, while still largely rural with 15% or less of the land area in developed land cover, are still showing moderate levels of growth.

Open space areas of farmland, forest and wetlands declined proportionately to the increase in development and land clearing (see Table 2). The comparative loss of cultivated/grassland vs. upland forest vs. wetlands varied by geographic region. Approximately 123,500 acres of non-forested open space (74,700 acres of cultivated land and 48,700 acres of grassland), much of this farmland, were converted to other land cover types during the 1984 to 1995 time period. The greatest loss of cultivated land and grassland occurred in the traditional farming counties of Burlington county (approx. 18,600 acres), Gloucester (13,650 acres), Cumberland (13,400 acres), Monmouth (9,600 acres), and Hunterdon (9,300 acres) counties. Upland forested areas declined by approximately 44,500 acres (3% loss of forest area from 1984). Ocean County had nearly double the amount of upland forest loss as any other county (approx. 10,835 acres). Other big losses were experienced in Somerset (5,525 acres), Atlantic (5,100 acres), Monmouth (4,140 acres) and Camden (3,750 acres) counties. An estimated 58,500 acres (6% of total wetlands that existed in 1984) were lost by 1995. The greatest wetlands loss occurred in Sussex County (approx. 8,380 acres), followed by Monmouth (7,450 acres), Morris (5,575 acres), Ocean (4,610 acres) and Middlesex (4,105 acres) counties. A large majority of this wetlands decline was due to the loss of forested wetlands.

Table 2. Land cover change by county between 1984 and 1995. Area change in acres.

COUNTY	Developed Change	Bare Land Change	Cultivated/ Grass Change	Upland Forest Change	Wetland Change	Shore/ Water Change
ATLANTIC	**+16,165**	+435	-8,665	**-5,100**	-3,845	**+1,010**
BERGEN	+2,415	-85	+1,060	-1,630	-1,600	-150
BURLINGTON	**+25,130**	+1,185	**-18,605**	-3,195	-2,790	**-1,735**
CAMDEN	+10,260	+550	-5,870	**-3,745**	-930	-265
CAPE_MAY	+6,245	+580	-4,670	-190	-1,680	-285
CUMBERLAND	+12,680	+1,400	**-13,405**	+475	-1,270	+135
ESSEX	+975	+20	+380	-770	-430	-180
GLOUCESTER	**+17,050**	+850	**-13,655**	-1,865	-1,390	**-990**
HUDSON	+200	-755	+720	+15	-680	+495
HUNTERDON	+12,415	+130	**-9,315**	-2,400	-870	+40
MERCER	+9,410	-10	-6,770	+1,275	-3,735	-170
MIDDLESEX	+9,275	-535	-2,665	-1,240	**-4,105**	**-730**
MONMOUTH	**+20,675**	+555	**-9,610**	**-4,140**	**-7,450**	-30
MORRIS	+12,975	+370	-4,420	-3,215	**-5,575**	-135
OCEAN	**+22,700**	+670	-7,300	**-10,835**	**-4,610**	-625
PASSAIC	+2,525	+30	-65	-1,070	-2,045	+620
SALEM	+9,355	+1,250	-8,315	+95	-1,745	-640
SOMERSET	+14,430	-110	-6,295	**-5,525**	-2,365	-130
SUSSEX	+9,320	+285	-1,540	+290	**-8,380**	+20
UNION	+645	-30	+200	-335	-445	-35
WARREN	+7,500	+390	-4,670	-1,520	-2,580	**+880**
TOTAL	+222,345	+7,175	-123,475	-44,625	- 58,520	-2,900

Entries in **bold** represent the top five counties in terms of change for each land cover category.

Table 3. Percentage of county (land area only, excluding water) developed in 1984 and 1995.

COUNTY	1984 %Developed	1995 %Developed	Change
ATLANTIC	13	17	+4
BERGEN	72	73	+2
BURLINGTON	**14**	**19**	**+5**
CAMDEN	**45**	**52**	**+7**
CAPE_MAY	15	19	+4
CUMBERLAND	10	14	+4
ESSEX	77	78	+1
GLOUCESTER	**25**	**33**	**+8**
HUDSON	78	80	+2
HUNTERDON	**18**	**22**	**+5**
MERCER	**35**	**42**	**+6**
MIDDLESEX	**47**	**52**	**+5**
MONMOUTH	**37**	**44**	**+7**
MORRIS	33	37	+4
OCEAN	**19**	**25**	**+5**
PASSAIC	37	39	+2
SALEM	9	13	+4
SOMERSET	**33**	**40**	**+7**
SUSSEX	11	13	+3
UNION	83	84	+1
WARREN	12	15	+3
TOTAL	25	30	+5

Entries in **bold** represent the counties exhibiting a 5% or greater change in land area developed.

Watershed Level Land Cover Change Analysis

A landscape change comparison was also undertaken at a watershed level. Figure 3 shows a map of 1995 land cover with the NJDEP watershed management area boundaries superimposed. Table 4 details the area amounts (in acres) of land cover change by type. Table 5 shows the percentage of the watershed land area (excludes water) that was in a developed land cover in 1984 and 1995 and the change over the time period. From a watershed perspective, the top hotspots for new development were the lower Delaware River and Bay, the Atlantic coastal and the Raritan River watersheds. The new development in the lower Delaware River and Bay watersheds (e.g., the Lower Delaware River tributaries, Maurice and Cohansey Rivers, Rancocas and Crosswicks Creeks) primarily replaced farming areas of cultivated land and grassland. These watersheds are largely absorbing the growth of the expanding Philadelphia metro area. The Atlantic coastal watersheds of the Great Egg Harbor/Tuckahoe, Barnegat Bay and Monmouth all showed an increase in the percentage of the watershed land area developed of 5% or greater. These watersheds were significant in terms of the upland forest and wetland (primarily forested wetlands) loss. In central Jersey, the larger Raritan River basin (which includes the North/South Branches, the Lower Raritan, and the Millstone watersheds) showed an increase in the percentage of the watershed land area developed of 6% or greater. The North and South Branches of the Raritan and the Millstone were notable for their loss of cultivated and grassland, while the lower Raritan had large losses of upland forest and wetlands.

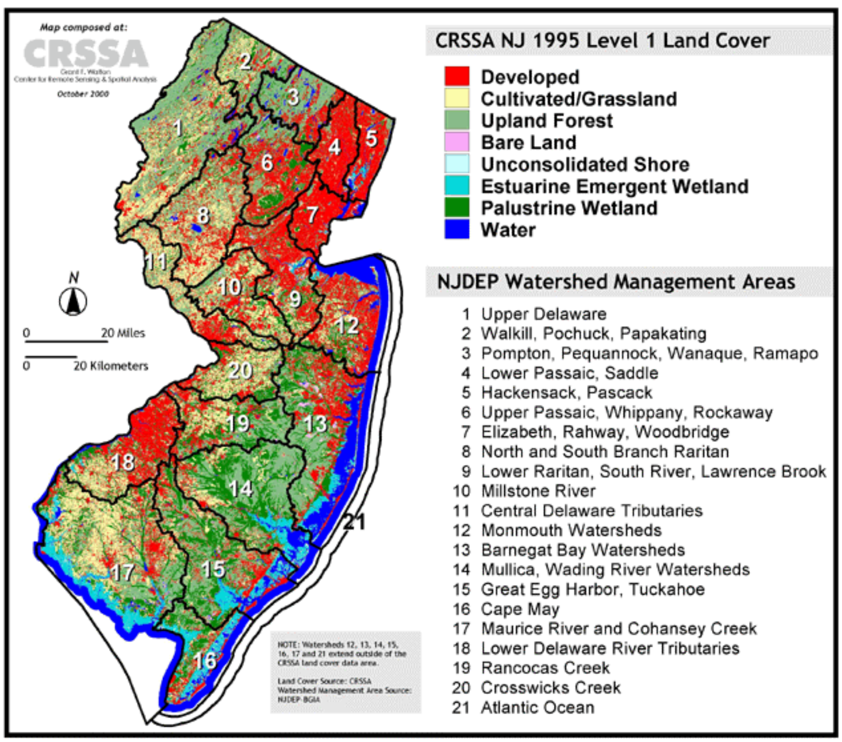

Figure 3. Map of New Jersey Level 1 land cover for the year 1995 with NJDEP watershed management areas boundaries.

Table 4. Land cover change by watershed management areas between 1984 and 1995. Area change in acres.

WMA Code & Label	Developed Change	Bare Land Change	Cultivated Grassland Change	Upland Forest Change	Wetland Change	Shore/ Water Change
1 Upper Delaware	+13,840	+640	-6,690	-1,810	**-7,070**	**+1,090**
2 Wallkill/Pochuck/Papakating	+3,830	+120	-390	+ 580	-3,985	-155
3 Pompton/Pequannock/Ramapo	+4,215	+105	-285	-1,835	-2,985	**+785**
4 Lower Passaic, Saddle	+1,595	-40	+650	-1,155	-1,040	-5
5 Hackensack, Pascack	+ 835	-625	+1,300	-275	-1,365	+130
6 Upper Passaic	+8,990	+230	-540	**-4,065**	**-4,185**	-430
7 Elizabeth, Rahway	+ 970	-365	+ 550	-475	-650	-30
8 North/South Branch Raritan	**+17,660**	+130	**-11,320**	**-4,390**	-2,045	-35
9 Lower Raritan/South River	+13,430	-250	-3,395	**-3,940**	**-5,175**	**-675**
10 Millstone River	+14,185	-345	**-9,515**	-1,115	-3,080	-130
11 Central Delaware	+ 7,685	+210	-6,650	+1,340	-2,610	+15
12 Monmouth Watersheds	+11,485	+270	-3,880	-2,570	**-5,290**	-20
13 Barnegat Bay Watersheds	**+22,205**	+330	-6,490	**-11,790**	**-3,800**	-455
14 Mullica/Wading Rivers	+ 7,985	-35	-5,610	-280	-1,515	-545
15 Great Egg Harbor/Tuckahoe	**+17,050**	**+885**	-8,870	**-6,320**	-3,295	+545
16 Cape May	+ 5,270	+225	-4,190	+365	-1,180	-495
17 Maurice/Cohansey River	**+25,005**	**+2,775**	**-22,860**	-1,045	-3,320	-555
18 Lower Delaware River	**+22,465**	**+1,160**	**-17,380**	-2,790	-2,290	**-1,170**
19 Rancocas Creek	+12,740	**+1,035**	-8,740	-2,445	-1,950	**-640**
20 Crosswicks Creek	+10,940	**+ 710**	**-9,095**	-610	-1,750	-200
Total	+222,380	+7,165	-123,400	-44,620	-58,580	-2,975

Entries in **bold** represent the watershed management areas exhibiting a 5% or greater change in land area developed.

Table 5. Percentage of watershed management areas (land area only, excluding water) developed in 1984 and 1995.

WMA Code & Label	1984 %Developed	1995 %Developed	Change
1 Upper Delaware	12	15	+3
2 Wallkill/Pochuck/Papakating	13	16	+3
3 Pompton/Pequannock/Ramapo	24	27	+3
4 Lower Passaic, Saddle	83	85	+1
5 Hackensack, Pascack	75	76	+1
6 Upper Passaic	41	45	+4
7 Elizabeth, Rahway	84	85	+1
8 North/South Branch Raritan	**23**	**29**	**+6**
9 Lower Raritan/South River	**47**	**54**	**+6**
10 Millstone River	**25**	**32**	**+8**
11 Central Delaware	**23**	**27**	**+5**
12 Monmouth Watersheds	**42**	**48**	**+5**
13 Barnegat Bay Watersheds	**21**	**26**	**+6**
14 Mullica/Wading Rivers	5	7	+2
15 Great Egg Harbor/Tuckahoe	**14**	**19**	**+5**
16 Cape May	13	16	+3
17 Maurice/Cohansey River	9	12	+4
18 Lower Delaware River	**43**	**52**	**+9**
19 Rancocas Creek	**17**	**23**	**+6**
20 Crosswicks Creek	**17**	**24**	**+7**

Entries in **bold** represent the watershed management areas exhibiting a 5% or greater change in land area developed.

Open Space Fragmentation

Preservation of open space has long been a priority for New Jersey citizens. The recent establishment of the New Jersey Green Trust with the stated goal of preserving an additional million acres of open space has given open space planning greater impetus. Large contiguous tracts of forest and wetland that are not fragmented by human development are especially valuable as wildlife habitat and recreational open space. Human development has the direct impact of removing existing natural habitat as well as fragmenting the habitat that remains into smaller pieces. Paved roads, residential and commercial development often serve as barrier or hazard to wildlife movement and native plant dispersal. Human development also has "indirect" impact by creating a number of different kinds of intrusions with varying depth of impact into adjacent natural habitat. These intrusions include increased air, water and noise pollution; changes in microclimatic conditions; increased populations of invasive "weed" species; and increased frequency of disturbance due to direct contact with humans, human pets and associated "rural/suburban pest" species. Similarly, large contiguous areas of farmland minimize the interface of suburban/agricultural land uses, reducing associated conflicts and thereby serving to maintain the integrity of the agricultural community and the aesthetic qualities of the agricultural landscape. While priority should be given to preserving large contiguous tracts, small, isolated parcels of forest or farmland may also have inherent value as oases in an otherwise homogeneous suburban landscape.

The NJLCCA data was used to map contiguous tracts (>2.5 acres) of forest land, both upland and wetland combined. Major roads (i.e., county level highways and higher) were included in the analysis as a fragmenting influence or barrier; such that a tract of forest that might otherwise be considered contiguous, if it were subdivided by a major road would be mapped as two separate parcels. Contiguous tracts of cultivated/grassland (primarily farmland but may also include some park lands) that were greater than 2.5 acres were also mapped. In the case of farm/park lands, major roads were not considered a fragmenting influence and were not included in the analysis. While some of the smaller tracts may represent a single ownership, most of the larger tracts will be composed of multiple ownerships, both public and private.

Comparison of the tract size distributions for the 1984 and 1995 NJLCCA data sets shows open space fragmentation is occurring with larger tracts broken into smaller ones and in both cases the overall number of tracts increases. For forest land, the largest tracts, those greater than 25,000 acres remained comparatively stable but the medium size tracts decreased in both number and area, while the number of smallest size tracts (i.e., those < 500 acres) increased in number (see Table 6). The greatest fragmentation of forest land appears to be occurring in the coastal plain of northern Ocean/southern Monmouth/Atlantic counties and southern Highlands area of Morris/Hunterdon/ Somerset counties (see Figure 4). Fragmentation of farm/parkland (i.e., cultivated land and grassland, primarily farmland) was quite dramatic with the loss of the largest tracts of contiguous farmland through subdivision into smaller pieces (see Table 7). Hotspots for farmland loss and fragmentation are western Hunterdon/Warren counties, the northern inner coastal plain area of Mercer/Monmouth/Burlington counties and the southern coastal plain area of Gloucester/Salem/Cumberland counties (see Figure 5).

Table 6. Size distribution of contiguous tracts of forest land (upland and wetland forest combined) that were not subdivided by a county level or higher highway. Forest tract less than 2.5 acres were excluded from analysis.

Forest tracts	1984 # of tracts	1984 total acres	1984 % area	1995 # of tracts	1995 total acres	1995 %area
< 500 acres	18,168	492,610	23.3	19,604	485,150	24.2
500-1,000 acres	193	132,830	6.3	195	137,100	6.8
1,000-2,500 acres	173	268,565	12.7	157	244,550	12.2
2,500-5,000 acres	82	290,960	13.8	71	250,260	12.5
5,000-10,000 acres	39	264,945	12.6	36	242,455	12.1
10,000-25,000 acres	19	322,020	15.3	19	308,450	15.4
>25,000 acres	7	338,380	16.0	7	339,375	16.9
Total	18,681	2,110,310	100.0	20,089	2,007,340	100.0

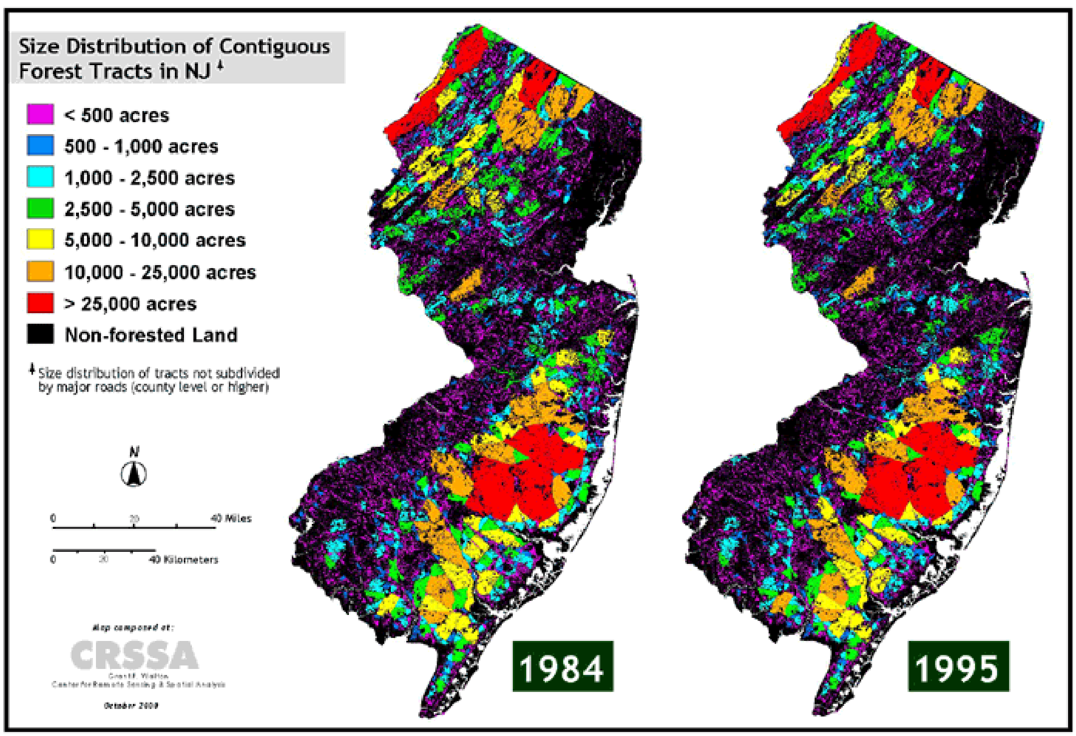

Figure 4. Map of contiguous tracts of forest land (both upland and wetland combined) for 1984 and 1995 time periods.

Table 7. Size distribution of contiguous tracts of cultivated/grassland, primarily farmland. Tracts less than 2.5 acres were excluded from analysis.

Cultivated/grassland tracts	1984 # of tracts	1984 total acres	1984 %area	1995 # of tracts	1995 total acres	1995 %area
< 500 acres	15,727	354,985	36.4	17,445	391,795	46.3
500-1,000 acres	106	74,050	7.6	114	76,875	9.1
1,000-2,500 acres	56	92,070	9.4	65	97,860	11.6
2,500-5,000 acres	28	95,105	9.7	25	78,595	9.3
5,000-10,000 acres	11	79,075	8.1	6	48,380	5.7
10,000-25,000 acres	1	14,295	1.5	5	84,140	10.0
>25,000 acres	6	267,060	27.3	1	68,115	8.0
Total	15,935	976,640	100.0	17,661	845,760	100.0

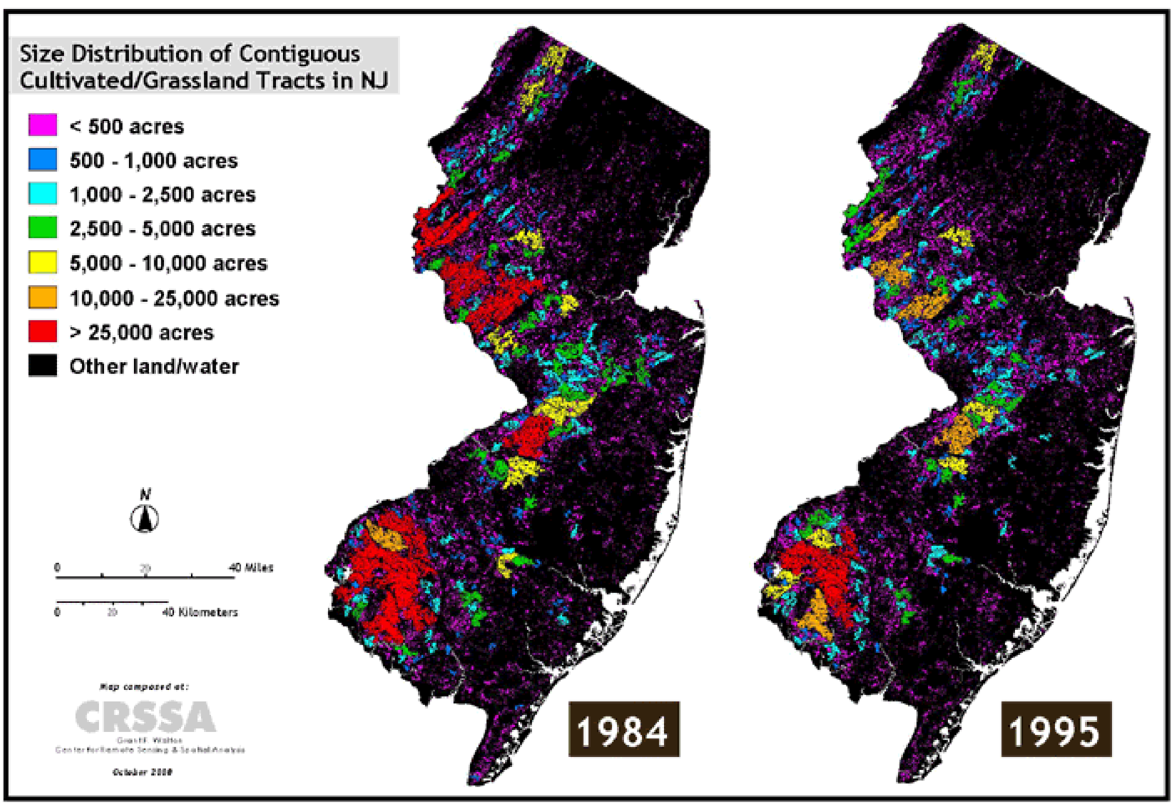

Figure 5. Map of contiguous tracts of cultivated/grassland (primarily farmland) for 1984 and 1995 time periods

Conclusions

New Jersey's landscape is constantly changing. While in many cases, landscape change is a natural process, human-induced landscape change is now the single most important factor influencing the state of land. The changes occurring to New Jersey's landscape are largely the result of human activities, namely residential, commercial, transportation and to a lesser extent industrial development. While some level of new development is needed to keep up with New Jersey's expanding population, it comes with a cost. Some of the most significant impacts of urban/suburban growth are loss of fertile agricultural lands, loss and fragmentation of wildlife habitat, loss of wetlands and increase in impervious surface with subsequent impacts on water quality and flooding, loss of open space for recreation, increased traffic and loss of aesthetic quality to the landscape. Dispersed development in rural areas has led to reduced flexibility in agricultural and forest land management, the potential for greater impacts due to natural hazards such as wildland fire, and increased human/wildlife conflicts (e.g., deer and bear).

New Jersey increased its developed land by 17% from approximately 1.20 million acres (25% of the total land area) in 1984 to approximately 1.43 million acres (30 % of the total land area) in 1995. This represents an increase in developed land area of approximately 222,400 acres or 20,200 acres per year. While to some extent the present development trends represent continuation of earlier post-World War II development patterns, the post-1972 land cover change maps clearly show the impact of expanded interstate/state highway construction and resultant changes in commuting patterns leading to sprawling residential development. Three major hotspots stand out: the Jersey Shore counties; the suburban fringe of the Philadelphia metro area in south Jersey; and the outer fringes of the New York metro area in central Jersey. Even in the more 'exurban' areas, high levels of dispersed development (e.g., single scattered homesites) is clearly evident and changing the character of these rural landscapes.

While land conversion due to development is evident everywhere across the state, some areas do stand out as areas of minimal change. The success of the Pinelands National Reserve in limiting landscape change within its jurisdictional area is clearly evident. The Kittatiny Ridge and upper Delaware Valley region of northwestern New Jersey have also been spared large scale land conversion and fragmentation under the jurisdiction of the Delaware Water Gap National Recreation Area in combination with a number of state forests, parks and wildlife management areas. Other areas in the state while still remaining largely rural are not similarly protected. The Delaware bayshore of Salem, Cumberland and Cape May counties and the Highlands region of Sussex, Warren, Passaic and Morris counties still remain as largely intact landscapes of farms, small villages and towns, forests and wetlands. Clearly, if present trends continue these areas will undergo radical changes in the next several decades.

New Jersey is obviously at a critical juncture. Continued development at the present pace and sprawling pattern will severely limit future options in preserving and managing farmland, wildlife habitat and open space. To ensure our present high quality of life, New Jersey citizens and government are faced with the challenge of planning for new development in such a fashion that maintains a viable agricultural community and abundant open space.

Appendix Land Cover Mapping Methodology

1. INTRODUCTION

Using established National Oceanic & Atmospheric Administration (NOAA) Coastal Change Analysis Program (CCAP) protocols (Dobson et al., 1995), Landsat Thematic Mapper (TM) imagery acquired in 1994 and 1995 have been classified to provide a baseline survey of coastal wetland and upland habitats. The Landsat TM imagery from 1994/1995 have been compared to earlier 1984 TM and 1972/73 Landsat Multispectral Scanner (MSS) imagery to map 20 years worth of land cover change.

2. GEO-PROCESSING SOFTWARE

Several versions of ERDAS image processing software were used during the life of this project, starting with ERDAS 7.5 and ending with UNIX ERDAS IMAGINE 8.3. UNIX ARC/INFO version 6.0-7.0 was used to process the vector (polygonal) data sets. The geo-processing was undertaken on a Sun Sparcstation 20 and a Silicon Graphics Challenge 10,000 processor.

3. DATA SETS

3.1 Remotely Sensed Imagery

3.1.1 LANDSAT data sets

Landsat TM imagery (Path/Row 14/31, 14/32, & 14/33) were acquired for a cloud-free dates in 1994 and 1995 (November 4, 1994 and September 4, 1995). Some cloud-covered areas in the November 1994 image were replaced with TM imagery from December 22, 1994. For the change detection efforts, corresponding "anniversary" images (Path/Row 14/32 & 14/33) from November 8, 1984 and September 21, 1984 were acquired and analyzed. For the earlier 1970's time period, Landsat MSS imagery (Path/Row 15/31, 15/32, 15/33) for October 10, 1972 (leaf-on) were acquired and analyzed. The "leaf-off" (November for TM) imagery is after normal deciduous plant leaf fall, allowing the clearer differentiation of evergreen vs. deciduous forests. The "leaf-on" (September for TM, early October for MSS) imagery permits the further discrimination of cultivated, wetland and developed areas. The Landsat TM normalized difference vegetation index (NDVI = [(TM Band 4 - TM Band 3)/(TM Band 4 + TM Band 3)], calculated from the normalized DN data) and Band 5 (Middle Infrared) were each taken from the September and November images.

3.1.2 Georectification

The LANDSAT image data sets were all originally georectified to a Universal Transverse Mercator (UTM) projection (UTM Zone 18; datum: NAD 27; spheroid: Clarke 1866). The TM data were rectified with a Root Mean Square error of approximately < 0.5 pixel (i.e., +- 15 m). Due to the coarser nature of the MSS data, the MSS images were rectified with a Root Mean Square error of approximately < 0.75 pixel (i.e., +- 60 m). Due to the adoption of the NAD83 datum, the final classified maps were re-projected and re-sampled to UTM with a NAD83 datum. The TM output imagery had a grid cell resolution of 30x30 m, while the MSS was 80x80m. The coregistration of the November 1984 and November 1994 was satisfactory. There appeared to be a slight (approx. 1 pixel) east-west shift in the September 1984 and September 1995 that was noticeable at the land-water interface and occasionally along major road corridors. The co-registration of the MSS appeared adequate but was difficult to compare with the TM data due to its coarser spatial resolution.

3.1.3 Image Normalization: 1984 to 1994/1995

To try to correct for various scene to scene differences in brightness and spectral response (including atmospheric influences), I used an image-to-image empirical normalization procedure that compared invariant scene targets. The 1994/1995 LANDSAT TM imagery data were used a baseline (i.e. digital numbers left unchanged) while the 1984 image digital numbers were altered to more closely match the appropriate anniversary image (i.e., Sept. 1984 normalized to Sept. 1995). Approximately 15 (in total) dark (lakes), medium (urban features: parking lots, industrial areas) and bright (gravel pits, sand beach) toned targets were chosen that appeared to be reasonably unchanged in spectral responses between scenes. Simple linear regression models were then developed for each of the LANDSAT TM's 7 spectral wavebands. The general form of the model was:

TM84 Band# DN = a + b*TM94/95# DN + error.

The linear relationship between the invariant scene targets for the two dates was quite strong with R^2 values of > 0.975. This approach was straight forward and gave reasonably good results. Due to the vastly different spectral wavebands of the Landsat TM and MSS sensors, no image normalization was attempted of the Landsat MSS imagery.

3.2 Ancillary Spatial Data Sets

Incorporation of additional mapped data sets in the context of a geographic information system (GIS) was used to provide further classification improvement. Existing digital data sets such as U.S. Fish and Wildlife Service National Wetland Inventory (NWI) (derived from visual interpretation of 1975-1977 aerial photography) (Tiner, 1985), New Jersey Department of Environmental Protection Freshwater Wetlands (FWW, 1:24,000 scale derived from visual interpretation of 1986 aerial photography), Integrated Terrain Unit (ITU, 1:24,000 scale derived from visual interpretation of 1986 aerial photography) (NJDEP, 1996), U.S. Geological Survey Land Use/Land Cover (LU/LC, 1:250,000 scale derived from visual interpretation of 1973 aerial photography) (USGS, 1986), Soil Conservation Service county level soils maps (as part of the NJDEP ITU coverage) and Census block-level Housing Density (1990 Census) data were incorporated into the classification process using a variety of approaches. These vector (polygonal) digital data layers were rasterized at 30m grid cell resolution and aligned with the satellite image data sets.

3.2.1 Wetlands data

To more accurately classify wetlands by reducing commission errors (calling uplands wetlands), we used a composite of existing wetland digital maps in combination with the spectral data. The NWI, FWW and ITU digital maps were recoded to binary wetland-upland thematic layers. In southern New Jersey (approx 40^{o} 15" south) the ITU mapped wetlands data was included. In northern New Jersey (approx 40^{o} 15" north) the ITU mapped soils data (based on Hydric code) was included. These 3 data layers were then composited into one map similar to a GIS matrix function resulting in 8 class values. These 8 class values were then recoded to represent the likelihood a pixel was wetland based on my subjective "expert opinion" of giving equal weight to the NWI and FWW data sets and lesser weight to the ITU:

ITU	NWI	FWW	Composite
N	N	N	0
Y	N	N	100
N	Y	N	150
N	N	Y	150
Y	Y	N	200
Y	N	Y	200
N	Y	Y	225
Y	Y	Y	250

It must be noted that the ITU did not map wetlands in great detail. The FWW did not map estuarine wetlands (freshwater wetlands only) but did include ITU mapped estuarine wetlands. This composite data was included as an additional data layer as part of the classification process (see below).

3.2.2 Census Housing Unit Density Data

To more accurately classify developed lands, U.S. Census housing unit density (# units/acre) was included as an additional data layer. The density values were then recoded to represent the likelihood a pixel was developed based on my subjective "expert opinion" with higher densities having a higher likelihood of being developed:

Density	DN Value	Density	DN Value
0	1	5<x<=6	95
0<x<=1	5	6<x<=7	120
1<x<=2	25	7<x<=8	150
2<x<=3	50	8<x<=9	185
3<x<=4	60	9<x<=10	225
4<x<=5	75	10<x	255

4. LAND COVER CLASSIFICATION

4.1 Classification Schemes

The classification scheme was designed to follow the CCAP Coastal Land Cover Classification System (Dobson et al., 1995) but include additional categories to meet ENSP's requirements. The classification was mapped at three levels of generalization: Level I, the most generalized with 8 classes (Table 1a); Level 2, closely matches the NOAA CCAP classification with 14 classes (Table 1b); and Level III, the most detailed with 40 land cover classes (Table 1c). The more generalized Level I classification scheme was used for the 1972 Landsat MSS-derived classification and for comparison purposes for the 1984 and 1994/95 classifications.

Table 1a. Level I (8 classes)

1.10 Developed (Level II Classes 1.11, 1.12)
1.20 Cultivated/Grassland (Level II Classes 1.20, 1.30)
1.40 Upland Forest (Level II Classes 1.41-1.43, 1.50)
1.60 Bare Land
2.00 Unconsolidated Shore
2.10 Estuarine Emergent Wetland
2.40 Palustrine Wetland (Level II Classes 2.30, 2.41 & 2.45)
2.50 Water

Table 1b. Level II (14 classes)

1.11 Developed: High Intensity (>75% impervious surface cover)
1.12 Developed: Low to Moderately Intensity (25-75% impervious surface cover)(Level III Classes 1.12, 1.13 & 1.14)
1.20 Cultivated
1.30 Grassland (Classes 1.31, 1.32, 1.33)
1.41 Upland Forest: Deciduous dominant (> 66%) (Level III Classes 1.41, 1.42(split), 145)
1.42 Upland Forest: Evergreen dominant (>66%) (Level III Classes 1.43(split), 144, 148, 149)
1.43 Upland Forest: Mixed Deciduous/Evergreen (Level III Classes 1.42(split), 1.43(split),1.46, 147)
1.50 Upland Scrub/Shrub (Level III Class 1.51, 1.52, 1.53)
1.60 Bare Land (sand/gravel pits, barren < 25% vegetation)
2.00 Unconsolidated Shore (Level III Classes 2.01, 2.02 & 2.20)
2.10 Estuarine Emergent Wetland (Level III Classes 2.11, 2.12, 2.13, 2.14)
2.30 Palustrine Emergent Wetland (Level III Classes 2.31, 2.32)
2.41 Palustrine Forest Wetland (Level III Classes 2.41, 2.42, 2.43, 2.44, 2.46, 2.47, 2.48)
2.45 Palustrine Shrub/scrub Wetland (Level III Classes 2.45 & 2.49)
2.50 Water (Level III Classes 2.51 & 2.52)

Table 1c. Level III (40 classes)

1.11	Developed: Highly (>75% impervious surface)
1.12	Developed: Moderately (50-75% impervious surface)
1.13	Developed: Lightly (25-50% impervious surface) - wooded
1.14	Developed: Lightly (25-50% impervious surface) - Unwooded
1.20	Cultivated: (actively tilled, fallow and recently abandoned)
1.31	Grassland: unmanaged (grazed land, old fields, abandoned land)
1.32	Grassland: managed (golf courses, residential/corporate lawn, parks)
1.33	Grassland: airport
1.41	Upland Forest: Coastal Plain Oak dominant (Oak > 75%)
1.42	Upland Forest: Coastal Plain Oak-pine (Oak 50-75%)
1.43	Upland Forest: Coastal Plain Pine-oak (Pine 50-75%)
1.44	Upland Forest: Coastal Plain Pine dominant (Pine > 75%)
1.45	Upland Forest: Highlands/Piedmont deciduous - mixed hardwoods dominant
1.46	Upland Forest: Highlands Piedmont mixed deciduous/coniferous - hemlock/pine
1.47	Upland Forest: Highlands/Piedmont mixed deciduous/coniferous - red cedar/pine
1.48	Upland Forest: Highlands/Piedmont coniferous - hemlock/pine dominant
1.49	Upland Forest: Highlands/Piedmont coniferous - red cedar/pine/plantation dominant
1.51	Upland Scrub/shrub: Coastal Plain mixed deciduous/coniferous
1.52	Upland Scrub/shrub: Coastal Plain mixed deciduous/coniferous - maritime/dune
1.53	Upland Scrub/shrub: Highlands/Piedmont mixed deciduous/coniferous
1.60	Barren soil/rock: (sand/gravel pits, barren < 25% vegetation)
2.01	Marine/Estuarine Unconsolidated shore: sand
2.02	Marine/Estuarine Unconsolidated shore: mud/organic
2.11	Estuarine emergent marsh: low salt marsh - Spartina alterniflora dominant (> 50%)
2.12	Estuarine emergent marsh: high salt marsh - Spartina patens dominant (> 50%)
2.13	Estuarine emergent marsh: high salt marsh - Phragmites australis dominant (> 50%)
2.14	Brackish tidal/fresh tidal marsh: mixed species
2.20	Riverine/lacustrine/palustrine unconsolidated shore: sand/mud/organic
2.30	Riverine/lacustrine/palustrine emergent marsh: mixed species
2.41	Wetland Forest: Coastal Plain hardwood swamp- (> 66% deciduous)
2.42	Wetland Forest: Coastal Plain pine lowland - (> 66% evergreen)
2.43	Wetland Forest: Coastal Plain mixed - hardwood/white cedar-pine-holly
2.44	Wetland Forest: Coastal Plain white cedar swamp - (> 66% evergreen)
2.45	Wetland Scrub/shrub: Coastal Plain mixed
2.46	Wetland Forest: Highlands/Piedmont hardwood swamp- (> 66% deciduous)
2.47	Wetland Forest: Highlands/Piedmont mixed - hardwood/hemlock/white cedar/pine
2.48	Wetland Forest: Highlands/Piedmont conifer swamp - hemlock/cedar/pine dominant (> 66% evergreen)
2.49	Wetland Scrub/shrub: Highlands/Piedmont mixed deciduous/evergreen
2.51	Marine/Estuarine Open water
2.52	Riverine/lacustrine/palustrine Open water

4.2 Classification Process for 1994/1995 time period

4.2.1 Cluster busting

A combination of unsupervised clustering, supervised training, spectral mixture modeling, GIS rules-based and on-screen digitizing approaches were used to classify the corrected Landsat TM image using the ERDAS image processing software. Unsupervised cluster busting was used to develop spectral classes. 75 clusters were specified in the 1st round of unsupervised classification (.95 convergence factor). Additional classes were removed and further clustered into another 50 clusters (i.e., 25 classes were "busted" further apart into 50 classes), bringing to a total of 125 clusters. Spectral classes were assigned to land cover information classes by overlaying the spectral class map on top of the original imagery and visual interpretation on-screen. The land cover percentages (e.g., Highly developed with approximately > 75% developed surface) are estimates made by ocular estimation of the aerial photography and Landsat imagery, no systematic ground checking was used to support these estimates. In this initial development of spectral classes, some clusters could not be solely assigned to one particular land cover category. For example, spectral clusters for emergent marsh wetlands did not distinguish between estuarine (Class 210) and palustrine (Class 230). A GIS rules-based approach was used to make this assignment later.

4.2.2 Spectral mixture modeling

A spectral mixture model approach was used in several cases where unsupervised cluster busting was not satisfactory in separating certain class types. A simple linear spectral mixture model algorithm was written using the IMAGINE Modeler software employing a simple least-squares unconstrained matrix approach. Spectral endmembers (i.e. "Pure" spectral classes) were developed by visual interpretation of the spectral feature space images and supervised training set delineation of known classes. The mixture model was used to estimate the relative proportions of the spectral endmembers and then classed into appropriate land cover types. This mixture modeling approach was used in the following cases: 1) separating deciduous vs. mixed vs. coniferous upland forest types; 2) separating deciduous vs. mixed vs. coniferous wetland forest types; and 3) cultivated areas vs. Deciduous forest.

4.2.3 Supervised classification

A supervised classification approach using seed pixel training set delineation and maximum likelihood distance thresholding was used to map certain land cover types, including: Class 244 (white cedar swamps); Class 213 (phragmites dominant wetlands).

4.2.4 GIS rules base approach

To assign spectral clusters to their appropriate land cover category with sufficient classification accuracy, a GIS rules-based approach was undertaken. The ITU and NWI data sets, along with user-digitized (primarily on-screen) masks were used to develop a series of classification rules in the IMAGINE Spatial Modeler. For example, a coastal littoral zone mask was digitized on-screen by visual interpretation of the LANDSAT TM imagery. This coastal mask was then used to assign the bare land spectral class to either Class 160 (Bare Upland) or Class 221 (M/E Unconsolidated Shore: Sand) and scrub/shrub to Class 152 (Scrub/shrub - maritime/dune). Similarly, the NWI data was used to create an estuarine vs. palustrine zone mask. Scrub/Shrub categories used a rule that applied a threshold value for the leaf-on NDVI imagery, if less than threshold NDVI and wooded, then scrub/shrub.

4.2.5 Developed area masking and classification

Based on further consideration, we decided to remove the effects of the Housing Density/Developed Likelihood data layer from the classification process and rely more strictly on spectral data alone. An Urban mask was created based on the NJDEP ITU land use/land cover data set. The NJDEP ITU data set was produced through the visual interpretation of 1:58,000 scale color infrared photography acquired in 1986, using a modified Anderson (Anderson et al., 1976) land use/land cover classification scheme (minimum mapping unit area = 2.5 acres) (NJDEP, 1996). To provide for updated land use information for the 1990, CRSSA obtained 1995-1997 color infrared digital orthophoto quarter-quads (DOQQ's). These DOQQ's were mosaicked together to create a seamless coverage at 5 meter grid cell resolution. The land use maps were updated by displaying the DOQQ's on the computer graphics terminal with the 1986 ITU land use maps overlaid in another graphics plane. Areas of new development (subsequent to 1986) were then interpreted and digitized on-screen. The original 1986 metadata was used as a guideline for both the digitizing and quality control processes to ensure consistency.

The idea behind using an Urban Mask was to reduce the amount of commission error by reducing the amount of nondeveloped area (e.g., bare agricultural fields) being classified wrongly as developed. The pixels within the Urban Mask could potentially be classified as some sort of development (e.g., 111 or 112) or some nondeveloped category (e.g., 130 or 140). This Urban Mask was used to extract the spectral image data and new spectral classes determined that correspond to the following land cover categories: 111, 112, 131, 132, 141, 143. These reclassified areas were then assigned to an appropriate land cover category and overlaid into the overall land cover map to replace the previous class assignment. The 1995-97 updated ITU data was also used to further define lightly developed categories, using the following rule: if ITU = developed and Spectral class = Wooded, then Class 113 (Lightly Developed - Wooded). A similar rule was used for Class 114 (Lightly Developed - Unwooded). AOI editing was further undertaken to clean up obvious misclassification.

4.2.6 Further clean-up processing

To remove "salt and pepper" typical of digitally image processed land cover maps, the resulting classified map was clumped (8 neighbor algorithm) with isolated single pixels eliminated and replaced by the majority category. On-screen editing using the IMAGINE Area-of-Interest (AOI) tool and recode function was also undertaken to clean up obvious instances of misclassification and to include classes that were difficult to get otherwise (e.g., Class 133: grassland - airports). Visual interpretation of the Sept. (Leaf-on) and Nov. (Leaf-off) imagery was used in making this judgement. AOI editing was also used to fill in areas misclassified due to cloud and cloud shadows.

4.3 Classification Process for 1984 time period

The 1984 Land Cover classification was developed using methods as closely comparable to those applied to create the 1994/95 land cover classification. A 1984 composite data set of Sept. and Nov. NDVI and Band 5 data along with the wetland composite and housing unit density layers was created similar in format to the 1994/95 data set and used. Because the 1984 data were normalized and to try to keep the classification for the two time periods as closely comparable as possible, the same training 100 signatures developed for 1994/95 were used to initially classify the 1984 data. An urban mask was similarly developed as for 1994/95 and the same classification rules and signatures used. Similarly, the same GIS-rules base developed for the 1994/95 data set was applied to further aid in land cover class assignment in 1984. AOI editing was used to clean up areas of obvious misclassification.

4.4 Classification Process for the 1972 time period

Due to the coarser spatial (80 m) and spectral (4 Visible, near infrared bands) of the Landsat MSS only a generalized Level I (8 class) classification scheme was employed. A combination of unsupervised clustering, GIS rules-based and on-screen digitizing approaches were used to classify the corrected Landsat MSS 1972/73 image data set using the ERDAS image processing software. The ITU-NWI-FWW composite wetland file was used to stratify the Landsat MSS imagery into wetlands vs. uplands (i.e., any pixel that was classified as a wetlands in the NWI or FWW maps was masked out as wetland). The wetlands and uplands imagery were separately processed using unsupervised clustering (50 clusters each, .95 convergence). Spectral classes were assigned to 1 or a mixture of 1 or 2 land cover information classes by overlaying the spectral class map on-top of the original imagery and visual interpretation on-screen. The land cover percentages (e.g., Developed with approximately > 50% developed surface) are estimates made by ocular estimation of the aerial photography and Landsat imagery, no systematic ground checking was used to support these estimates.

In the initial identification of spectral classes, some clusters could not be solely assigned to one particular land cover category. To assign spectral clusters to their appropriate land cover category with sufficient classification accuracy, a GIS rules-based approach was undertaken as above for the Landsat TM classification. The USGS LU/LC data set (1:250,000 scale derived from high altitude aerial photography nearly coincident in time to the Landsat MSS) (minimum mapping unit area = 10 acres), along with user-digitized (primarily on-screen) masks were used to develop a series of classification rules in the IMAGINE Spatial Modeler. These wetland and USGS LU/LC digital data sets, originally in vector format, were rasterized to an 80 m grid cell to match the Landsat MSS data.

5. ACCURACY ASSESSMENT

A "ground-truthing" field campaign to verify the accuracy of the 1994/1995 CCAP land Cover Map was used to assess the accuracy of the ENSP Delaware Bay/Cape May Habitat Map. The ground truthing was undertaken at two time periods: 1) pre-classification - during the fall of 1994 and winter/spring months of 1995; and 2) post-classification - during June 1997 and May 2000.

5.1 Pre-classification field checking

During the first field campaign 314 field sites were visited to serve as accuracy assessment (240 points in the South Jersey study area and 73 points in the North Jersey study area). These sites were visited by Rutgers University Center for Remote Sensing & Spatial Analysis personnel; one person was primarily responsible for this effort to ensure consistency. These field sites were chosen using a stratified random sampling technique. The initial stratification was developed using the 1986 ITU data. A differential Global Positioning System (GPS) receiver was used to georeference the training site locations. Field notes and slides were taken for each field reference point. High altitude color infrared aerial photography (acquired March 1991 and March 1995) was used to quality check the ground reference data in the accuracy assessment. In some cases, the original GPS-derived location was moved slightly to a new location more closely correspond with the field note description and ground photo.

5.2 Post-classification field checking

Two additional field campaigns were undertaken subsequent to the classification process. The southern New Jersey study area was assessed during June 9-12, 1997 and the northern New Jersey study area during May 15-17, 2000. A validation team from the NOAA Coastal Services Center participated in each data verification exercise. The team was equipped with 2 portable color laptop computers linked to real-time differentially corrected Global Positioning System (GPS) receivers. The field station runs software that supports the classified data as a raster background with the road network as a vector overlay with a simultaneous display of live GPS coordinates. Accuracy assessment points were generated by NOAA Coastal Services Center personnel with ERDAS IMAGINE software using a stratified random sample. To reduce problems in locating the field reference sites due to GPS positional inaccuracy or on-the-ground observer classification indecision due to spatial heterogeneity, an additional criteria was that field reference sites were located in areas that were homogeneous within a 3x3 pixel neighborhood. To make acquisition of the field reference data more practical, a sixteen pixel buffer area around roads (i.e., 8 pixels on each side of the road) was created. Several thousand random points were generated. 606 points were field checked in the south Jersey study area. 491 points were field checked in the North Jersey study area. Due to the absence of concurrent field reference data, no attempt was made to independently assess the accuracy of the 1972 or 1984 time period image maps.

5.3 Overall Accuracy Assessment

The pre- and post-classification field checked reference data were pooled to give 847 points for the southern New Jersey study area and 564 points for the northern New Jersey study area, for a total of 1411 points. Only the accuracy of the Level II and I land cover maps can be assessed. No separate validation was conducted of the Level III land cover map due to the often small areas for some of the land cover classes which it made it difficult to adequately sample these classes. An error matrix was determined and the Producer's (a measure of omission error), User's Accuracy (a measure of commission error) and the Kappa coefficient of agreement were calculated for each class and for the overall map. The Kappa coefficient measures the agreement between the classified and reference data corrected for chance agreement (Congalton and Green, 1999). A value greater than 0.80 represents strong agreement and a value between 0.40 and 0.80 represents moderate agreement. A minimum sample size of thirty points per class is generally recommended for a valid accuracy assessment for that particular class. Some of the rarer classes (i.e., those classes of land cover that represent a relatively small proportion of the state's area) fell below this recommended minimum sample size.

See the accuracy assessment tables below for results of the data verification exercise. The overall accuracies for the Level I and Level II maps were quite high with the Level II maps greater than 85% correct and the Level I map greater than 90% correct. The accuracy of the New Jersey Level I classification was 93.0% (Kappa coefficient = 0.9129) (Table 2). The New Jersey Level II map had a classification accuracy of 85.2% (Kappa coefficient = 0.8348) (Table 3). However, not all categories met this level of accuracy. The classification of grasslands, such as pastures, showed accuracies in the 55% to 80% range with frequent mis-classification as cultivated land. The upland scrub/shrub (e.g., abandoned agricultural fields in mid-to-late stages of vegetation succession, power lines, open ridges and pine barrens) and wetland scrub/shrub categories were poorly sampled making a proper accuracy assessment difficult. Anecdotal evidence suggests that this upland scrub/shrub category is problematic and regularly mis-classified with cultivated land, grassland and forest land. A similar situation occurs with the wetland scrub/shrub category being frequently mis-classified with emergent and forested wetland. The unconsolidated shore (i.e., sand beaches, lakeshores and tidal mudflats) was also under-sampled due to its relative infrequent occurrence. This category also had a lower classification accuracy due to confusion with associated categories of water and emergent wetland.

6. AREA ESTIMATION AND CHANGE MAPPING

The area in acres and hectares were calculated for each land cover category in the Level I and II land cover maps. It must be remembered that due to inaccuracies in the classification, these land cover area figures represent an estimate. Confidence limits around these area estimates are difficult to obtain and beyond the scope of this study. Table 4 contains the areas estimates for the Level I land cover maps for the 1972, 1984 and 1995 time periods. Table 5 Contains the area estimates for the Level II land cover maps for the 1984 and 1995 time periods. The area estimates have been rounded to the nearest ten's place. Appendix B includes area estimates for each of New Jersey's 21 counties. Appendix C includes area estimates for each of NJDEP's 21 watershed management areas.

Comparison of the 1972, 1984 and 1995 land cover maps show the types of landscape change that occurred during the period of analysis. As the 1984 and 1995 land cover sets were created from the same satellite sensor and comparable auxiliary data sets, they provide a good estimate of land cover change during this time period. Due to the cruder technology of the Landsat Multispectral Scanner, the 1972 land cover map provides a coarser view of land cover during this earlier time period and the area estimates are not directly comparable to the later 1984 and 1995 series maps. Our qualitative accuracy assessment for the 1972 land cover map suggests that due to the larger minimum mapping unit (coarser scale) of the developed land cover mask (derived from 1:250,000 scale USGS LU/LC data) developed area is underestimated. Housing or commercial/industrial developments and other developed land covers smaller than approximately 10 acres (4 ha) are not consistently mapped in the 1972 time period. The minimum mapping unit for the 1984 and 1995 developed land cover mask (derived from NJDEP ITU and CRSSA photo-interpreted data) is approximately 2.5 acres. Comparison of the Developed land cover area estimates across the three time periods shows an increase of 316,400 acres between 1972 and 1984 (Tables 4a, 4b) and an increase of 222,390 acres between 1984 and 1995 (Tables 4b, 4c). A substantial (but un-quantified) portion of the Developed area increase between 1972 and 1984 is an artifact due to a change in the methods. Dispersed suburban/exurban development that may have existed in 1972 was not mapped and shows up for the first time in the 1984 land cover map.

Though every effort was taken to ensure consistency between the 1984 and 1995 land cover mapping, there are some changes in land cover area that may be due more to an artifact of the classification methodology than a real on-the-ground change. Two cases are especially suspect. The first case is the apparent increase in evergreen-dominated upland forest in 1995 as compared to the 1984 time period (85,350 vs. 59,290 acres, respectively). This corresponds to a decrease in the amount of mixed evergreen-deciduous upland forest during the same time period (598,025 acres in 1984 and 515,795 acres in 1995). Due to the difficulty in consistently differentiating evergreen-dominated vs. mixed deciduous-evergreen upland forest (see Tables3a, 3b), some of this change is probably due to slight differences in the image data and/or methods that affected the classification. A similar situation occurs explanation can be given for the variation in the amounts of palustrine emergent, forested and scrub/shrub wetland. The increase in area of palustrine emergent and scrub/shrub wetland in 1995 is somewhat balanced by the decrease in palustrine forested wetland.

Table 2A. New Jersey Level I Accuracy Assessment: Contingency Matrix

Reference Data

Class. Data	1.10	1.20	1.40	1.60	2.00	2.10	2.40	2.50	Row Total
1.10	308	23	12	1	0	1	3	0	348
1.20	2	279	9	2	0	0	2	1	295
1.40	0	1	372	0	1	1	4	0	379
1.60	0	1	0	26	0	0	0	0	27
2.00	0	0	1	0	10	0	2	5	18
2.10	1	0	2	0	2	93	1	0	99
2.40	3	1	12	0	0	1	176	1	194
2.50	1	0	0	0	0	1	1	48	51
Col Total	315	305	408	29	13	972	189	55	1411

Table 2B. New Jersey Level I Accuracy Assessment: Accuracy Measures

Code	Land Cover Description	Number Correct	Producer's Accuracy	User's Accuracy	Kappa
1.10	Developed	308	97.8	88.5	08520
1.20	Cultivated/Grassland	279	91.5	94.6	0.9308
1.40	Forest/Scrub/Shrub	372	91.2	98.2	0.9740
1.60	Barren	26	89.7	96.3	0.9622
2.00	Unconsolidated Shore	10	76.9	55.6	**
2.10	Estuarine Emergent Wetland	93	95.9	93.9	0.9349
2.40	Palustrine Wetland: Emergent/Forested	176	93.1	90.7	0.8929
2.50	Water	48	87.3	94.1	0.9388
	Totals	1312			0.9127

** Sample Size for this Land Cover Class Too Small (< 25) for valid Kappa measure

Overall Classification Accuracy = 93.0%

Table 3A. New Jersey Level II Accuracy Assessment: Contingency Matrix

Reference Data

Class Data	1.11	1.12	1.20	1.30	1.41	1.42	1.43	1.50	1.60	2.00	2.10	2.30	2.40	2.45	2.50	Row Total
1.11	108	4	0	2	0	0	0	0	1	0	1	0	0	0	0	116
1.12	8	188	4	17	9	0	6	0	0	0	0	0	3	0	0	235
1.20	0	1	191	26	1	1	1	2	0	0	0	0	1	0	1	225
1.30	0	1	4	58	1	0	2	3	2	0	0	1	0	0	0	72
1.41	0	0	0	1	161	0	7	5	0	0	0	1	2	0	0	177
1.42	0	0	0	0	0	45	3	0	0	0	0	0	0	0	0	48
1.43	0	0	0	0	19	11	114	2	0	0	0	0	0	0	0	146
1.50	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	3
1.60	0	0	0	1	0	0	0	0	26	0	0	0	0	0	0	27
2.00	0	0	0	0	0	0	0	1	0	10	0	1	0	1	5	18
2.10	0	1	0	0	0	0	0	2	0	2	93	1	0	0	0	99
2.30	0	0	0	0	0	0	0	0	0	0	0	25	3	5	1	34
2.40	0	3	1	0	1	5	5	1	0	0	1	1	127	4	0	149
2.45	0	0	0	0	0	0	0	0	0	0	0	0	3	8	0	11
2.50	0	1	0	0	0	0	0	0	0	0	1	1	0	0	48	51
Col Total	116	199	200	105	192	62	138	16	29	13	97	31	139	19	55	1411

Table 3B. New Jersey Level II Accuracy Assessment: Accuracy Measures

Code	Land Cover Description	Number Correct	Producer's Accuracy	User's Accuracy	Kappa
1.11	Highly Developed	108	93.1	93.1	0.9249
1.12	Moderately to Lightly Developed	188	94.5	80.0	0.7672
1.20	Cultivated	191	95.5	84.9	0.8239
1.30	Grassland	58	55.2	80.6	0.7899
1.41	Deciduous Forest	161	83.8	91.0	0.8954
1.42	Coniferous Forest	45	72.6	93.8	0.9346
1.43	Mixed D/C Forest	114	82.6	78.1	0.7571
1.50	Scrub/shrub	0	0.0	0.0	**
1.60	Barren	26	89.7	96.3	0.9622
2.00	Unconsolidated Shore	10	76.9	55.6	**
2.10	Estuarine Emergent Wetland	93	95.9	93.9	0.9349
2.30	Palustrine Emergent Wetland	25	80.6	73.5	0.7293
2.40	Palustrine Forested Wetland	127	91.4	85.2	0.8362
2.45	Palustrine Scrub/shrub Wetland	8	42.1	72.7	**
2.50	Water	48	87.3	94.1	0.9388
	Totals	1202			.8348

** Sample Size for this Land Cover Class Too Small (< 25) for valid Kappa measure

Overall Classification Accuracy = 85.2%

Table 4. Area Estimates For Level I 1972, 1984 and 1995 Statewide Land Cover Maps

Table 4a. 1972 Level I Land Cover

Code	Land Cover Description	Acres *	Hectares*
1.10	Developed	888,520	359,570
1.20	Cultivated/Grassland	999,340	404,420
1.40	Forest/Scrub/Shrub	1,673,110	677,090
1.60	Barren	29,840	12,080
2.00	Unconsolidated Shore	12,310	4,980
2.10	Estuarine Emergent Wetland	220,720	89,320
2.40	Palustrine Wetland: Emergent/Forested	925,300	374,460
2.50	Water	517,700	209,510
	Totals	5,266,840	2,131,43

* area amount rounded to nearest ten's place

Table 4b. 1984 Level I Land Cover

Code	Land Cover Description	Acres*	Hectares*
1.10	Developed	1,204,920	487,620
1.20	Cultivated/Grassland	1,006,980	407,510
1.40	Forest/Scrub/Shrub	1,465,680	593,140
1.60	Barren	38,450	15,560
2.00	Unconsolidated Shore	47,160	19,080
2.10	Estuarine Emergent Wetland	208,280	84,290
2.40	Palustrine Wetland: Emergent/Forested	788,870	319,250
2.50	Water	516,570	209,050
	Totals	5,276,910	2,135,490

* area amount rounded to nearest ten's place

Table 4c. 1995 Level I Land Cover

Code	Land Cover Description	Acres*	Hectares*
1.10	Developed	1,427,310	577,610
1.20	Cultivated/Grassland	883,590	357,580
1.40	Forest/Scrub/Shrub	1,421,060	575,080
1.60	Barren	45,530	18,420
2.00	Unconsolidated Shore	45,880	18,570
2.10	Estuarine Emergent Wetland	201,570	81,570
2.40	Palustrine Wetland: Emergent/Forested	737,010	298,260
2.50	Water	514,960	208,400
	Totals	5,276,910	2,135,490

* area amount rounded to nearest ten’s place

Table 5. Area estimates for Level II Land Cover Maps

Table 5a. Level II 1984 Land Cover Map

Code	Land Cover Description	Acres*	Hectares*
1.11	Developed: High Intensity	239,115	96,765
1.12	Developed: Low to Moderate Intensity	965,800	390,850
1.20	Cultivated Land	779,820	315,580
1.30	Grassland	227,165	91,930
1.41	Upland Forest: Deciduous Dominant	773,655	313,090
1.42	Upland Forest: Evergreen Dominant	59,290	23,995
1.43	Upland Forest: Mixed Deciduous/evergreen	598,025	242,015
1.50	Upland Scrub/shrub	34,705	14,045
1.60	Bare Land	38,445	15,560
2.00	Unconsolidated Shore	47,160	19,085
2.10	Estuarine Emergent Wetland	208,280	84,285
2.30	Palustrine Emergent Wetland	79,875	32,325
2.40	Palustrine Forested Wetland	691,260	279,745
2.45	Palustrine Scrub/shrub Wetland	17,740	7,180
2.50	Water	516,570	209,050
	Totals	5,276,900	2,135,495

* area amount rounded to nearest five's place

Table 5b. Level II 1995 Land Cover Map

Code	Land Cover Description	Acres*	Hectares*
1.11	Developed: High Intensity	275,500	111,490
1.12	Developed: Low to Moderate Intensity	1,151,805	466,120
1.20	Cultivated Land	705,105	285,345
1.30	Grassland	178,490	72,230
1.41	Upland Forest: Deciduous Dominant	785,980	318,075
1.42	Upland Forest: Evergreen Dominant	85,350	34,540
1.43	Upland Forest: Mixed Deciduous/evergreen	515,795	208,735
1.50	Upland Scrub/shrub	33,925	13,730
1.60	Bare Land	45,530	18,425
2.00	Unconsolidated Shore	45,880	18,565
2.10	Estuarine Emergent Wetland	201,570	81,570
2.30	Palustrine Emergent Wetland	97,045	39,275
2.40	Palustrine Forested Wetland	604,645	244,695
2.45	Palustrine Scrub/shrub Wetland	35,320	14,295
2.50	Water	514,955	208,395
	Totals	5,276,900	2,135,495

* area amount rounded to nearest five's place

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