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Developing Impervious Surface Estimates for Coastal New Hampshire

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DEVELOPING IMPERVIOUS SURFACE ESTIMATES FOR COASTAL NEW HAMPSHIRE

A Final Report to

The New Hampshire Estuaries Project

Submitted by

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New Hampshire Estuaries Project

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Executive Summary

Estimates of impervious surface acreage in 1990 and 2000 were generated for a 48-town region in coastal New Hampshire, including the 43 towns within Zones A and B of the New Hampshire Estuaries Project (NHEP) Area. The estimates were based on applying both traditional and subpixel classification techniques to 30-meter Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) satellite image data. The classifications indicated that 4.3% (31,233 acres) of the study area was impervious in 1990, with an increase to 6.3% (45,445 acres) impervious coverage in 2000. At the subwatershed level, the Portsmouth Harbor subwatershed recorded the highest percentage of impervious surface acreage in both 1990 and 2000, with 19.8% coverage (2,310 acres) and 25.5% coverage (2,975 acres) respectively.

The regional accuracy assessment indicated an overall accuracy of 98.6% for the 1990 data and 93.1% for the 2000 data. Planimetric data, including 1994 building and pavement footprints, were obtained from the City of Portsmouth to further assess the classification results for a small area within the city limits. The estimate of 729 impervious surface acres from the planimetric data was within approximately 0.7% of the 724 acres derived from the 1990 image classification. (While the temporal difference in the data sets would be problematic in rural regions, the area of Portsmouth utilized for the comparison was largely built-out by 1990.)

Exploratory classifications using multispectral, 1-meter (pan-sharpened) IKONOS data, acquired in 2000, showed promising results for a pilot region in Portsmouth. When compared to the Portsmouth planimetric data set, the acreages derived from the large-scale imagery corresponded to within approximately 1.9%.

The two regional data sets, representing impervious surface acreage in 1990 and 2000, have been archived in the GRANIT GIS clearinghouse, thereby making them available to the coastal resource community as well as the general public.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 them to support larger scale mapping and applications. It is also noted that the IKONOS imagery provided reliable results for the pilot area, and should be considered when large-scale mapping of impervious surfaces is required.

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Introduction

Future population growth and the corresponding increase in development in the coastal zone of NH 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. The primary goals of this project were to provide an accurate, current description of the extent of impervious surface coverage in this region, as well as an estimate of change in the amount of "imperviousness" over a recent, ten-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.

Previous 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 recent 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

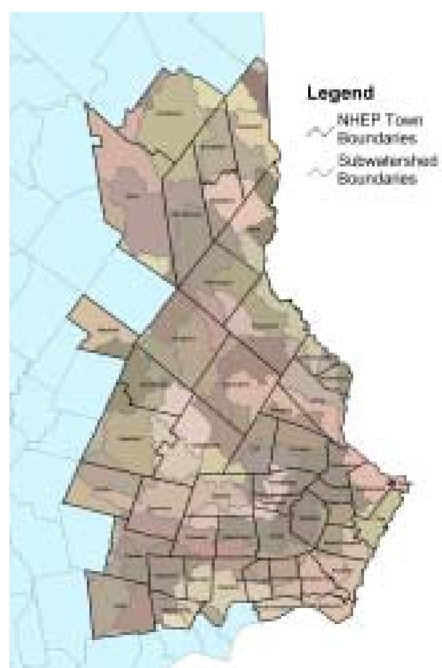
The primary objective of this study was to utilize Landsat Thematic Mapper (TM) imagery to map impervious surfaces within a 48-town area of coastal New Hampshire, including the 43 towns within Zones A and B of the New Hampshire Estuaries Project (NHEP) Area. Impervious surfaces were defined as surfaces through which water cannot penetrate, and included roadways, parking lots, rooftops, paved driveways, and any other paved surfaces identified. The goal was to develop data for two points in time – 1990 and 2000 – 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 a baseline impervious surface estimate for 1990
- Utilize subpixel processing techniques as applied to TM imagery to develop an estimate of impervious surfaces in 2000
- Calculate the change in impervious surface acreage over the ten-year period
- Report the results at the subwatershed level
- Convert the data for each year to a GRID format, with corresponding attribute tables reporting the degree of imperviousness for each cell (in ranges of 10%)
- Develop appropriate metadata, or data documentation
- Make the spatial data and metadata available through 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

A secondary objective of the project was to explore the feasibility of using higher-resolution, commercially available data as a source for mapping impervious surfaces. A 1-meter resolution IKONOS image (acquired June 8, 2000) covering the Portsmouth, NH area was available, and provided an excellent source data set for a traditional, supervised classification approach. The researchers proposed to compare and contrast the results of the TM subpixel technique with those derived from the IKONOS supervised classification approach. It was expected from the outset that the larger-scale imagery would yield a more refined product, but at a considerably greater expense.

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 of increasing levels of impervious surfaces in coastal New Hampshire.

Figure 1. Subwatersheds within Project Study Area



Methods

The impervious surface mapping project consisted of two phases. The first phase focused on using moderate resolution satellite imagery to produce a regional estimate of impervious surface acreage for the 759,313 acres within the 48- town project area (see Figure 1). The second, pilot component concentrated on using higher resolution imagery to map impervious surfaces in a small region within the City of Portsmouth, NH.

I. Regional Impervious Surface Estimates

The regional mapping phase utilized 30-meter resolution TM imagery to generate an estimate of impervious surface acreage for two years: 1990 and 2000. The GRANIT database, resident at Complex Systems Research Center, contained an archived image

(Landsat 7 Enhanced TM Plus - path 12, row 30) acquired on September 27, 2000, which provided the current "view" of the study area. A second image (Landsat 5 TM), acquired September 9, 1990, was purchased to provide the historical perspective and to accommodate the change analysis.

a. Traditional Classification

The impervious surface mapping began by conducting traditional supervised classifications on the 1990 and 2000 data sets to generate an initial delineation of the developed/undeveloped land features in each year. 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.

A body of 75 training sites, representing various types of impervious surfaces, was utilized in the traditional classification. These data were available as a result of numerous land cover classifications conducted within the project area over the past several years. Coupled with local knowledge, the training data were used to perform maximum likelihood classifications on the satellite imagery, yielding a data set of developed/undeveloped features for each year. The developed/urban class included areas characterized by a high percentage (typically 50% or greater) of constructed materials (asphalt, concrete, buildings, etc.). The identification of specific areas as urban was based strictly on features visible in the imagery, and thus only the areas within large subdivisions that were actually constructed were classified as urban.

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 using either an iterative process, whereby training data were added/deleted and the classification re-run, or by using on-screen editing to delete misclassified pixels in the final data set. 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 additional estimates of "proportion of imperviousness" for each urban 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 technique is non-traditional in nature. Best results are achieved by working with data sets having minimal resampling, and processed using the nearest neighbor technique. Adherence to this rule requires that a geographic transformation model be developed and used to georeference the final data set. This was conducted for both the 1990 and 2000 image data. Figure 2 illustrates the base 1990 TM data after being georeferenced using the model transformation.

Figure 2. Georeferenced Subset of Landsat 5 Thematic Mapper Image (bands 3, 2, 1 – acquired 9/8/90) for an area around Great Bay. Red vectors represent NH Department of Transportation road centerline data overlain on the source imagery.

The subpixel processing approach followed generally accepted techniques (Flanagan, 2000; Flanagan and Civco, 2001; ERDAS, 2000). The 2000 TM data set was initially used to generate 15–20 potential signatures, which were evaluated by running an MOI classification and displaying the results on the underlying imagery. The results were evaluated both by visual inspection of 1998 USGS Digital Orthophotoquads (DOQs), 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, as we had no data to effect the latter type of comparison.

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 of these signature derivations and classification tests, 12 signatures were accepted to generate the final impervious surface data set. These signatures provided a reasonable classification that could be edited to derive a provisional impervious surface data set.

Unlike traditional supervised classifications, the subpixel approach typically produces classifications based on a single signature. Accordingly, 12 data sets were produced and subsequently 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.

Processing of the 1990 data was completed in a slightly different manner. One advantage of the subpixel classification technique was that signatures derived from one image (in this case, the 2000 ETM+ data) could be successfully applied to the second data set. We were able to utilize this functionality to classify impervious surface MOI’s for the 1990 TM data set, using 10 of the 12 signatures derived for the 2000 image. However, visual inspection indicated that some impervious surface features were under represented in the initial results. Thus, 10 additional signatures were derived from the 1990 image to support the classifications. Again, the results were mosaiced into a single, 20-band data set, with the maximum layer value assigned to each pixel in the provisional data set.

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 obtained for this phase:

- US Fish & Wildlife Service National Wetlands Inventory (NWI) data, based on aerial photography acquired in the mid-1980’s, as archived in the GRANIT database; and
- New Hampshire Department of Transportation (NHDOT) road centerline data – both public and private roads, as of August, 2002

The provisional impervious surface classification included some recurring errors – typically misclassified pixels occurring in open water, wetland and forests. The image analyst could often quickly identify these errors using pattern recognition, past experience and in some cases, DOQ 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, because of 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 NHDOT data in the final product, 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. A default pavement width of 20 ft. was assigned to the appropriate subset. In addition, no historical record of roads in the state was available. A second editing task was required to subset roads (both public and private) that were present in 1990, and to approximate the public road pavement width at that time. The default 20 ft. width was again assigned to the paved, private roads. The editing was accomplished by on-screen visual inspection, comparing the NHDOT road centerlines with 1992 DOQ images, the 1990 TM image and 1992 SPOT imagery. Once the editing was complete, the pavement width characteristic was used to "burn" the paved, 1990 and 2000 road centerline data into the appropriate classified data sets.

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 150 assessment sites was randomly selected from the project area – 50 sites in each of three categories:

- coded as not impervious 1990, not impervious 2000
- coded as not impervious 1990, impervious 2000
- coded as impervious 1990, impervious 2000

An analyst drove by each of the 150 sites, and recorded its impervious status for each time step (1990 and 2000). Navigation to each site was facilitated by use of a laptop computer operating GPS equipped ArcPad software.

As might be expected, impervious status could not be determined at each location. For example, it was not always evident when a relatively new housing development was constructed. In such cases, the site was marked as undetermined, and re-evaluated in the office using 1992 DOQ's. If neither method was able to produce a reliable determination, the site was discarded from the assessment. Ultimately, 139 sites contributed to the 1990 assessment, and 145 sites contributed to the 2000 assessment.

e. Reporting and Metadata

The results of the impervious surface mapping were tabulated for each year – 1990 and 2000 – both for the full study area and by subwatershed. For each image date, 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 full, Federal Geographic Data Committee (FGDC)-compliant metadata record for the two impervious surface data sets. These documents detail the data production and assessment aspects of the project, and are an essential reference for the community utilizing the data.

II. Exploratory Work in Portsmouth

The secondary objective of the project was to explore the suitability of using IKONOS data to map impervious surfaces for a small area in Portsmouth, NH. A 1 meter panchromatic IKONOS data set was used to "pan-sharpen" a corresponding 4 meter multi-resolution IKONOS image, producing a 1 meter multispectral image. The data set was then classified using the Imagine isodata algorithm. The resulting 200-cluster data set was visually inspected to determine suitable classes to carry forward to the final product, with unsuitable classes reserved to mask the original data for further analysis. Again, isodata was used to produce a 50-cluster data set, which was evaluated and coded for inclusion in the final data set.

Visual inspection of the classified data showed that small interior gaps consistently occurred. Arc GRID functionality was used to expand, and then contract, impervious regions to fill these interior gaps while maintaining the exterior edge of each region. This procedure successfully filled holes in the data, creating a more consistent and reliable product.

Finally, on screen editing was performed to eliminate obvious misclassified areas. As with the TM-based classification, most of the required edits occurred in the wetland/water areas of the IKONOS-based data.

Planimetric data, outlining building and pavement footprints derived from 1994 aerial photography, was acquired from the City of Portsmouth and used to assess the IKONOS-derived impervious surface data. Unlike the TM-derived impervious surface assessment, this accuracy test produced impervious surface acres mapped by each source. Of course, the discrepancy in the source data vintage is recognized. However, the researchers feel that this comparison is a useful gauge of IKONOS based impervious surface mapping.

Results and Discussion

I. Regional Impervious Surface Estimates

The primary results of this project are 1990 and 2000 impervious surface estimates for the 48 towns in coastal New Hampshire (Figures 3 and 4). Figures 5 and 6 provide somewhat larger-scale illustrations of mapped impervious surface features for the Exeter, NH vicinity. These figures show clear examples of new housing subdivisions, roads, and businesses evident in the 2000 data.

Tables 2 and 3 summarize these results by subwatershed, reporting acreages at 3 levels for each unit. (As previously noted, the subpixel classification reports 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.) Table 2 reveals that 31,233 acres, or 4.3% of the land surface area in the 48 towns, were estimated to be impervious in 1990. By the year 2000, Table 3 reports that the acreage had increased to 45,445 acres (6.3%), a marked increase of 14,212 acres. This represents a 2% change, or 45.5% increase, in impervious surface acreage over the ten-year period (see Table 4).

Additionally, one can look at the impervious surface estimates at the watershed level. In 1990, there was a range of impervious surface estimates from 0% (Branch Brook and Massabesic Lake) to 19.8% (Portsmouth Harbor). The corresponding 2000 estimates ranged from 0% to 25.5%. Other significant results included the Hampton Harbor (4.5% change), Taylor River-Hampton River (4.1% change), Winnicut River (3.7% change), Squamscott River (3.5% change), and Lower Spickett River (3.4% change) watersheds. The average impervious surface percentage by watershed was 4.1% in 1990. By 2000, this number increased to 5.9%.

Associated with the satellite image based mapping are error matrices, 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 assessments 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, error matrices are presented in Tables 5 and 6. The tables show that reasonable overall accuracies were achieved for both the 1990 (98.6% correct) and 2000 (93.1% correct) data sets. 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 assessments provide a general estimate of the data reliability.

It is interesting to note the increased accuracy of the 1990 data over that of 2000, particularly since many of the subpixel signatures were derived from the later data set. A possible reason for the difference is that the 2000 data underwent additional processing prior to its acquisition. As mentioned earlier, the subpixel technique is most effectively applied to minimally resampled imagery.

Figure 3. Regional mapping of impervious surfaces, 1990. Impervious surface features are shown in red, and are displayed on the 12-digit watershed units.

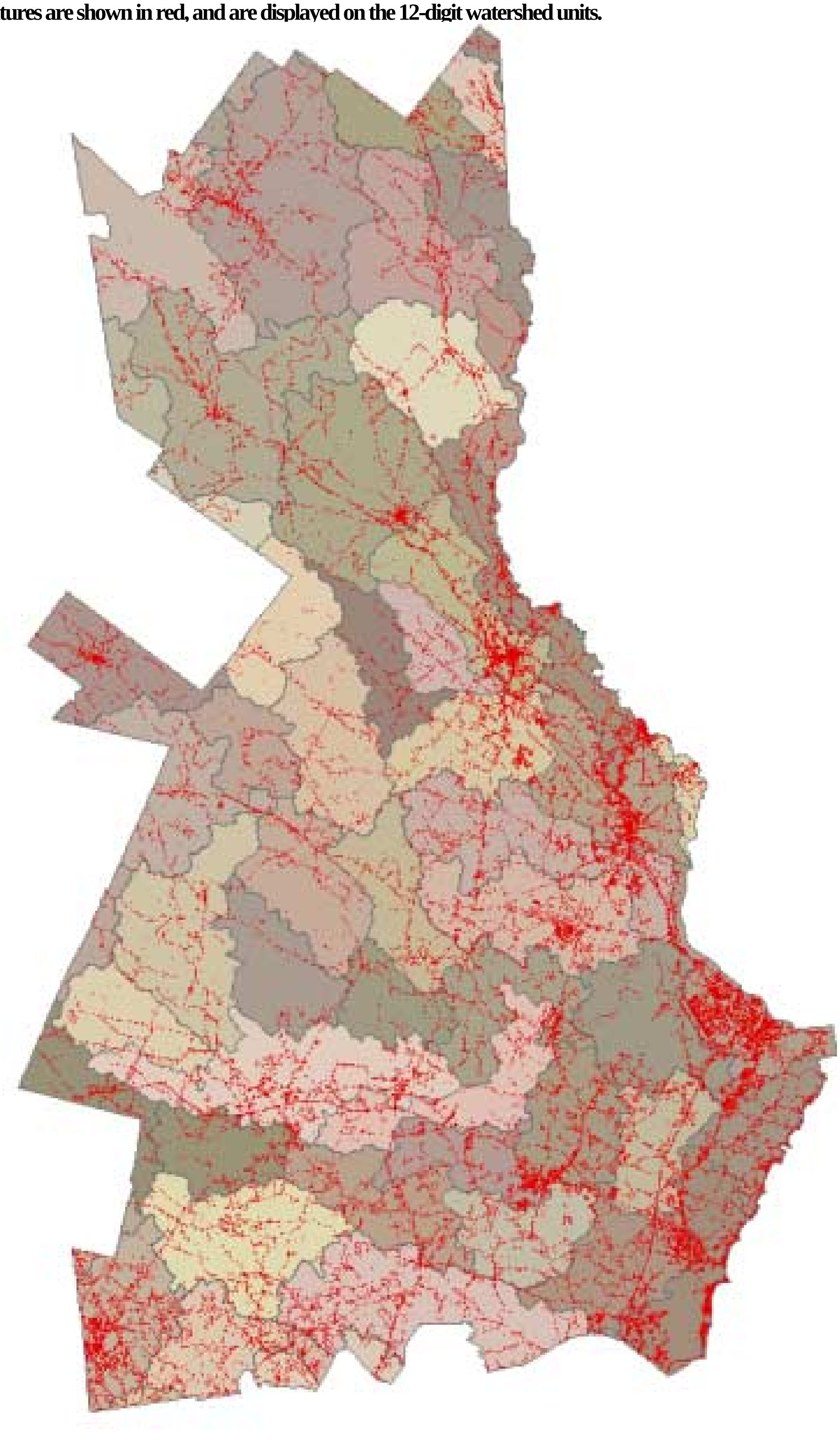


Figure 4. Regional mapping of impervious surfaces, 2000. Impervious surface features are shown in red, and are displayed on the 12-digit watershed units.

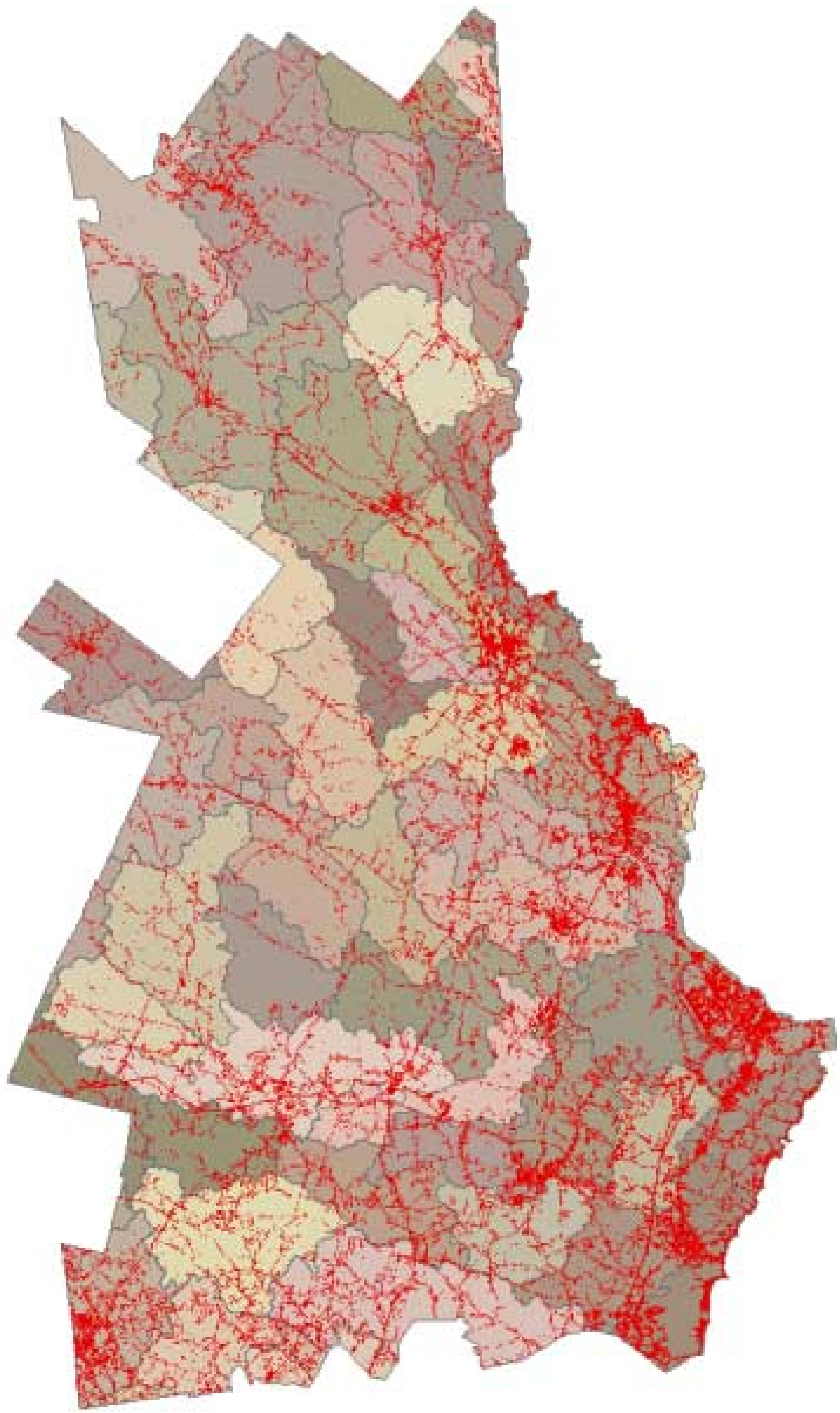


Figure 5. Regional mapping of impervious surfaces, 1990, for the Exeter, NH vicinity.

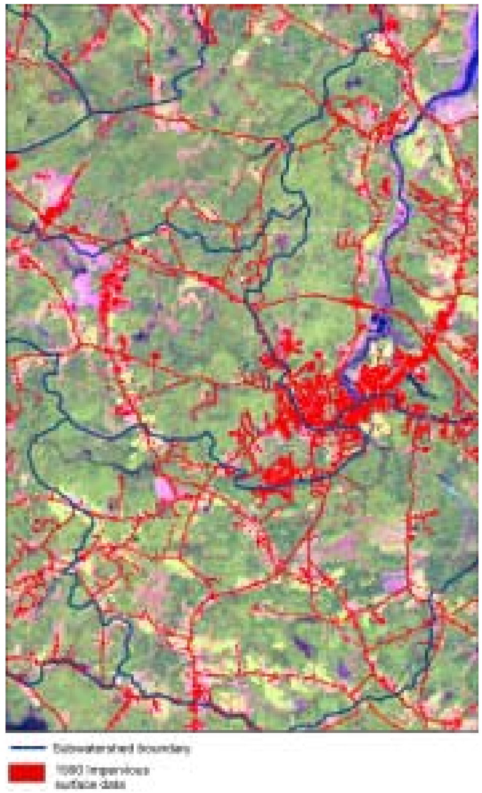


Figure 6. Regional mapping of impervious surfaces, 2000, for the Exeter, NH vicinity.

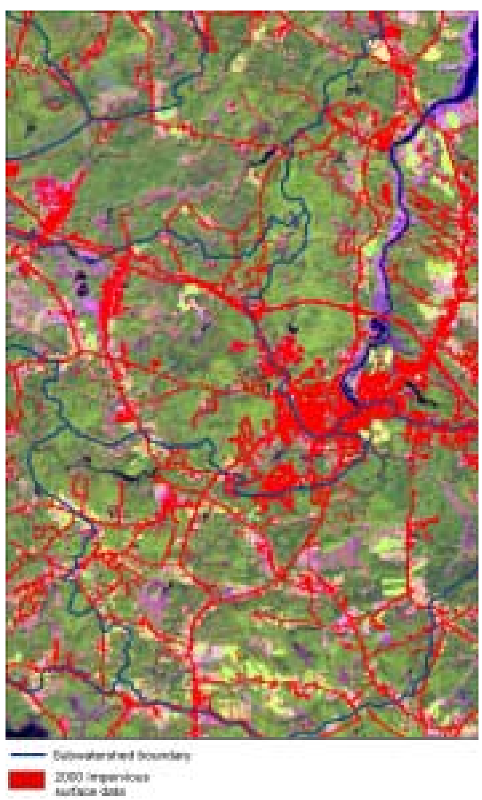


Table 2. Impervious Surface Acreage and Total Acreage by Subwatershed, 1990

12-Digit HUC Subwatershed Name	Impervious Acres						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
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

Table 2 (cont.)

12-Digit HUC Subwatershed Name	Impervious Acres						Total Acres			
	Low Range	% Land Area	Mid Range	% Land Area	High Range	% Land Area	Mapped Area [1]	Surface Water	Land Area	Total Watershed
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 3. Impervious Surface Acreage and Total Acreage by Subwatershed, 2000

12-Digit HUC Subwatershed Name	Impervious Acres						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
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

Table 3 (cont.)

12-Digit HUC Subwatershed Name	Impervious Acres						Total Acres			
	Low Range	% Land Area	Mid Range	% Land Area	High Range	% Land Area	Mapped Area [(1)]	Surface Water	Land Area	Total Watershed
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. Change in Impervious Surface Acreage by Subwatershed, 1990 – 2000

12-Digit HUC Subwatershed Name	Impervious Acres, 1990 (mid point)	% Impervious, 1990	Impervious Acres, 2000 (mid point)	% Impervious, 2000	Change in % Impervious, 1990 - 2000
Alton Bay	698	2.4	929	3.2	0.8
Arlington Mill Reservoir	591	5.6	854	8.1	2.5
Axe Handle Brook	212	3.0	290	4.1	1.1
Bean River	256	1.7	374	2.5	0.8
Beech River	14	1.1	27	2.1	0.9
Bellamy River	1,148	5.4	1,708	8.1	2.6
Berrys Brook-Rye Harbor	843	8.0	1,237	11.8	3.8
Big River	85	0.8	141	1.3	0.5
Bow Lake	121	1.5	185	2.3	0.8
Branch Brook	0	0.0	0	0.0	0.0
Cohas Brook	53	4.7	77	6.7	2.1
Crystal Lake	33	0.7	48	1.0	0.3
Great Bay	810	4.5	1,186	6.5	2.1
Great Brook-Exeter River	497	4.0	783	6.4	2.3
Hampton Harbor	1,529	10.8	2,163	15.3	4.5
Headwaters-Great East Lake	168	1.9	247	2.8	0.9
Headwaters-Lamprey River	372	1.7	593	2.7	1.0
Junes Brook-Branch River	319	1.9	443	2.6	0.7
Little River (Exeter)	563	5.7	823	8.4	2.6
Little River (Lamprey)	289	2.3	446	3.5	1.2
Little River (Merrimack)	227	6.6	370	10.8	4.2
Little Suncook River	333	2.5	492	3.6	1.2
Long Pond	148	1.5	221	2.2	0.7
Lower Cocheco River	1,502	9.3	2,080	12.9	3.6
Lower Isinglass River	803	5.6	1,184	8.3	2.7
Lower Lamprey River	521	4.0	768	5.8	1.9
Lower Salmon Falls River	296	9.7	379	12.4	2.7
Lower Spickett River	211	6.7	320	10.1	3.4
Lower Suncook River	30	0.9	42	1.3	0.4
Massabesic Lake	0	0.0	0	0.0	0.0
Middle Cocheco River	1,267	8.0	1,685	10.6	2.6
Middle Lamprey River	1,232	4.8	1,880	7.3	2.5
Middle Salmon Falls River	1,094	7.0	1,536	9.9	2.8
Milton Pond	195	2.8	275	3.9	1.1
Moultonborough Bay	10	0.8	13	1.1	0.2
Nippo Brook-Isinglass River	266	1.6	374	2.2	0.6
North Branch River	255	2.3	393	3.6	1.3
North River	156	1.8	256	3.0	1.2
Oyster River	969	4.9	1,480	7.5	2.6
Pawtuckaway Pond	112	0.9	171	1.4	0.5
Pine River	191	2.2	281	3.2	1.0
Piscassic River	514	3.6	885	6.1	2.6

Table 4 (cont.)

12-Digit HUC Subwatershed Name	Impervious Acres, 1990 (mid point)	% Impervious, 1990	Impervious Acres, 2000 (mid point)	% Impervious, 2000	Change in % Impervious, 1990 - 2000
Pittsfield Tributaries	383	3.0	493	3.8	0.9
Portsmouth Harbor	2,310	19.8	2,975	25.5	5.7
Powwow River	1,075	4.4	1,661	6.8	2.4
Shapleigh Pond	185	4.3	254	5.9	1.6
South River	21	3.2	30	4.5	1.4
Spruce Swamp-Little River	649	4.5	1,023	7.1	2.6
Squamscott River	915	6.9	1,380	10.4	3.5
Sucker Brook	234	2.7	344	4.0	1.3
Taylor River-Hampton River	1,157	8.0	1,745	12.1	4.1
The Broads	327	3.1	466	4.5	1.3
Towle Brook-Lily Pond	650	3.1	1,091	5.2	2.1
Upper Beaver Brook	1,309	9.1	1,831	12.8	3.6
Upper Branch River-Lovell Lake	403	2.3	555	3.2	0.9
Upper Cocheco River	700	2.6	970	3.6	1.0
Upper Suncook River	56	1.6	77	2.2	0.6
Watson Brook	331	3.2	532	5.1	1.9
Winnicut River	778	7.0	1,190	10.7	3.7
Wolfeboro Bay	818	2.6	1,192	3.8	1.2
Total	31,233	4.3	45,445	6.3	2.0

Table 5. Accuracy Assessment Error Matrix, 1990

CLASSIFIED DATA / REFERENCE DATA

1990 Data	Impervious	Non Impervious	Total	User's Accuracy
Impervious	47	1	48	97.9%
Non Impervious	1	90	91	98.9%
Total	48.0	91.0	139	
Producers Accuracy	97.9%	98.9%		
Overall Accuracy				98.6%

Table 6. Accuracy Assessment Error Matrix, 2000

CLASSIFIED DATA / REFERENCE DATA

2000 Data	Impervious	Non Impervious	Total	User's Accuracy
Impervious	92	6	98	93.9%
Non Impervious	4	43	47	91.5%
Total	96	49	145	
Producers Accuracy	95.8%	87.8%		
Overall Accuracy				93.1%

II. Exploratory Work in Portsmouth

Table 7 shows the comparison between impervious surfaces mapped using IKONOS data, the TM based subpixel derived data, and the planimetric data obtained from the City of Portsmouth. Clearly, we see that there is a remarkable similarity in the impervious surface acreage mapped using each image data source as compared to the planimetric data.

Table 7. Accuracy Assessment Results for Portsmouth Pilot Area

Data Source	Impervious Surface Acreage
Portsmouth Planimetric Data	729
IKONOS	743
1990 Impervious (TM based)	724

This is somewhat perplexing given the difference in data source acquisition dates (TM based subpixel, 1990; planimetric, 1994; IKONOS, 2000). One possible explanatory factor is that, within the small area of Portsmouth for which all data sources were usable, most of the land surface area was already developed as of 1990. Thus, the lack of any post-1990 development resulted in similar impervious surface acreages. Yet, it is still encouraging to see the similar acreages mapped by both IKONOS and TM based subpixel processing. Comparison of these mapping techniques in a more rural, developmentally dynamic region would be useful.

It should be noted that, while impervious surface acreage is consistent among the varying data sources, there are significant advantages and disadvantages associated with each. For example, the TM based subpixel derived data reports impervious surface acreage as percent ranges per pixel. The location of the material within each pixel is unknown. As a consequence, it may be preferable to use a high-resolution data source, such as IKONOS, when precise physical location (e.g. location of a driveway or individual house) is of greater importance than acreage summaries covering broad region (see Figure 7).

Conversely, when regional scale acreage summaries are the objective, the TM based subpixel approach provides a more cost effective method for providing this information. A single georeferenced TM scene, covering approximately 185 kilometers on a side, provides full coverage for the NHEP Area at an approximate cost of $1000-$1200. A comparable set of IKONOS images for the full study area would cost in excess of $250,000. The latter estimate is based on prices posted in December, 2002, at http://www.infoterra-global.com/ikonos.html, and discounts for large area acquisitions may be available. Nevertheless, the cost differential would clearly be significant. In addition to the significantly different image acquisition costs, the higher resolution imagery entails increased processing costs due to the magnitude of data sets being handled and managed.

Figure 7. Comparison of IKONOS 1-meter imagery and Landsat Thematic Mapper 30-meter imagery

Conclusions

The basic conclusion of this study is that impervious surface acreage within coastal New Hampshire increased over the decade between 1990 and 2000 (Table 4). While these results are not surprising, this study provides the first quantitative estimate of the extent of the change. The accuracy assessment indicates that the data are accurate and reliable – where mapped, impervious surfaces typically did occur.

In general, TM-based subpixel classifications provide a useful means of characterizing regional estimates of impervious surface acreages. 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. The researchers also recognize that IKONOS-based classifications, while entailing significantly greater expense, are a useful tool for large-scale applications requiring specific knowledge about the spatial distribution of the impervious surface features.

Recommendations

Given the rapid population growth in the state and the region, the researchers recommend that the impervious assessment be repeated on a 3-5 year cycle. The results achieved using TM-based imagery, processed using the subpixel techniques described herein, suggest that this methodology is appropriate for future applications where regional acreage estimates are required.

If the specific locations of impervious surfaces are of interest, additional exploration into the functionality of IKONOS based mapping should be conducted. We suggest testing this methodology in more rural areas of the seacoast.

Because the data from this study comprise estimates of degrees of imperviousness, rather than a more traditional delineation of specific impervious features, we recommend that educational materials be developed to accompany the distribution of the data. These materials may be in the form of a distributable slide show overview of the processes used to generate the data. Additionally, an educational piece focused on the appropriate use of the data, rather than the development techniques, would be useful. While similar educational materials have been available in the past, they have not included maps to illustrate (vividly) potential impacts of impervious surfaces.

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