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Impervious Surface Mapping in Coastal New Hampshire (2005)

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A Final Report to

The New Hampshire Estuaries Project

Submitted by

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Executive Summary

Estimates of impervious surface acreage in 2005 were generated and compared to prior estimates for 1990 and 2000 for a 48-town region in coastal New Hampshire, including the 42 towns within Zones A and B of the New Hampshire Estuaries Project (NHEP) area. The estimates were based on applying both traditional and subpixel image classification techniques to 30-meter Landsat 5 Thematic Mapper (TM) satellite data, acquired 3 October 2005. The classifications indicated that impervious surface acreage increased from 4.3% (31,233 acres) in 1990, to 6.3% (45,445 acres) in 2000, to 7.4% (53,408 acres) in 2005. At the subwatershed level, the Portsmouth Harbor subwatershed recorded the highest percentage of impervious surface acreage in 1990 with 19.8% coverage (2,310 acres) and in 2000 with 25.5% coverage (2,975 acres), and this finding continued in 2005 with 28.9% (3,364 acres) of the watershed mapped as impervious.

An accuracy assessment was applied to the regional data, and indicated an accuracy of 98.3% for the 2005 data, which compared favorably with the assessment of the 1990 effort (98.6% correct) as well as the 2000 data (93.1% correct). These figures reflect the overall presence/absence of impervious surfaces within the randomly selected pixels. The accuracy was further evaluated against April, 2003 Emerge 1-ft. resolution aerial photography to estimate the validity of the predicted range of imperviousness for a second set of randomly selected pixels. This assessment proved disappointing, as only 7% of the pixels sampled predicted the correct impervious percentage range.

The data set representing impervious surface acreage in 2005 has been archived in the GRANIT GIS clearinghouse, thereby making it available to the coastal resource community as well as the general public. The data are appropriate for watershed and subwatershed level characterizations. Users are discouraged from accessing these data to support larger scale mapping and applications.

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Introduction

Future population growth and the corresponding increase in development in the coastal zone of New Hampshire are widely recognized as major threats to the integrity of coastal systems and their watersheds. The potential impacts associated with the expansion of developed land, and specifically with increasing amounts of impervious surfaces – rooftops, sidewalks, roads, and parking lots - may include significant changes in water quantity, degradation in water quality, and habitat loss. Because asphalt, concrete, stone, and other impenetrable materials effectively seal the ground surface, water is repelled and is prevented from infiltrating soils. Instead, stormwater runoff flows directly into our surface waters, depositing metals, excess nutrients, organics, and other pollutants into the receiving bodies. In addition to these environmental impacts, increasing levels of imperviousness can dramatically alter our landscapes, as forested and other natural settings are converted to urban/suburban uses.

Many of the impacts associated with impervious surfaces had been well documented by studies in other areas of the country. However, comprehensive studies in coastal New Hampshire had not been undertaken until our exploratory work in 2002 (see Justice and Rubin, 2002), which documented impervious surface acreage over the decade from 1990 to 2000. The primary goals of the current project were to map the spatial extent of impervious surface coverage in this region as of 2005, as well as to provide an estimate of change in the amount of "imperviousness" over the preceding fifteen-year period.

Geospatial technologies provide effective tools to map and quantify impervious surfaces, and to monitor changes over time. Moderate resolution Landsat Thematic Mapper (TM) satellite imagery, coupled with image processing software and GIS tools, can be utilized to estimate amounts of imperviousness at relatively modest cost, thereby providing a mechanism for measuring "imperviousness" at frequent, repeated intervals. Resource managers and other professionals may effectively utilize the resulting data as they develop watershed management plans and tools.

Prior pilot mapping efforts in coastal New Hampshire explored alternative strategies and methodologies for estimating impervious surfaces. Typically they reported that traditional satellite image classification methods, while successful in mapping impervious surfaces, were constrained by the resolution of the source imagery. This occurred because an entire cell or pixel in the imagery was coded as being impervious or not. With the 30-meter resolution of TM imagery, results tended to considerably under- or overestimate the actual degree of imperviousness in a target area. However, a 2001 pilot project (Rubin and Justice, 2001) demonstrated that subpixel processing methodologies applied to TM data generated satisfactory acreage calculations for impervious surface coverage within coastal New Hampshire. Within the limited extent of the study, the results indicated that the estimate of impervious surface coverage generated by the subpixel approach (10.0%) closely approximated those generated by on-screen digitizing of high-resolution aerial photographs (7.4%). Accordingly, it was recommended that subpixel processing of TM imagery be utilized as a low-cost, repeatable approach to recording changes in impervious surface coverage in coastal New Hampshire.

Project Goals and Objectives

The primary objective of this study was to utilize Landsat Thematic Mapper (TM) imagery to map impervious surfaces within a 48-town area of coastal New Hampshire, including the 42 towns within Zones A and B of the New Hampshire Estuaries Project (NHEP) area. Impervious surfaces were defined as surfaces through which water cannot penetrate, and included roadways, parking lots, rooftops, paved driveways, and any other paved surfaces identified. The goal was to develop impervious surface data based on 2005 Landsat TM imagery in order to quantify the current extent of coverage and to provide indications of rates of change. The specific objectives of the study were to:

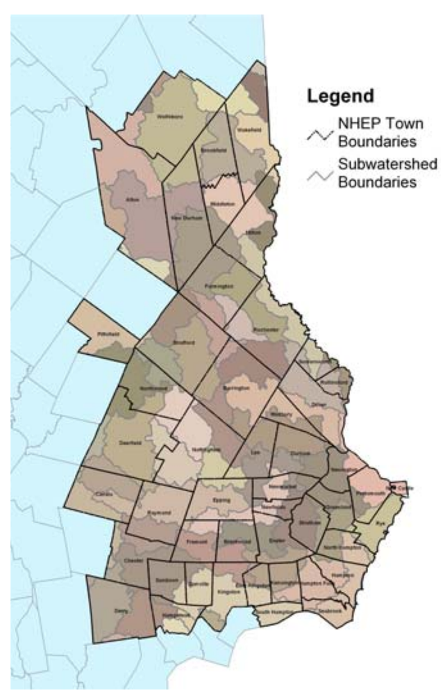
- Utilize subpixel processing techniques as applied to TM imagery to develop impervious surface estimates for 2005
- Calculate the change in impervious surface acreage over the fifteen-year period (1990 – 2005)
- Report the results by subwatershed and by town
- Convert the data to a GRID format, with corresponding attribute tables reporting the degree of imperviousness for each cell (in ranges of 10%)
- Develop appropriate Federal Geographic Data Committee-compliant metadata
- Post the spatial data and metadata on the GRANIT GIS clearinghouse
- Provide the project results to the Rockingham Planning Commission and the Strafford Regional Planning Commission, for further dissemination to their respective communities

Finally, the larger objective of the study was to provide a data resource for land use boards, conservation commissions, and other local decision-makers to use in assessing potential environmental impacts caused by increasing levels of impervious surfaces in coastal New Hampshire.

Methods

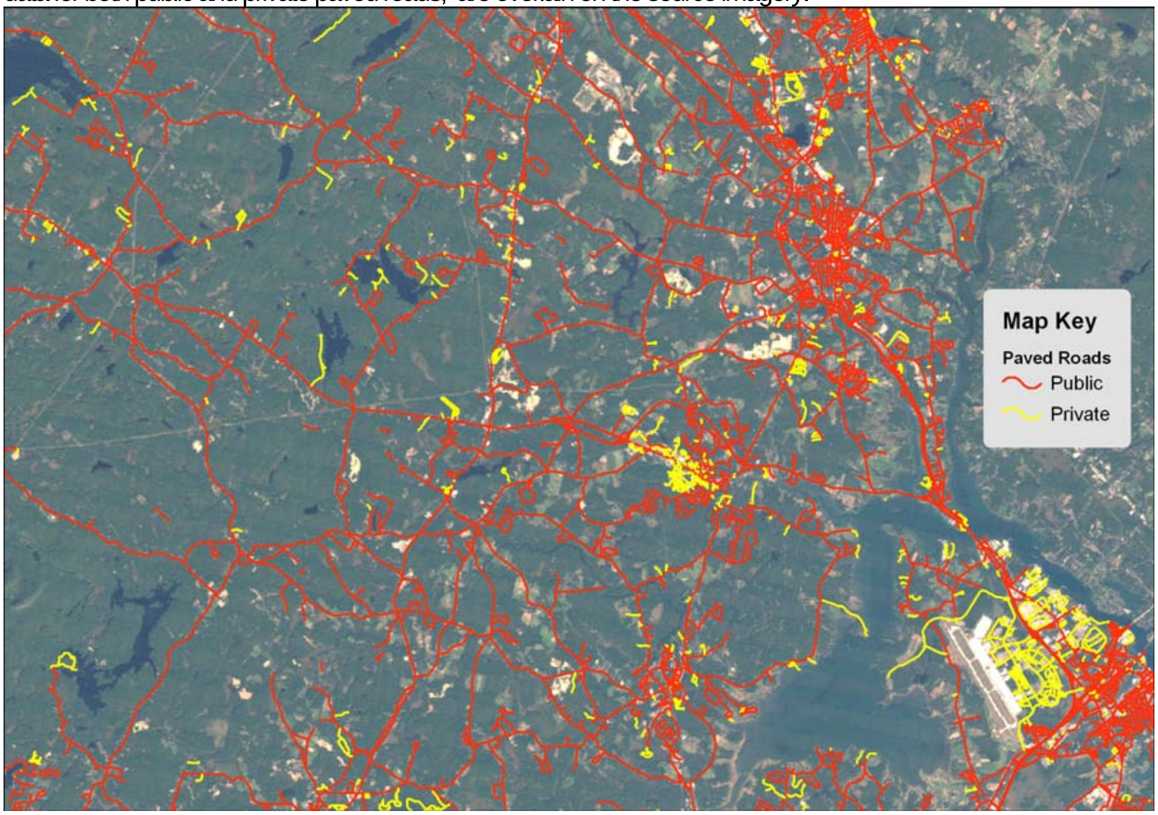
The regional mapping phase utilized 30-meter resolution TM imagery to generate a current estimate of impervious surface acreage for the 759,313 acres within the 48-town study area (see Figure 1). A Landsat 5 TM image, acquired October 03, 2005 was purchased as the primary data source for the image processing.

Figure 1. Subwatersheds within Project Study Area



The subpixel technique used in this mapping effort is non-traditional in nature. Best results are achieved by working with data sets having minimal resampling, and processed using the nearest neighbor technique. Accordingly, the image was purchased as Level 1G, indicating minimal processing. This required that we develop a geographic transformation model, which was then applied to the source data set (for unsupervised classification and reference purposes) and to the results of the subpixel classification(s). Figure 2 illustrates the base 2005 TM data after being terrain corrected and georeferenced to New Hampshire State Plane feet, NAD1983.

Figure 2. Georeferenced Subset of Landsat 5 Thematic Mapper Image (bands 3, 2, 1 – acquired 10/03/05) for an area around Great Bay. Red and yellow vectors, representing NH Department of Transportation road centerline data for both public and private paved roads, are overlain on the source imagery.



a. Traditional Classification

The impervious surface mapping began by conducting a traditional unsupervised classification on the georeferenced 2005 data set to generate an initial delineation of the developed/undeveloped land features. Past mapping efforts indicated that the subpixel technique may omit certain types of impervious features, due in part to the variety of specific surface types that constitute impervious surfaces. The generalized mapping was conducted to anticipate some of these “gaps”. It also provided a reference data set to supplement the visual interpretation of the subsequent subpixel classifications.

In contrast to our previous impervious surface mapping effort which began with a supervised classification, in this project our initial step was to conduct an unsupervised classification of the input data. We found that this approach provided a satisfactory starting point and alleviated some of the tweaking (adding and deleting of training sites) procedures that are often necessary with supervised classifications. The unsupervised classification produced 50 clusters which were visually inspected and coded into one of two categories – impervious and non-impervious. This dataset was then recoded into a final, two class image comprising these categories.

Some obvious misclassifications were identified in the preliminary results. Tidal flats and wetlands, shallow water, and scrub-shrub wetlands most often contributed to the problematic situations. These "problem pixels" were addressed by using on-screen editing to delete misclassified pixels. After satisfactory results were obtained, the data were available for subsequent use.

b. Subpixel Processing

The ERDAS Imagine Subpixel analysis tool was then applied to derive estimates of "percentage of imperviousness" for each impervious cell in the study area. This methodology (more fully described at www.discover-aai.com and www.erdas.com) is capable of detecting materials of interest (MOI) - in this case, impervious surfaces - that occur within each pixel. The classification describes each pixel as having a percentage of the MOI ranging from 20 to 100, reported in increments of 10% (see Table 1). Additional processing using road centerline data, described further below, resulted in the inclusion of the lower, 0-19% range.

Table 1. Percent Ranges for Impervious Surface Estimates

Percent ranges
0 - 19%
20 - 29%
30 - 39%
40 - 49%
50 - 59%
60 - 69%
70 - 79%
80 - 89%
90 - 99%
100%

Note that the spatial extent of the impervious surface (the MOI) within each pixel is not identified. Rather, the entire pixel is reported as having a certain percentage of the MOI. By factoring the area of each pixel by the percent of that pixel containing the MOI, acreage summaries may be generated.

The subpixel processing approach followed generally accepted techniques (Flanagan, 2000; Flanagan and Civco, 2001; ERDAS, 2000). A unique aspect of the subpixel software is that signatures are transferable from one image to another. In this case, signatures derived from the 2000 ETM+ image were used to classify impervious surfaces in the 2005 TM image. In excess of twenty signatures from this earlier work were evaluated by using each to classify the

2005 TM image. The result of each classification was visually evaluated against the base TM image, National Agricultural Imagery Program (NAIP) 2003 photography, and by reference to personal knowledge of the area. However, it is important to recognize that the evaluation of each classification compared the presence/absence of impervious surface MOI and not the actual percentage mapped per image pixel.

Upon inspection, signatures were marked as “good”, having “potential”, or “unusable”. Good signatures were those that provided tight classifications and would require little if any on-screen editing. Signatures having “potential” were those that mapped much of an area correctly, but would need some data clean up. Potential signatures were also those that could be altered using classification tolerances, (a standard feature of the subpixel classification routine), such that more or fewer image pixels would be included in the classification set. Signatures were considered “unusable” when too many pixels were included in the classification and an unreasonable amount of on-screen editing would be required to produce an acceptable data set. As a result, four classifications derived from the 2000 TM signatures were accepted as input layers to contribute to the final impervious surface layer.

The 2005 TM data set was then used to generate in excess of fifty additional signatures. As described above, each prospective signature was used to classify the TM scene and the subsequent data set was inspected to determine its validity and potential for contribution to the final impervious surface layer. As a result of this classification/evaluation process, thirteen of the original fifty data sets were selected for incorporation in the final data.

Unlike traditional supervised classifications, the subpixel approach typically produces classifications based on a single signature. Accordingly, the seventeen data sets - four from the 2000 data and thirteen from the 2005 data - were merged into one. This was achieved by “layer stacking” the images and then using Imagine statistical functions to select the maximum layer value (e.g. maximum percentage of imperviousness) at each pixel. These results were then merged with the results of the initial unsupervised classification. Where there was overlap, the subpixel impervious pixels (with the percent imperviousness) took precedence over the pixels mapped as impervious from the unsupervised processing. Pixels mapped as impervious from the unsupervised classification but not captured by the subpixel processing were coded as 100% impervious.

c. Post Processing

The post processing phase of the project was designed to enhance the classification phase by addressing two specific issues – the correction of any remaining, obvious errors in the classification results, and the incorporation (or “burning in”) of road centerline data to optimize the mapping of pavement as an impervious surface feature. Two ancillary data sets were accessed for this phase, both available from the GRANIT database:

- US Fish & Wildlife Service National Wetlands Inventory (NWI) data, based on aerial photography acquired in the mid-1980’s; and
- New Hampshire Department of Transportation (NHDOT) road centerline data – both public and private roads, as of November, 2005.

The provisional impervious surface classification included some recurring errors – typically misclassified pixels occurring in open water, wetland, forests, gravel excavations, and fields. The image analyst could often quickly identify these errors using pattern recognition, past experience and in some cases, NAIP reference images. Errors were removed from the classification by defining polygons around the misclassifications and recoding, as appropriate. Because many of the misclassified pixels occurred in wetlands, NWI data were converted to a grid format and used as a mask to rapidly isolate and review potential problem areas. However, pixels concurrent with the NWI grid were not simply converted to non-impervious status, since there were numerous cases where wetlands had been filled since the NWI photo date and were properly coded as impervious.

Finally, the methodology included the incorporation of paved roads from the NHDOT centerlines in the impervious data set, where the imperviousness of each pixel was assigned based on the road pavement width. (Because of their relatively narrow, linear shape, road features are occasionally omitted in the classification phase.) However, the pavement characteristic was only available for the public road data set. Thus, an editing task was required to identify the surface type (paved/unpaved) of private roads. Where un-coded road surface types could be satisfactorily identified from in-office sources (such as NAIP), each segment was coded. However, in the almost 1700 cases where these distinctions could not be determined, personnel drove to the road segment and determined its surface type in the field. In some instances, the entire length was driven and appropriately coded while in others, an assessment was determined based on the entry point to the road segment.

Once the editing was complete, the pavement width characteristic was used to "burn" the paved road data into the classified data set. For all private, paved roads, and for public paved roads where pavement width was unavailable from the DOT data, a default pavement width of 20 ft. was assigned.

d. Accuracy Assessment

A critical component of the project was the accuracy assessment, which was conducted by selecting a random set of locations and "driving by" those locations to determine the presence/absence of impervious surfaces. While this approach did not provide detailed information on the actual percentage of each pixel's "imperviousness", it provided a basic understanding of the accuracy of the classified data.

Two constraints were applied during the site selection process. First, a road proximity constraint was applied (within 5 pixels or approximately 467 feet of a NHDOT road) to facilitate the completion of the assessment. Second, each impervious surface feature was "shrunk" by 1 pixel width prior to the selection process to exclude confusion among edge pixels.

A set of 120 assessment sites was randomly selected from the project area – 60 sites in each of two categories:

- coded as not impervious

- coded as impervious

Due to access constraints, one site was discarded from the overall assessment. An analyst drove by the remaining 119 sites, and recorded its impervious status. Navigation to each site was facilitated by use of a laptop computer operating GPS equipped ArcMap software.

A second accuracy evaluation was conducted to compare the percentage range classified by the subpixel software to that of features digitized from high resolution aerial photography. The GRANIT database archives digital 1 foot resolution aerial photography (from Emerge, Inc., 2003) covering a small portion of the study area along US Route 1. Where available, we randomly selected 30 pixel-sized footprints (93.5 feet on a side) for each of the impervious range classes of 2-9. (We omitted classes 1 and 10 because these were not solely derived from the subpixel process.) For each of these areas, impervious surface features were screen digitized using the Emerge data as the source. Each digitized feature was compared to the classified value acquired via the subpixel processing. Since there was a 2 year gap between data sets, we omitted those pixels classified by the subpixel process as impervious but showing no impervious features in the Emerge data. We also included the sites that were identified as impervious from the field visits within the Emerge coverage area, to compare against the digitized, high resolution photography. Ultimately, we were able to compare 209 pixels in the second assessment.

e. Reporting and Metadata

The results of the impervious surface mapping were tabulated for 2005 – for the full study area, by subwatershed, and by town. For each unit of geography, acreage totals were calculated for three impervious levels: low, middle, and high. (These levels result from the detection of the MOIs in 10 percent ranges, typically beginning at the 20-29% range. However, the post-processing introduction of impervious surface percentages based on NHDOT pavement widths created impervious percentages smaller than the normal 20% minimum value.)

The final reporting step was the development of a Federal Geographic Data Committee (FGDC)-compliant metadata record for the 2005 impervious surface data set. This document details the data production and assessment aspects of the project, and is an essential reference for the community utilizing the data.

The data and the associated metadata have been posted to the GRANIT clearinghouse (www.granit.sr.unh.edu) for distribution to coastal resource managers and to the general public. In addition, the Strafford Regional and Rockingham Planning Commissions have been notified of the 2005 data availability.

Results and Discussion

The primary results of this project are 2005 impervious surface estimates for the 48 towns in coastal New Hampshire (Figure 3). Figure 4 provides a larger-scale illustration of mapped impervious surface features in both 2000 and 2005 for the Exeter, NH vicinity. This figure shows several clear examples of new housing subdivisions, roads, and businesses evident in the 2005 data.

Table 2 summarizes the 2005 results by subwatershed, reporting acreages at 3 levels for each unit. (As previously noted, the subpixel classification reports the results by percentage range. To convert the ranges to discrete acreage estimates, the low, mid and high points of each range were selected. All further discussion in this document utilizes the estimate derived from the mid point of the range.) Tables 3 and 4 present the corresponding figures for the years 2000 and 1990, and are included to facilitate comparisons over time. Table 2 reveals that 53,408 acres, or 7.4% of the land surface area in the 48 towns, were estimated to be impervious in 2005. This represents a 1.1% change in total percent impervious over the five-year period (2000 - 2005), or a 3.5% annual increase. Further, it suggests a decline in the rate of change, as the period from 1990 to 2000 exhibited a 4.5% annual increase in impervious surfaces. Over the entire preceding fifteen-year period (1990-2005), the results indicate a 3.1% change in total percent impervious, or a 4.7% annual increase,

Table 5 presents the 1990-2005 change in impervious surface estimates at the subwatershed level. Subwatershed estimates in 1990 ranged from 0.0% (Branch Brook and Massabesic Lake) to 19.8% (Portsmouth Harbor). Results from 2000 showed a similar pattern, with estimates again ranging from a low of 0.0% (Branch Brook and Massabesic Lake) to a high of 25.5% (Portsmouth Harbor). The corresponding 2005 estimates ranged from 0.1% (Branch Brook) to 28.9% (Portsmouth Harbor). This 5-year increase of 3.4% was the largest observed in that period. Other significant 5-year increases included Hampton River (2.8% change), Hampton Harbor (2.5% change), Lower Spickett River (2.2% change), and Taylor River-Squamscott River (2.0% change) watersheds. The average impervious surface percentage by watershed was 4.11% in 1990 and 5.97% in 2000. This number increased to 6.98% in 2005.

Table 6 presents the change in impervious surface estimates for the period 1990-2005 at the town level. Not surprisingly, the towns/cities with the highest percent impervious estimates in 2005 were the seacoast communities of New Castle (33.9%), Portsmouth (30.5%), and Seabrook (27.1%). Northern and western Strafford County towns displayed the lowest percent impervious estimates for 2005, including Brookfield (1.4%), Strafford (2.3%), and New Durham and Nottingham (both at 2.8%).

Associated with the satellite image based mapping is an error matrix, used to report the approximate accuracy of the results. Typically, a matrix presents classified data results (e.g. derived from image processing) relative to reference data (e.g. data acquired via field visits or from some other source of known reliability). While the assessment for this project utilized the standard technique, the methodology cannot fully characterize the reliability of our results because the impervious surface pixels were mapped on a percentage basis. The accuracy assessment only evaluated the presence/absence of imperviousness at a given site, not the percentage impervious.

With this caveat, the error matrix is presented in Table 7. The table shows that a satisfactory overall accuracy was achieved for 2005 (98.3% correct). This figure compares favorably with our previous effort, where the overall percentages of correct assessments were 98.6% (1990) and 93.1% (2000). Admittedly, by constraining our accuracy assessment selection technique, the site selections were probably biased in favor of those areas that are most easily mapped (e.g. large parking lots, buildings, and residential subdivisions rather than single houses and isolated features). Nevertheless, the assessment provides a general estimate of the data reliability.

The Emerge based accuracy assessment proved disappointing, however. As noted above, we compared 209 pixel footprints against screen digitized impervious surfaces derived from the Route 1 Emerge data. The resulting accuracy indicated that only 7 percent of the impervious class ranges predicted by the subpixel classification matched what was mapped from the Emerge data. One possible explanation is the potential for spatial misregistration between the TM data and Emerge photography. Typically, the TM data are within .5 pixel of the actual ground location. If we can assume that the Emerge data are located in their true spatial position, it is possible that as much as half of the TM pixel (.1 acre) may be offset from what was digitized via the Emerge methodology. A second factor may relate to the subpixel process classifying data based on very specific MOI's. Assume, for simplicity sake, we describe our MOI as a white roof. If there are buildings with multicolor roofs in a pixel, the software will detect only the white portion of these features. In contrast, the Emerge digitized approach captured the entirety of the impervious feature. This is simply a limitation of the software and needs to be accepted as such.

It is interesting to note our findings from our earlier project (Justice and Rubin, 2002), where the subpixel acreage estimates compared quite favorably with predictions from Ikonos data and planimetric data for the City of Portsmouth. Here, all three data sources resulted in estimates which were within 19 acres of one another. However, the previous effort did not attempt to assess error on an individual pixel basis. This supports our contention that the subpixel processing approach is a valid technique for regional assessments, but is not appropriate for large-scale mapping.

Figure 3. Regional mapping of impervious surfaces, 2005. Impervious surface features are shown in red, and are displayed on the 12-digit watershed units.

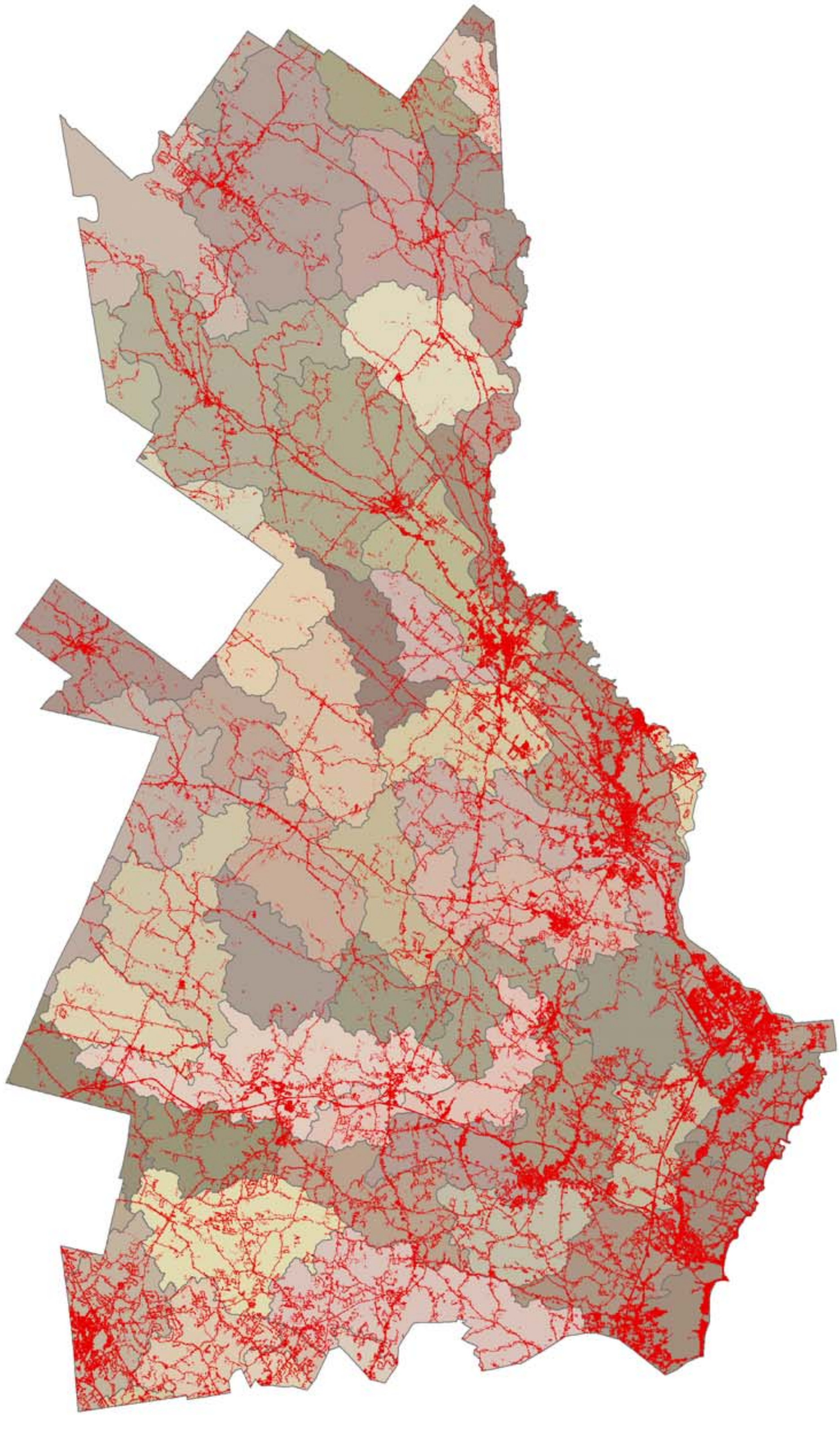


Figure 4. Regional mapping of impervious surfaces, 2000 and 2005, for the Exeter, NH vicinity

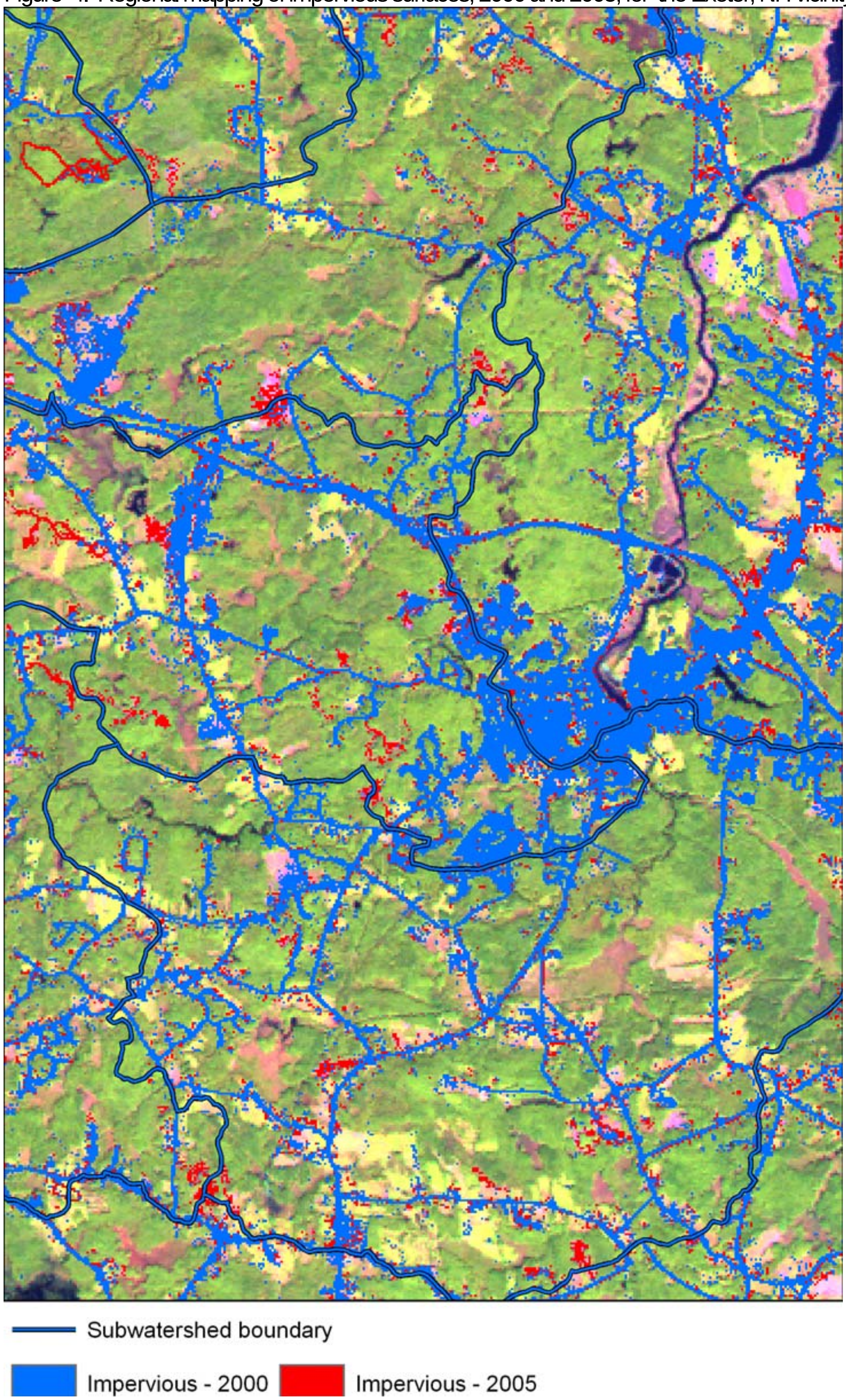


Table 2. Impervious Surface Acreage and Total Acreage by Subwatershed, 2005

	Impervious Acres - 2005						Total Acres			
12-Digit HUC Subwatershed Name	**Low Range**	**% Land Area**	**Mid Range**	**% Land Area**	**High Range**	**% Land Area**	**Mapped Area (1)**	**Surface Water**	**Land Area**	**Total Watershed**
Alton Bay	965	3.3	1,145	3.9	1,235	4.2	32,003	2,910	29,093	32,072
Arlington Mill Reservoir	838	8.0	976	9.3	1,050	10.0	11,244	747	10,497	14,352
Axe Handle Brook	319	4.5	364	5.1	390	5.5	7,397	310	7,087	7,397
Bean River	400	2.7	462	3.1	496	3.3	15,072	252	14,820	15,072
Beech River	29	2.2	32	2.5	34	2.6	1,437	145	1,291	12,042
Bellamy River	1,784	8.4	2,028	9.6	2,162	10.2	21,634	467	21,167	21,634
Berrys Brook-Rye Harbor	1,261	12.0	1,415	13.5	1,503	14.3	10,626	123	10,503	10,634
Big River	143	1.3	162	1.5	173	1.6	10,912	222	10,690	18,574
Bow Lake	178	2.3	217	2.7	234	3.0	9,125	1,240	7,885	9,125
Branch Brook	0	0.1	0	0.1	0	0.1	138	0	138	9,413
Cohas Brook	76	6.7	86	7.6	92	8.1	1,136	0	1,135	14,938
Crystal Lake	39	0.8	49	1.1	53	1.2	4,873	294	4,579	17,375
Great Bay	1,192	6.6	1,342	7.4	1,428	7.8	18,327	135	18,192	18,327
Great Brook-Exeter River	802	6.5	929	7.5	995	8.1	12,363	53	12,309	12,363
Hampton Harbor	2,261	16.0	2,519	17.8	2,666	18.9	14,286	172	14,114	19,670
Headwaters-Great East Lake	248	2.8	288	3.3	311	3.5	10,068	1,307	8,761	17,674
Headwaters-Lamprey River	627	2.9	727	3.3	778	3.6	21,927	200	21,727	21,927
Junes Brook-Branch River	428	2.5	497	2.9	533	3.1	17,240	166	17,074	17,240
Little River (Exeter)	463	4.7	531	5.4	569	5.8	9,889	34	9,855	9,889
Little River (Lamprey)	890	7.0	1,001	7.8	1,065	8.3	13,173	369	12,804	13,173
Little River (Merrimack)	415	12.1	460	13.5	489	14.3	3,449	33	3,416	18,005
Little Suncook River	481	3.6	558	4.1	599	4.4	15,237	1,696	13,541	25,368
Long Pond	213	2.2	249	2.5	269	2.7	10,153	324	9,829	10,153
Lower Cocheco River	2,274	14.1	2,535	15.8	2,689	16.7	16,184	100	16,084	16,184
Lower Isinglass River	1,194	8.4	1,339	9.4	1,426	10.0	14,609	337	14,271	14,609
Lower Lamprey River	718	5.5	831	6.3	893	6.8	13,226	86	13,141	13,226
Lower Salmon Falls River	377	12.3	436	14.3	467	15.3	3,059	5	3,054	13,837
Lower Spickett River	345	10.9	391	12.3	417	13.2	3,207	41	3,166	35,103
Lower Suncook River	35	1.1	44	1.4	48	1.5	3,166	7	3,159	40,189
Massabesic Lake	0	0.0	0	0.6	0	0.6	18	0	18	11,024
Middle Cocheco River	1,698	10.7	1,912	12.1	2,030	12.8	15,952	98	15,853	15,952
Middle Lamprey River	1,957	7.6	2,217	8.6	2,364	9.2	26,222	426	25,796	26,222
Middle Salmon Falls River	1,716	11.0	1,929	12.4	2,050	13.2	15,755	193	15,563	38,449
Milton Pond	282	4.0	327	4.7	350	5.0	7,325	323	7,002	14,840
Moultonborough Bay	6	0.5	8	0.6	9	0.7	1,255	0	1,255	29,777
Nippo Brook-Isinglass River	389	2.3	453	2.6	488	2.8	17,389	250	17,139	17,389
North Branch River	399	3.6	459	4.2	492	4.5	11,047	114	10,933	11,047
North River	277	3.2	321	3.7	344	4.0	8,622	66	8,555	8,622
Oyster River	1,447	7.3	1,664	8.4	1,784	9.0	19,875	161	19,714	19,875

Table 2 (cont.)

12-Digit HUC Subwatershed Name	Impervious Acres - 2005 Low Range	% Land Area	Mid Range	% Land Area	High Range	% Land Area	Total Acres Mapped Area [1]	Surface Water	Land Area	Total Watershed
Pawtuckaway Pond	171	1.4	194	1.6	208	1.7	13,052	913	12,140	13,052
Pine River	276	3.1	311	3.5	331	3.8	9,407	603	8,804	35,248
Piscassic River	957	6.6	1,091	7.6	1,165	8.1	14,510	96	14,414	14,510
Pittsfield Tributaries	552	4.3	633	4.9	677	5.3	13,105	280	12,825	34,222
Portsmouth Harbor	3,034	26.0	3,364	28.9	3,560	30.6	11,855	205	11,650	31,049
Powwow River	1,768	7.2	2,022	8.3	2,160	8.9	25,792	1,391	24,401	37,955
Shapleigh Pond	270	6.2	298	6.9	316	7.3	4,849	523	4,326	14,016
South River	25	3.8	31	4.6	33	5.0	1,049	380	669	20,063
Spruce Swamp-Little River	1,036	7.2	1,179	8.2	1,260	8.8	14,384	46	14,338	14,384
Squamscott River	1,455	11.0	1,645	12.4	1,751	13.2	13,294	25	13,269	13,294
Sucker Brook	365	4.2	414	4.8	444	5.2	8,741	157	8,585	18,812
Taylor River-Hampton River	1,911	13.3	2,145	14.9	2,279	15.8	14,607	195	14,412	14,607
The Broads	401	3.8	479	4.6	520	5.0	21,730	11,261	10,469	38,888
Towle Brook-Lily Pond	1,170	5.6	1,361	6.5	1,459	7.0	21,208	222	20,985	21,208
Upper Beaver Brook	1,863	13.0	2,137	14.9	2,284	15.9	14,644	290	14,354	34,758
Upper Branch River-Lovell Lake	520	3.0	617	3.5	665	3.8	18,383	840	17,543	18,383
Upper Cocheco River	1,011	3.7	1,175	4.3	1,261	4.6	27,657	516	27,141	27,657
Upper Suncook River	85	2.4	98	2.8	105	3.0	3,745	183	3,562	28,013
Watson Brook	569	5.4	642	6.1	687	6.5	10,575	91	10,484	10,575
Winnicut River	1,225	11.0	1,381	12.4	1,472	13.2	11,214	67	11,147	11,214
Wolfeboro Bay	1,090	3.5	1,290	4.1	1,392	4.5	36,897	5,768	31,128	36,965
Total	46,917	6.5	53,408	7.4	56,999	7.9	759,313	37,457	721,856	1,181,635

[1] Total mapped area may be less than total watershed area due to partial watersheds in the 48-town region.

Table 3. Impervious Surface Acreage and Total Acreage by Subwatershed, 2000

12-Digit HUC Subwatershed Name	Impervious Acres - 2000						Total Acres			
	Low Range	% Land Area	Mid Range	% Land Area	High Range	% Land Area	Mapped Area [1]	Surface Water	Land Area	Total Watershed
Alton Bay	740	2.5	929	3.2	1,020	3.5	32,003	2,910	29,093	32,072
Arlington Mill Reservoir	714	6.8	854	8.1	928	8.8	11,244	747	10,497	14,352
Axe Handle Brook	242	3.4	290	4.1	317	4.5	7,397	310	7,087	7,397
Bean River	301	2.0	374	2.5	409	2.8	15,072	252	14,820	15,072
Beech River	23	1.8	27	2.1	29	2.2	1,437	145	1,291	12,042
Bellamy River	1,459	6.9	1,708	8.1	1,841	8.7	21,634	467	21,167	21,634
Berrys Brook-Rye Harbor	1,081	10.3	1,237	11.8	1,326	12.6	10,626	123	10,503	10,634
Big River	120	1.1	141	1.3	152	1.4	10,912	222	10,690	18,574
Bow Lake	141	1.8	185	2.3	204	2.6	9,125	1,240	7,885	9,125
Branch Brook	0	0.0	0	0.0	0	0.0	138	0	138	9,413
Cohas Brook	66	5.8	77	6.7	83	7.3	1,136	0	1,135	14,938
Crystal Lake	35	0.8	48	1.0	54	1.2	4,873	294	4,579	17,375
Great Bay	1,026	5.6	1,186	6.5	1,276	7.0	18,327	135	18,192	18,327
Great Brook-Exeter River	655	5.3	783	6.4	847	6.9	12,363	53	12,309	12,363
Hampton Harbor	1,918	13.6	2,163	15.3	2,303	16.3	14,286	172	14,114	19,670
Headwaters-Great East Lake	195	2.2	247	2.8	272	3.1	10,068	1,307	8,761	17,674
Headwaters-Lamprey River	479	2.2	593	2.7	645	3.0	21,927	200	21,727	21,927
Junes Brook-Branch River	366	2.1	443	2.6	481	2.8	17,240	166	17,074	17,240
Little River (Exeter)	715	7.3	823	8.4	884	9.0	9,889	34	9,855	9,889
Little River (Lamprey)	366	2.9	446	3.5	486	3.8	13,173	369	12,804	13,173
Little River (Merrimack)	326	9.5	370	10.8	397	11.6	3,449	33	3,416	18,005
Little Suncook River	400	3.0	492	3.6	538	4.0	15,237	1,696	13,541	25,368
Long Pond	182	1.9	221	2.2	241	2.5	10,153	324	9,829	10,153
Lower Cocheco River	1,825	11.3	2,080	12.9	2,229	13.9	16,184	100	16,084	16,184
Lower Isinglass River	1,031	7.2	1,184	8.3	1,275	8.9	14,609	337	14,271	14,609
Lower Lamprey River	646	4.9	768	5.8	833	6.3	13,226	86	13,141	13,226
Lower Salmon Falls River	317	10.4	379	12.4	410	13.4	3,059	5	3,054	13,837
Lower Spickett River	275	8.7	320	10.1	346	10.9	3,207	41	3,166	35,103
Lower Suncook River	32	1.0	42	1.3	46	1.5	3,166	7	3,159	40,189
Massabesic Lake	0	0.0	0	0.0	0	0.0	18	0	18	11,024
Middle Cocheco River	1,457	9.2	1,685	10.6	1,807	11.4	15,952	98	15,853	15,952
Middle Lamprey River	1,619	6.3	1,880	7.3	2,024	7.8	26,222	426	25,796	26,222
Middle Salmon Falls River	1,316	8.5	1,536	9.9	1,653	10.6	15,755	193	15,563	38,449
Milton Pond	220	3.1	275	3.9	299	4.3	7,325	323	7,002	14,840
Moultonborough Bay	9	0.7	13	1.1	14	1.1	1,255	0	1,255	29,777
Nippo Brook-Isinglass River	307	1.8	374	2.2	409	2.4	17,389	250	17,139	17,389
North Branch River	330	3.0	393	3.6	425	3.9	11,047	114	10,933	11,047
North River	209	2.4	256	3.0	278	3.3	8,622	66	8,555	8,622
Oyster River	1,248	6.3	1,480	7.5	1,604	8.1	19,875	161	19,714	19,875

Table 3 (cont.)

12-Digit HUC Subwatershed Name	Impervious Acres - 2000: Low Range	% Land Area	Mid Range	% Land Area	High Range	% Land Area	Total Acres: Mapped Area [1]	Surface Water	Land Area	Total Watershed
Pawtuckaway Pond	139	1.1	171	1.4	187	1.5	13,052	913	12,140	13,052
Pine River	233	2.6	281	3.2	307	3.5	9,407	603	8,804	35,248
Piscassic River	753	5.2	885	6.1	955	6.6	14,510	96	14,414	14,510
Pittsfield Tributaries	410	3.2	493	3.8	537	4.2	13,105	280	12,825	34,222
Portsmouth Harbor	2,647	22.7	2,975	25.5	3,170	27.2	11,855	205	11,650	31,049
Powwow River	1,400	5.7	1,661	6.8	1,799	7.4	25,792	1,391	24,401	37,955
Shapleigh Pond	212	4.9	254	5.9	277	6.4	4,849	523	4,326	14,016
South River	23	3.4	30	4.5	34	5.1	1,049	380	669	20,063
Spruce Swamp-Little River	878	6.1	1,023	7.1	1,102	7.7	14,384	46	14,338	14,384
Squamscott River	1,195	9.0	1,380	10.4	1,481	11.2	13,294	25	13,269	13,294
Sucker Brook	298	3.5	344	4.0	373	4.3	8,741	157	8,585	18,812
Taylor River-Hampton River	1,523	10.6	1,745	12.1	1,870	13.0	14,607	195	14,412	14,607
The Broads	377	3.6	466	4.5	513	4.9	21,730	11,261	10,469	38,888
Towle Brook-Lily Pond	894	4.3	1,091	5.2	1,186	5.7	21,208	222	20,985	21,208
Upper Beaver Brook	1,553	10.8	1,831	12.8	1,977	13.8	14,644	290	14,354	34,758
Upper Branch River-Lovell Lake	435	2.5	555	3.2	608	3.5	18,383	840	17,543	18,383
Upper Cocheco River	796	2.9	970	3.6	1,058	3.9	27,657	516	27,141	27,657
Upper Suncook River	64	1.8	77	2.2	84	2.4	3,745	183	3,562	28,013
Watson Brook	460	4.4	532	5.1	574	5.5	10,575	91	10,484	10,575
Winnicut River	1,036	9.3	1,190	10.7	1,277	11.5	11,214	67	11,147	11,214
Wolfeboro Bay	969	3.1	1,192	3.8	1,302	4.2	36,897	5,768	31,128	36,965
Total	38,683	5.4	45,445	6.3	49,052	6.8	759,313	37,457	721,856	1,181,635

[1] Total mapped area may be less than total watershed area due to partial watersheds in the 48-town region.

Table 4. Impervious Surface Acreage and Total Acreage by Subwatershed, 1990

12-Digit HUC Subwatershed Name	Impervious Acres - 1990						Total Acres			
	Low Range	% Land Area	Mid Range	% Land Area	High Range	% Land Area	Mapped Area [(1)]	Surface Water	Land Area	Total Watershed
Alton Bay	551	1.9	698	2.4	768	2.6	32,003	2,910	29,093	32,072
Arlington Mill Reservoir	482	4.6	591	5.6	647	6.2	11,244	747	10,497	14,352
Axe Handle Brook	175	2.5	212	3.0	232	3.3	7,397	310	7,087	7,397
Bean River	201	1.4	256	1.7	282	1.9	15,072	252	14,820	15,072
Beech River	12	0.9	14	1.1	16	1.2	1,437	145	1,291	12,042
Bellamy River	959	4.5	1,148	5.4	1,248	5.9	21,634	467	21,167	21,634
Berrys Brook-Rye Harbor	724	6.9	843	8.0	910	8.7	10,626	123	10,503	10,634
Big River	70	0.7	85	0.8	92	0.9	10,912	222	10,690	18,574
Bow Lake	88	1.1	121	1.5	135	1.7	9,125	1,240	7,885	9,125
Branch Brook	0	0.0	0	0.0	0	0.0	138	0	138	9,413
Cohas Brook	45	4.0	53	4.7	58	5.1	1,136	0	1,135	14,938
Crystal Lake	23	0.5	33	0.7	37	0.8	4,873	294	4,579	17,375
Great Bay	692	3.8	810	4.5	876	4.8	18,327	135	18,192	18,327
Great Brook-Exeter River	402	3.3	497	4.0	543	4.4	12,363	53	12,309	12,363
Hampton Harbor	1,336	9.5	1,529	10.8	1,637	11.6	14,286	172	14,114	19,670
Headwaters-Great East Lake	129	1.5	168	1.9	187	2.1	10,068	1,307	8,761	17,674
Headwaters-Lamprey River	289	1.3	372	1.7	408	1.9	21,927	200	21,727	21,927
Junes Brook-Branch River	261	1.5	319	1.9	348	2.0	17,240	166	17,074	17,240
Little River (Exeter)	484	4.9	563	5.7	608	6.2	9,889	34	9,855	9,889
Little River (Lamprey)	229	1.8	289	2.3	318	2.5	13,173	369	12,804	13,173
Little River (Merrimack)	196	5.7	227	6.6	247	7.2	3,449	33	3,416	18,005
Little Suncook River	265	2.0	333	2.5	366	2.7	15,237	1,696	13,541	25,368
Long Pond	119	1.2	148	1.5	163	1.7	10,153	324	9,829	10,153
Lower Cocheco River	1,303	8.1	1,502	9.3	1,618	10.1	16,184	100	16,084	16,184
Lower Isinglass River	687	4.8	803	5.6	870	6.1	14,609	337	14,271	14,609
Lower Lamprey River	428	3.3	521	4.0	570	4.3	13,226	86	13,141	13,226
Lower Salmon Falls River	245	8.0	296	9.7	321	10.5	3,059	5	3,054	13,837
Lower Spickett River	177	5.6	211	6.7	231	7.3	3,207	41	3,166	35,103
Lower Suncook River	22	0.7	30	0.9	33	1.1	3,166	7	3,159	40,189
Massabesic Lake	0	0.0	0	0.0	0	0.0	18	0	18	11,024
Middle Cocheco River	1,083	6.8	1,267	8.0	1,365	8.6	15,952	98	15,853	15,952
Middle Lamprey River	1,036	4.0	1,232	4.8	1,340	5.2	26,222	426	25,796	26,222
Middle Salmon Falls River	922	5.9	1,094	7.0	1,184	7.6	15,755	193	15,563	38,449
Milton Pond	152	2.2	195	2.8	213	3.0	7,325	323	7,002	14,840
Moultonborough Bay	8	0.6	10	0.8	11	0.9	1,255	0	1,255	29,777
Nippo Brook-Isinglass River	215	1.3	266	1.6	293	1.7	17,389	250	17,139	17,389
North Branch River	208	1.9	255	2.3	278	2.5	11,047	114	10,933	11,047
North River	121	1.4	156	1.8	172	2.0	8,622	66	8,555	8,622
Oyster River	794	4.0	969	4.9	1,061	5.4	19,875	161	19,714	19,875

Table 4 (cont.)

12-Digit HUC Subwatershed Name	Impervious Acres - 1990						Total Acres			
	Low Range	% Land Area	Mid Range	% Land Area	High Range	% Land Area	Mapped Area [1]	Surface Water	Land Area	Total Watershed
Pawtuckaway Pond	88	0.7	112	0.9	123	1.0	13,052	913	12,140	13,052
Pine River	154	1.8	191	2.2	211	2.4	9,407	603	8,804	35,248
Piscassic River	421	2.9	514	3.6	561	3.9	14,510	96	14,414	14,510
Pittsfield Tributaries	318	2.5	383	3.0	417	3.2	13,105	280	12,825	34,222
Portsmouth Harbor	2,035	17.5	2,310	19.8	2,473	21.2	11,855	205	11,650	31,049
Powwow River	880	3.6	1,075	4.4	1,177	4.8	25,792	1,391	24,401	37,955
Shapleigh Pond	152	3.5	185	4.3	202	4.7	4,849	523	4,326	14,016
South River	15	2.3	21	3.2	24	3.6	1,049	380	669	20,063
Spruce Swamp-Little River	540	3.8	649	4.5	708	4.9	14,384	46	14,338	14,384
Squamscott River	778	5.9	915	6.9	989	7.5	13,294	25	13,269	13,294
Sucker Brook	200	2.3	234	2.7	256	3.0	8,741	157	8,585	18,812
Taylor River-Hampton River	992	6.9	1,157	8.0	1,248	8.7	14,607	195	14,412	14,607
The Broads	261	2.5	327	3.1	362	3.5	21,730	11,261	10,469	38,888
Towle Brook-Lily Pond	506	2.4	650	3.1	716	3.4	21,208	222	20,985	21,208
Upper Beaver Brook	1,090	7.6	1,309	9.1	1,424	9.9	14,644	290	14,354	34,758
Upper Branch River-Lovell Lake	311	1.8	403	2.3	443	2.5	18,383	840	17,543	18,383
Upper Cocheco River	566	2.1	700	2.6	767	2.8	27,657	516	27,141	27,657
Upper Suncook River	46	1.3	56	1.6	61	1.7	3,745	183	3,562	28,013
Watson Brook	280	2.7	331	3.2	360	3.4	10,575	91	10,484	10,575
Winnicut River	662	5.9	778	7.0	842	7.6	11,214	67	11,147	11,214
Wolfeboro Bay	650	2.1	818	2.6	900	2.9	36,897	5,768	31,128	36,965
Total	26,078	3.6	31,233	4.3	33,947	4.7	759,313	37,457	721,856	1,181,635

(1) Total mapped area may be less than total watershed area due to partial watersheds in the 48-town region.

Table 5. Change in Impervious Surface Acreage by Subwatershed, 1990 – 2005

12-Digit HUC Subwatershed Name	Imp. Acres, 1990 (mid point)	% Imp., 1990	Imp. Acres, 2000 (mid point)	% Imp., 2000	Imp. Acres, 2005 (mid point)	% Imp., 2005	Change in % Imp., 1990 - 2005	Change in % Imp., 2000 - 2005
Alton Bay	698	2.4	929	3.2	1,145	3.9	1.5	0.7
Arlington Mill Reservoir	591	5.6	854	8.1	976	9.3	3.7	1.2
Axe Handle Brook	212	3.0	290	4.1	364	5.1	2.1	1.0
Bean River	256	1.7	374	2.5	462	3.1	1.4	0.6
Beech River	14	1.1	27	2.1	32	2.5	1.4	0.4
Bellamy River	1148	5.4	1,708	8.1	2,028	9.6	4.2	1.5
Berrys Brook-Rye Harbor	843	8.0	1,237	11.8	1,415	13.5	5.4	1.7
Big River	85	0.8	141	1.3	162	1.5	0.7	0.2
Bow Lake	121	1.5	185	2.3	217	2.7	1.2	0.4
Branch Brook	0	0.0	0	0.0	0	0.1	0.1	0.1
Cohas Brook	53	4.7	77	6.7	86	7.6	2.9	0.8
Crystal Lake	33	0.7	48	1.0	49	1.1	0.3	0.0
Great Bay	810	4.5	1,186	6.5	1,342	7.4	2.9	0.9
Great Brook-Exeter River	497	4.0	783	6.4	929	7.5	3.5	1.2
Hampton Harbor	1529	10.8	2,163	15.3	2,519	17.8	7.0	2.5
Headwaters-Great East Lake	168	1.9	247	2.8	288	3.3	1.4	0.5
Headwaters-Lamprey River	372	1.7	593	2.7	727	3.3	1.6	0.6
Junes Brook-Branch River	319	1.9	443	2.6	497	2.9	1.0	0.3
Little River (Exeter)	563	5.7	823	8.4	531	5.4	-0.3	-3.0
Little River (Lamprey)	289	2.3	446	3.5	1,001	7.8	5.6	4.3
Little River (Merrimack)	227	6.6	370	10.8	460	13.5	6.8	2.6
Little Suncook River	333	2.5	492	3.6	558	4.1	1.7	0.5
Long Pond	148	1.5	221	2.2	249	2.5	1.0	0.3
Lower Cocheco River	1502	9.3	2,080	12.9	2,535	15.8	6.4	2.8
Lower Isinglass River	803	5.6	1,184	8.3	1,339	9.4	3.8	1.1
Lower Lamprey River	521	4.0	768	5.8	831	6.3	2.4	0.5
Lower Salmon Falls River	296	9.7	379	12.4	436	14.3	4.6	1.9
Lower Spickett River	211	6.7	320	10.1	391	12.3	5.7	2.2
Lower Suncook River	30	0.9	42	1.3	44	1.4	0.4	0.1
Massabesic Lake	0	0.0	0	0.0	0	0.6	0.6	0.6
Middle Cocheco River	1267	8.0	1,685	10.6	1,912	12.1	4.1	1.4
Middle Lamprey River	1232	4.8	1,880	7.3	2,217	8.6	3.8	1.3
Middle Salmon Falls River	1094	7.0	1,536	9.9	1,929	12.4	5.4	2.5
Milton Pond	195	2.8	275	3.9	327	4.7	1.9	0.7
Moultonborough Bay	10	0.8	13	1.1	8	0.6	-0.2	-0.4
Nippo Brook-Isinglass River	266	1.6	374	2.2	453	2.6	1.1	0.5
North Branch River	255	2.3	393	3.6	459	4.2	1.9	0.6
North River	156	1.8	256	3.0	321	3.7	1.9	0.8
Oyster River	969	4.9	1,480	7.5	1,664	8.4	3.5	0.9

Table 5 (cont.)

12-Digit HUC Subwatershed Name	Imp. Acres, 1990 (mid point)	% Imp., 1990	Imp. Acres, 2000 (mid point)	% Imp., 2000	Imp. Acres, 2005 (mid point)	% Imp., 2005	Change in % Imp., 1990 - 2005	Change in % Imp., 2000 - 2005
Pawtuckaway Pond	112	0.9	171	1.4	194	1.6	0.7	0.2
Pine River	191	2.2	281	3.2	311	3.5	1.4	0.3
Piscassic River	514	3.6	885	6.1	1,091	7.6	4.0	1.4
Pittsfield Tributaries	383	3.0	493	3.8	633	4.9	2.0	1.1
Portsmouth Harbor	2310	19.8	2,975	25.5	3,364	28.9	9.0	3.3
Powwow River	1075	4.4	1,661	6.8	2,022	8.3	3.9	1.5
Shapleigh Pond	185	4.3	254	5.9	298	6.9	2.6	1.0
South River	21	3.2	30	4.5	31	4.6	1.4	0.0
Spruce Swamp-Little River	649	4.5	1,023	7.1	1,179	8.2	3.7	1.1
Squamscott River	915	6.9	1,380	10.4	1,645	12.4	5.5	2.0
Sucker Brook	234	2.7	344	4.0	414	4.8	2.1	0.8
Taylor River-Hampton River	1157	8.0	1,745	12.1	2,145	14.9	6.9	2.8
The Broads	327	3.1	466	4.5	479	4.6	1.4	0.1
Towle Brook-Lily Pond	650	3.1	1,091	5.2	1,361	6.5	3.4	1.3
Upper Beaver Brook	1309	9.1	1,831	12.8	2,137	14.9	5.8	2.1
Upper Branch River-Lovell Lake	403	2.3	555	3.2	617	3.5	1.2	0.3
Upper Cocheco River	700	2.6	970	3.6	1,175	4.3	1.7	0.8
Upper Suncook River	56	1.6	77	2.2	98	2.8	1.2	0.6
Watson Brook	331	3.2	532	5.1	642	6.1	3.0	1.1
Winnicut River	778	7.0	1,190	10.7	1,381	12.4	5.4	1.7
Wolfeboro Bay	818	2.6	1,192	3.8	1,290	4.1	1.5	0.3
Total	31,233	4.3	45,445	6.3	53,408	7.4	3.1	1.1

Table 6. Change in Impervious Surface Acreage by Town, 1990 – 2005

Town		Mapped Area (acres)			Impervious Surface (acres)			% Imp. Land Area		
Name	**FIPS**	**Total**	**Water**	**Land**	**1990**	**2000**	**2005**	**1990**	**2000**	**2005**
Alton	01005	53230.5	12601.9	40628.6	871.6	1208.2	1434.10	2.1	3.0	3.5
Barrington	17005	31117.0	1397.6	29719.4	763.5	1186.7	1387.00	2.6	4.0	4.7
Brentwood	15015	10862.5	120.6	10741.9	532.1	828.8	1023.20	5.0	7.7	9.5
Brookfield	03015	14880.3	286.8	14593.5	139.2	190.8	198.20	1.0	1.3	1.4
Candia	15020	19557.0	214.9	19342.1	531.4	794.0	930.90	2.7	4.1	4.8
Chester	15025	16717.7	97.7	16620.0	423.4	720.4	855.50	2.5	4.3	5.1
Danville	15030	7569.4	130.5	7438.9	260.4	445.3	533.70	3.5	6.0	7.2
Deerfield	15035	33348.8	761.6	32587.2	492.0	768.0	969.00	1.5	2.4	3.0
Derry	15040	23225.6	545.2	22680.4	1825.7	2566.5	2966.20	8.0	11.3	13.1
Dover	17010	18592.2	1498.0	17094.2	1872.6	2626.4	3171.60	11.0	15.4	18.6
Durham	17015	15851.6	1543.5	14308.2	675.0	1025.6	1098.00	4.7	7.2	7.7
East Kingston	15045	6380.7	61.8	6318.9	221.5	335.2	439.30	3.5	5.3	7.0
Epping	15050	16775.6	307.6	16467.9	657.8	1070.8	1291.80	4.0	6.5	7.8
Exeter	15055	12813.7	261.2	12552.5	937.4	1375.8	1559.30	7.5	11.0	12.4
Farmington	17020	23639.7	418.8	23220.8	687.1	965.6	1089.50	3.0	4.2	4.7
Fremont	15060	11142.5	106.8	11035.8	329.3	537.9	654.30	3.0	4.9	5.9
Greenland	15065	8524.5	1744.5	6780.0	455.0	712.6	844.90	6.7	10.5	12.5
Hampstead	15070	9014.1	470.7	8543.4	640.1	974.3	1172.10	7.5	11.4	13.7
Hampton	15075	9071.3	753.9	8317.4	1179.3	1605.5	1717.10	14.2	19.3	20.6
Hampton Falls	15073	8077.0	357.8	7719.2	341.8	536.1	698.70	4.4	6.9	9.1
Kensington	15085	7667.8	30.6	7637.2	243.3	378.4	469.80	3.2	5.0	6.2
Kingston	15090	13450.3	955.1	12495.2	651.0	1018.7	1211.70	5.2	8.2	9.7
Lee	17025	12927.6	247.8	12679.8	467.6	740.5	840.60	3.7	5.8	6.6
Madbury	17030	7799.2	396.0	7403.1	251.5	393.7	391.70	3.4	5.3	5.3
Middleton	17035	11843.0	283.4	11559.6	204.5	284.2	350.40	1.8	2.5	3.0
Milton	17040	21935.3	836.4	21098.9	597.4	838.8	985.30	2.8	4.0	4.7
New Castle	15100	1347.6	843.2	504.5	108.1	155.0	170.90	21.4	30.7	33.9
New Durham	17045	28053.9	1706.7	26347.3	458.3	627.9	727.20	1.7	2.4	2.8
Newfields	15105	4646.7	104.6	4542.1	141.6	250.6	307.50	3.1	5.5	6.8
Newington	15110	7916.3	2701.5	5214.9	686.9	941.0	1055.80	13.2	18.0	20.2
Newmarket	15115	9080.4	1007.2	8073.3	479.7	706.6	818.80	5.9	8.8	10.1
North Hampton	15125	8922.0	57.1	8864.9	647.5	957.6	1100.20	7.3	10.8	12.4
Northwood	15130	19355.7	1380.0	17975.7	424.1	610.1	716.70	2.4	3.4	4.0
Nottingham	15135	30996.7	1116.4	29880.3	447.9	692.7	842.20	1.5	2.3	2.8
Pittsfield	13110	15558.7	369.1	15189.6	428.6	555.2	702.00	2.8	3.7	4.6
Portsmouth	15145	10763.2	762.3	10000.9	2128.3	2726.0	3054.30	21.3	27.3	30.5
Raymond	15150	18943.5	495.2	18448.3	977.3	1483.6	1713.60	5.3	8.0	9.3
Rochester	17050	29080.9	749.9	28331.0	2395.2	3304.5	3942.30	8.5	11.7	13.9
Rollinsford	17055	4842.7	160.6	4682.1	265.5	381.3	437.40	5.7	8.1	9.3
Rye	15155	8423.8	426.5	7997.3	586.5	877.9	1026.30	7.3	11.0	12.8
Sandown	15165	9231.8	342.6	8889.2	337.2	544.2	701.30	3.8	6.1	7.9
Seabrook	15170	6160.4	491.1	5669.4	801.6	1206.1	1538.70	14.1	21.3	27.1
Somersworth	17060	6399.0	179.1	6219.9	767.7	1021.2	1256.70	12.3	16.4	20.2
South Hampton	15175	5146.6	102.3	5044.3	123.2	192.5	241.00	2.4	3.8	4.8
Strafford	17065	32778.8	1625.6	31153.3	434.0	637.9	726.60	1.4	2.0	2.3
Stratham	15180	9900.8	228.4	9672.4	628.3	979.2	1245.70	6.5	10.1	12.9
Wakefield	3090	28716.1	3452.4	25263.8	877.9	1224.8	1407.10	3.5	4.8	5.6
Wolfeboro	03095	37405.5	6712.5	30693.0	870.4	1274.6	1399.10	2.8	4.2	4.6
Total		759685.9	51444.7	708241.2	31267.1	45478.8	53415.3	4.4	6.4	7.5

Table 7. Accuracy Assessment Error Matrix, 2005

CLASSIFIED DATA / REFERENCE DATA

2005 Data	Impervious	Non Impervious	Total	User's Accuracy
Impervious	59	1	60	98.3%
Non Impervious	1	58	59	96.7%
Total	60	59	119	
Producers Accuracy	98.3%	96.7%		
Overall Accuracy				98.3%

Conclusions

The study demonstrates that impervious surface acreage within coastal New Hampshire has continued to increase over the fifteen-year period between 1990 and 2005 (Table 5). Interestingly, the rate of increase has slowed from an annual increase of 4.5% from 1990 to 2000 to an annual rate of 3.5% from 2000 to 2005. The regional assessment of 98.3% accuracy suggests a high degree of confidence in these results, indicating that where mapped, impervious surfaces typically did occur. The Emerge data showed that the per pixel estimates were less successful, suggesting that higher resolution imagery is a more appropriate source for large scale mapping applications.

In general, TM-based subpixel classifications provide a useful means of generating regional estimates of impervious surface acreage. The techniques described herein are low-cost and repeatable, and may be used in the future to monitor changes in impervious surface acreage in the region.

Recommendations

Recent state figures project increases of almost 21% in the populations of both Rockingham and Strafford Counties over the period 2005-2025 (NH Office of Energy and Planning, 2006). Accordingly, the researchers recommend that the impervious assessment be repeated on a 3-5 year cycle in order to monitor increases in coverage and to mitigate potential impacts. Further, we recommend continuation of the processing methodology utilized to generate the 1990, 2000, and 2005 estimates, as it is cost-effective and will yield results that will support trend analyses.

References

ERDAS, 2000. Imagine Subpixel Classifier Version 8.4, Product Brochure. 11 p.

Justice, D. and Rubin, F. 2002. Final Report: Developing Impervious Surface Estimates for Coastal New Hampshire. 25 p.

Flanagan, M. and Civco, D.L. 2001. Subpixel Impervious Surface Mapping. Proc. 2001 ASPRS Annual Convention, St. Louis, MO.

Flanagan, M.C. 2000. Subpixel Impervious Surface Modelling using Landsat Thematic Mapper Data. M.S. Thesis, Department of Natural Resources Management and Engineering, The University of Connecticut, Storrs, CT. 125 p.

New Hampshire Office of Energy and Planning, 2006. New Hampshire Population Projections for State and Counties, 2005 to 2025. 20 p.

Rubin, F. and Justice, D. 2001. Final Report: Impervious Surface Mapping Pilot Project. 10 p.