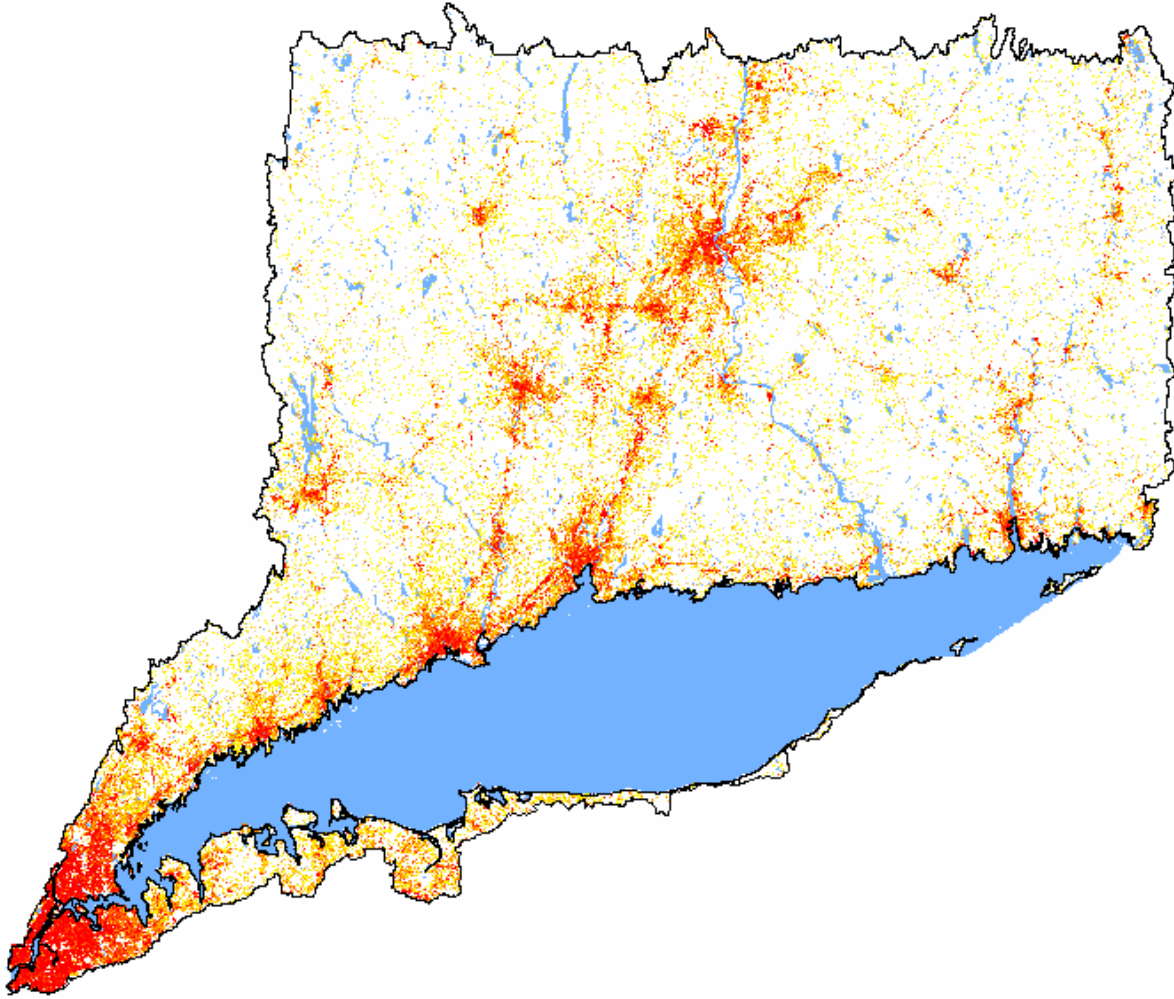


PROJECT COMPLETION REPORT

Mapping and Monitoring Changes in Impervious Surfaces in the Long Island Sound Watershed



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Introduction

Nonpoint source pollution (NPS) has been cited as one of the top contributors to water quality problems in the United States (U. S. EPA, 1994). An increase in urbanization and resulting impervious surfaces increases concentrations of nitrogen and phosphorus in streams, lakes, and estuaries (Wickham *et al.*, 2002). These pollutants have been identified as the primary nutrients responsible for algal blooms caused by eutrophication which results in fish die-off, endangers human health, and impacts the economic and recreational use of water resources (Carpenter *et al.*, 1998; U.S. EPA, 1996). Urban runoff has been found to contribute a significant amount of these and other nonpoint source pollutants to our water resources (Beach, 2002; Boyer *et al.*, 2002; U.S. EPA, 2002). In addition, it has been well-documented that urbanization increases the volume, duration, and intensity of stormwater runoff (Booth and Reinfelt, 1993). Imperviousness influences hydrology (*e.g.*, an increase in imperviousness is directly related to increase in the volume and velocity of runoff), stream habitat (*e.g.*, the hydrological impacts of increased imperviousness lead to increased stream bank erosion, loss of riparian habitat, and degradation of in-stream habitat), chemical water quality (*i.e.*, increases in imperviousness and runoff directly effect the transport of non-point source pollutants including pathogens, nutrients, toxic contaminants, and sediment), and biological water-quality (*e.g.*, all the above changes have an adverse impact on the diversity of in-stream fauna) (Schueler, 1994; Arnold and Gibbons, 1996). These hydrological impacts of urbanization, particularly impervious surfaces, are depicted in Figure 1. Additional research has suggested that the amount of urban runoff and its impacts on stream conditions and water quality are strongly correlated to the percent area of impervious surfaces within a watershed (Schueler, 1994; Arnold and Gibbons, 1996; Clausen *et al.*, 2003). This strong relationship implies impervious surfaces can serve as an important indicator of water quality, not only because imperviousness has been consistently shown to affect stream hydrology and water quality, but because it can also be readily measured at a variety of scales (*e.g.*, from the parcel level to the watershed and regional levels) (Schueler, 1994).

Understanding the degree and location of impervious surfaces and limiting the amount of impervious surface in a watershed is an important component of overall watershed management. Coastal resource and land use managers need to be able to determine the existing percent imperviousness for an area in order to develop appropriate watershed management and/or NPS mitigation plans and to understand the link between water quality and impervious surfaces. Much research has focused on determining the relationship between watershed impervious surface coverage and water resources impacts. Many of these have identified a positive correlation among percentage of urban land or imperviousness and select water quality parameters (Herlihy *et al.*, 1998; Brabec *et al.*, 2002; Boyer *et al.*, 2002; Clausen *et al.*, 2003; Roy *et al.*, 2003). Within the past few years, numerous research projects have been undertaken to develop methods to measure impervious surfaces at the watershed scale or larger (Ji and Jensen, 1999; Bird *et al.*, 2000; Wang *et al.*, 2000; Ward *et al.*, 2000; Bird *et al.*, 2002; Justice and Rubin, 2003; Yang *et al.*, 2003). Past efforts to determine watershed imperviousness have been hampered by inconsistent methods and outdated or unavailable data. There is a need for a consistent and replicable technique to calculate easily and quickly watershed imperviousness from readily available and cost effective remote sensing information that achieves an acceptable level of accuracy. The research reported here strives to attain that level of consistency and accuracy in

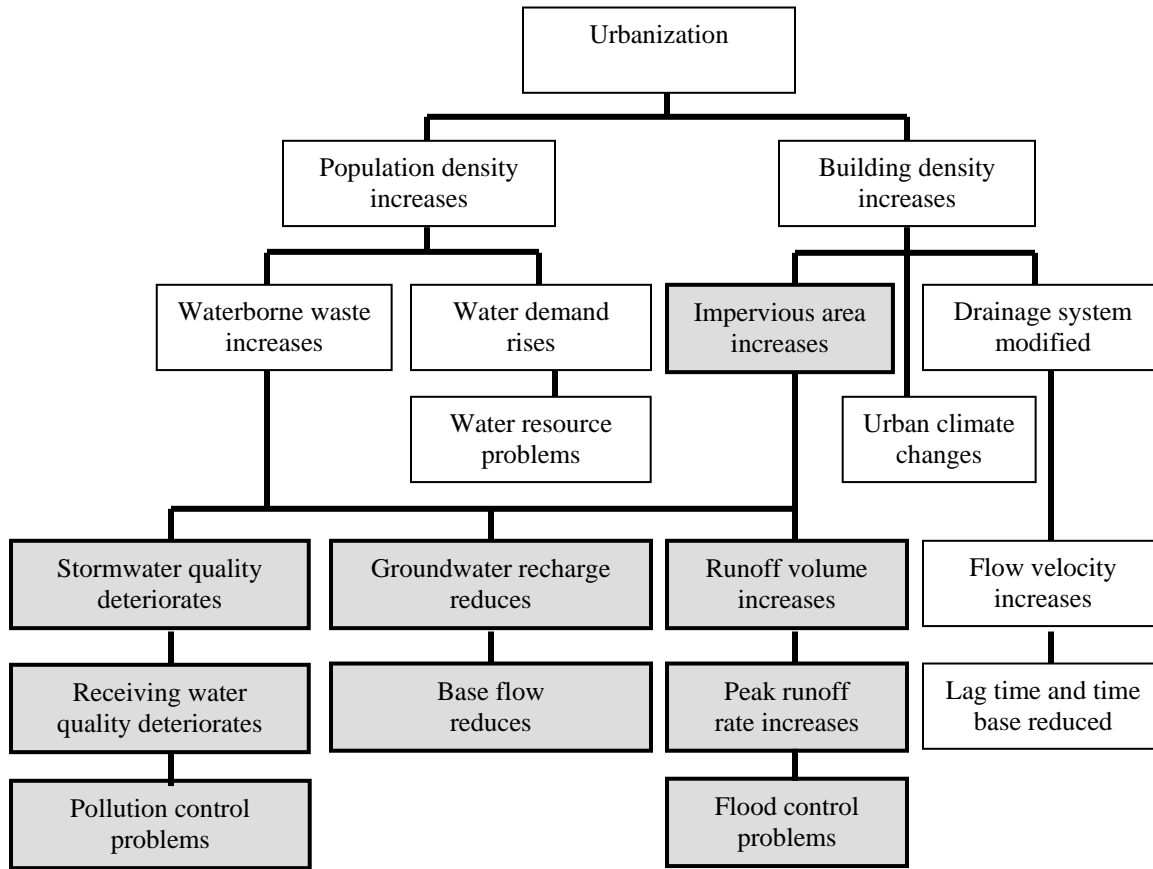


Figure 1. Hydrologic impact of urbanization. Gray boxes identify impacts directly related to impervious surfaces (adapted from Hall, 1984).

regards to developing a temporal set of impervious surface estimations covering four dates spanning a 17 year period (1985, 1990, 1995, and 2002). This data will provide coastal resource and land use managers a means to assess changes in land cover and impervious surfaces and the potential impact on water resources.

Study Area and Data

The study area for this project includes those watersheds in Connecticut and New York that contribute to the Long Island Sound watershed (Figure 2). To cover this area, three Landsat scenes were required for each date, following the World Reference System, from WRS Path 13 Row 31 (majority of Connecticut, northern Westchester County), Path 13 Row 32 (most of Long Island, new York City area and southern Westchester County), Path 12 Row 31 (southeastern Connecticut and northeastern Long Island). Table 1 provides the date and path/row identifier for each of the Landsat scenes used. Images from path 13 were mosaicked to generate a single image layer for use in the sub-pixel classification process. This was possible since each of these images were of similar spectral and phonological characteristics. The Path 12 Row 31 image was classified separately.

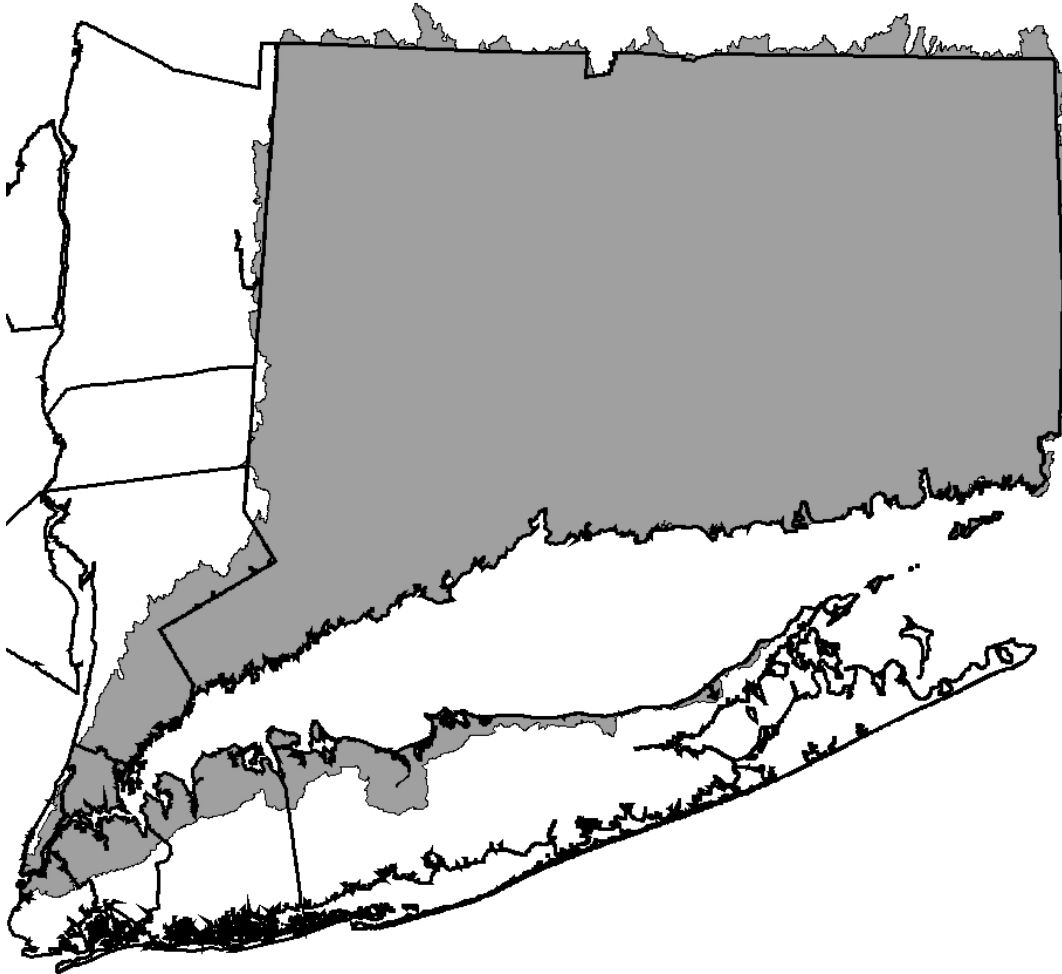


Figure 2. Long Island Sound watershed study area used in the land cover classification and sub-pixel impervious surface estimation (shaded in grey). Connecticut state and New York county boundaries are identified as black lines.

Table 1 Dates of Landsat imagery used for land cover classification and impervious surface estimation.

Classification Period	Landsat Date	WRS Path/Row
circa 1985	April 26, 1985	13/31
	April 26, 1985	13/32
	August 9, 1985	12/31
circa 1990	August 30, 1990	13/31
	October 17, 1990	13/32
	September 16, 1987	12/31
circa 1995	August 28, 1995	13/31
	August 30, 1996	13/32
	September 19, 1994	12/31
circa 2002	September 8, 2002	13/31
	September 8, 2002	13/32
	July 31, 2002	12/31

Land Cover Classification

The first phase of this project was to complete land cover classification for the Connecticut and the New York portions of the Long Island Sound watershed. These data will supply information regarding the changes in land cover over the 17 year period between 1985 and 2002, and also be utilized as a mask for the impervious surface estimation. Land cover was derived using various classification techniques. These will be briefly described here. For a more detailed description of the four date land cover classification process, please see Hurd *et al.* (2003). To begin, a base land cover image was generated from the April 26, 1985 and August 9, 1985 Landsat TM scenes. The classification process used Leica Geosystems's¹ ERDAS Imagine image processing software and consisted of Maximum Likelihood classification, ISODATA unsupervised classification, inclusion of a rasterized road network, and substantial on-screen digitization to eliminate classification errors. The resulting classification consisted of 11 general land cover categories. These are: developed, turf & grass, other grasses & agriculture, deciduous forest, coniferous forest, water, non-forested wetland, forested wetland, tidal wetland, barren land, and utility right-of-ways. Significant time was spent getting this (1985) classification as accurate as possible because it would serve as the basis for subsequent land cover classification for 1990, 1995, and 2002.

Cross-correlation Analysis (CCA), developed by Earthsat, Inc, was chosen as the method for determining subsequent land cover because it overcomes many of the limitations of conventional change detection methods and is able to produce a consistent set of land cover information over the four dates of imagery. Cross-correlation works by using the land cover categories identified in the base land cover classification (1985) to derive an "expected" class average spectral response (Koeln and Bissonnette, 2000; Smith *et al.*, 2002). This information is used to derive a Z-statistic for each pixel falling within a given land cover type. The Z-statistic describes how close a pixel's response is to the "expected" spectral response of its corresponding class value in the land cover image. Pixels that have undergone change between the date of the land cover image and the multispectral image will produce high Z-statistic values, while pixels that have not changed will produce low Z-statistic values. The benefit of this technique is that it eliminates the problems associated with radiometric and phenological differences that are so readily experienced when performing change detection.

In the case of this work, CCA was applied to five groups of land cover categories: 1) water; 2) deciduous forest, coniferous forest, and forested wetlands; 3) turf & grass and other grasses & agriculture; 4) barren; and 5) non-forested wetlands and tidal wetlands. Using the 1985 land cover, pixels belonging to each group were extracted from the August 30, 1990 TM image (*i.e.* for the deciduous, coniferous and forested wetlands group, pixels classified as these categories in 1985 were extracted from the August 30, 1990 TM image). The CCA procedure was applied to the extracted pixels and the results were visually examined with the recent image data to determine the threshold between probable change pixels and non-changed pixels. Those pixels identified as having changed were extracted from the August 30, 1990 image. ISODATA classification was performed to identify the category to which each pixel now belonged. These steps were repeated for each class group. Once completed, each group of classifications was combined into a single image and edited to remove apparent errors. These pixels were then fused with the previous land cover to produce an updated land cover image. This updated land cover (1990) was then used on the August 28, 1995 TM image and that result used on the September 8,

¹ <http://gis.leica-geosystems.com/Products/Imagine/>

2002 TM image. Figure 3 provides an example of the final land cover classification for each date.

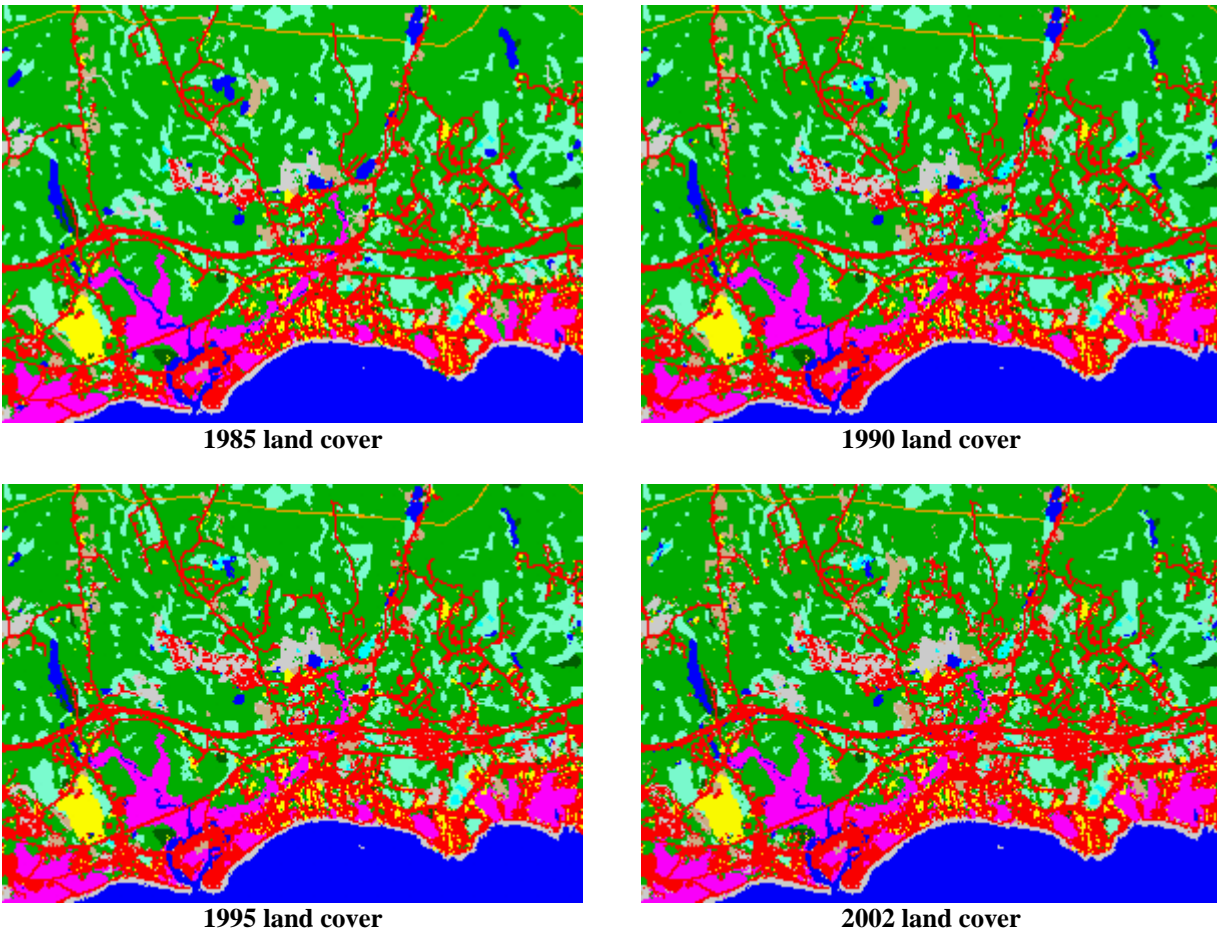


Figure 3. Examples of land cover for each of the four dates classified for a portion of coastal Connecticut

Sub-Pixel Classification Overview

To derive impervious surface estimates directly from Landsat Thematic Mapper imagery for each of the four dates, a pixel spectral un-mixing process was utilized. The Sub-Pixel Classifier™ (SPC), an add-on module to Leica Geosystems' ERDAS Imagine and engineered by Applied Analysis Inc.², is a supervised classifier that enables the detection of materials of interest (MOIs) as a whole or fractional component of an image pixel (100 foot spatial resolution in this case), with a minimum detectable threshold of 20 percent and in increments of 10 percent (*i.e.*, 20-30%, 30-40%, ... 90-100%) (Flanagan and Civco, 2001a; Flanagan and Civco, 2001b). The process consists of identifying and removing the unwanted spectral contribution of materials that make up the background of the pixels and comparing the remaining spectrum to the signature of the material of interest. (Huguenin *et al.*, 2004). The pixel is considered to contain some portion of the MOI if the remaining spectrum matches the signature spectrum.

² http://www.discover-aai.com/software/products/IMAGINE_Subpixel_Classifier.htm

IMAGINE Subpixel Classifier Process

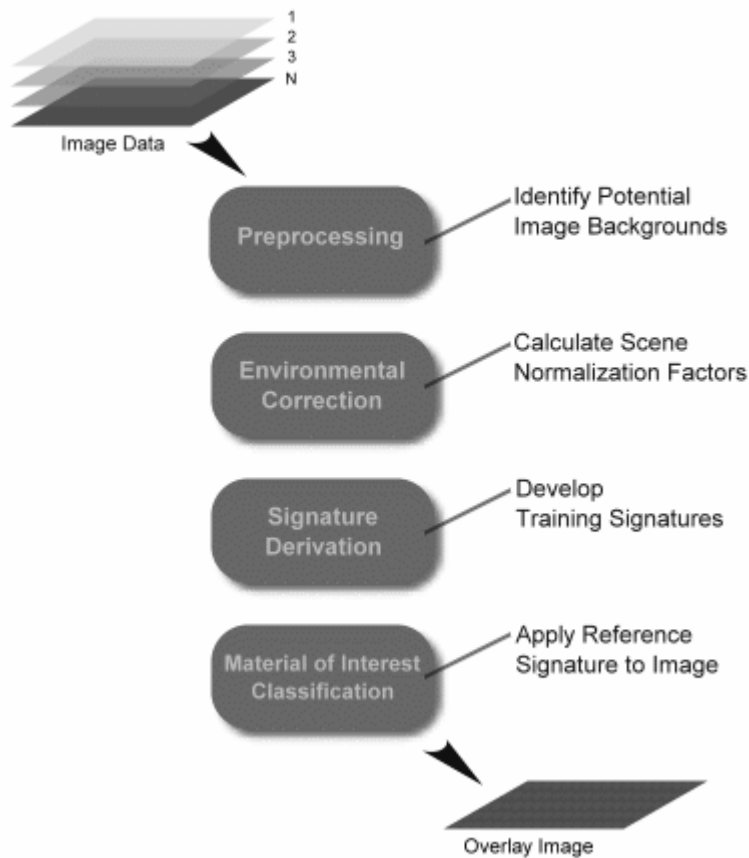


Figure 4. General workflow for conducting a sub-pixel classification.

‘family’ using the optional Signature Combiner function in the SPC. The final step is MOI Classification, utilizes the initial preprocessed image, corresponding environmental correction file, and the ‘family’ signature file. Additional parameters that can be set by the user are the classification tolerance and number of output classes. Signature tolerance is a parameter that can be used to adjust the number of MOI detections, and its value can be increased to include more pixels in the classification result, or decreased to reduce false detections. The number of output classes can vary from two, four, or eight. For this project, eight output classes (intervals of imperviousness) were specified.

Because of the combination of signatures representing the four brightness classes of impervious surface, the output image contains five thematic layers, one for each of the sub-class signatures and one showing detections for the combined contribution of the four sub-classes. It is this composite layer that is used as the impervious surface estimation. The following sections describe the iterative procedure used to derive impervious surface estimates for each of the years 1985, 1990, 1995, and 2002.

The SPC module is comprised of four required steps: image preprocessing, image environmental correction, signature derivation, and MOI classification (Figure 4). The first two steps are autonomous – preprocessing resulting in a hidden companion file to the original image being classified, and environmental correction resulting in a CORENV companion file that contains information pertaining to atmospheric and environmental correction factors. Signature derivation is conducted manually using the Imagine Area-of-Interest (AOI) tool to identify pixels with a minimum of 90 percent imperviousness. Because of the diverse reflectance characteristics of impervious surfaces, signatures were created individually for bright, medium, dark, and very dark sub-classes of impervious surfaces. These sub-classes were grouped into a single signature file known as a

Initial Sub-pixel Classification

Sub-pixel classification was applied independently to each of the four dates of Landsat imagery (1985, 1990, 1995, and 2002) that comprise the study area. To begin, a Tasseled Cap³ (TC) transformation was applied to the 1985 Landsat data to derive a simple brightness layer. This layer was generated to serve solely as a visual guide for the selection of training pixels that represent the four brightness conditions of impervious surfaces. The TC brightness channel was divided into four levels to identify bright, medium, dark, and very dark reflective pixels within the entire scene. The four brightness levels represent various spectral characteristics of the landscape including concrete and asphalt from newly paved conditions to older, more aged conditions, and various reflective characteristics of different roofing and construction materials. It should be noted that these distinctions among impervious surface classes are spectrally-based and do not imply the function of the impervious surface (*i.e.* roof, road, parking lot, etc...) (Flanagan and Civco, 2001a).

Image preprocessing and generation of an environmental correction file were performed as required by the SPC on each of the four dates of Landsat images. Using the derived TC image to differentiate the four brightness levels, training pixels were selected from the Landsat image that represent, at minimum, 90 percent imperviousness. Training pixels were selected for each date concurrently to assure the same training pixel for each date of imagery was used. This process was repeated for each of the four brightness sub-classes with 50–60 training pixels selected for each sub-class. For a successful sub-pixel classification, the quantity of training pixels is less critical than the quality of the pixels (*i.e.*, pixels that represent nearly 100 percent imperviousness), but it is important to try to select pixels that represent the full spectral range of impervious surfaces within each sub-class. The signatures for each sub-class were combined using the SPC Signature Combiner then MOI Classification was performed. Based on tests conducted on a subset of Landsat TM data, a classification tolerance of 1.2 was used. This parameter is used to adjust the number of detections reported by the Sub-pixel Classifier. The number of output classes was set to the maximum of eight classes (*i.e.*, class 1 = 20-30%, class 2 = 30-40%, ... class 8 = 90-100%). Figure 3 provides an example of the raw sub-pixel classification for each of the four dates.

Post-Classification Processing

A fundamental problem in developing IS estimates for multiple dates was to maintain consistency in IS estimates among the four dates so regions can be accurately compared over time. In addition, it is desirable to have the four dates of impervious surface data be compatible with land cover information derived from the same Landsat imagery. As can be seen in Figure 5, a significant amount of area was identified as containing some level of imperviousness, and these vary over the four date period despite using the same training pixel for each date. This variability is due to the different spectral and phenological characteristics of each of the Landsat images. To make the data consistent among dates, compatible with derived land cover data, and enhance classification accuracy, a series of post-processing steps was developed using the Spatial Model Maker in ERDAS Imagine. These models are based on various assumptions that were developed

³ The tasseled cap transformation is a method to compress Landsat reflective bands into fewer bands of information that are associated with the physical scene characteristics of brightness, greenness, and wetness.

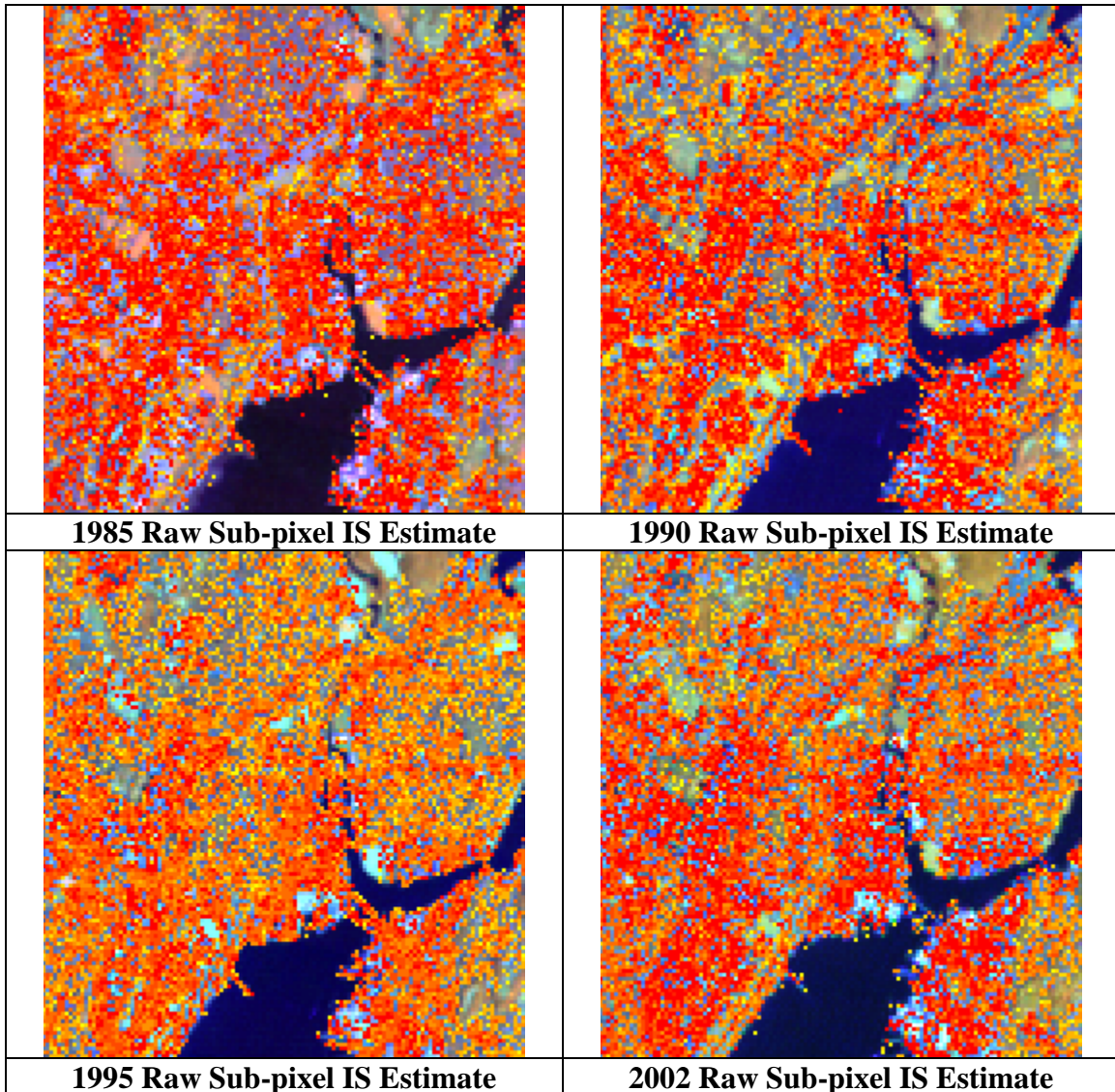


Figure 5. Examples of the raw Sub-pixel impervious surface estimates overlaid on the Landsat Thematic Mapper image for each of the four dates for the New Haven, Connecticut area. Colors range from yellow for low imperviousness to red for high imperviousness.

during this phase of the project and are described below. Overall, three primary concerns existed. These were 1) eliminate the chance of a given pixel to fluctuate between dates such as losing imperviousness between 1985 and 1990, gaining imperviousness between 1990 and 1995, then losing imperviousness again between 1995 and 2002, 2) producing unlikely increases or decreases in imperviousness over time, and 3) filling in pixels that were not detected by the sub-pixel classifier as being impervious in one or more dates but likely to be impervious in reality. A seven step process, described in detail below, was developed to achieve these goals.

Step 1, Combine IS Layers: The first step generates a modified 2002 IS estimate by identifying the highest value (class 0, no imperviousness to class 8, high imperviousness) per pixel among each of the four IS estimates. To begin, the highest per pixel value between the 2002 and 1995 IS estimate layers are identified and maintained to produce a new temporary IS layer. The highest value between this layer and the 1990 IS estimate are then identified and maintained in a second

temporary IS layer and then this layer is compared to the 1985 IS estimated to identify and maintain the highest per pixel value among these two layers to produce the modified 2002 IS estimate. The reasoning behind this step was to fill in any IS data that might have been omitted by the classifier during the classification of any one of the four dates, and to also eliminate fluctuating in IS levels between dates. The modified 2002 IS estimate now represents the maximum level of imperviousness among the four dates and is the primary IS layer on which the other three IS layers are derived following additional post-processing.

Step 2, Derive Average Per-pixel IS for omitted pixels: This step assigns an average per-pixel IS estimate (class 0 through class 8) for each pixel located at the center of a 3-by-3 roving window. The first part of this step is to identify the maximum IS value within a 3-by-3 window and assign it to the center pixel, given the center pixel has a value of zero. All values are used in the 3-by-3 assessment, but assigned only if the center value is zero. Next, this 3-by-3 maximum value layer was averaged with the original IS layer to derive an averaged IS layer. This process was applied to each of the four dates of IS. For the 2002 date, it was applied to the modified 2002 IS layer. The goal of this step was to fill-in missing pixels of imperviousness based on the existence of IS in the surrounding 3-by-3 neighborhood. This situation typically occurred in areas that contain lower levels of impervious surfaces such as residential neighborhoods, but also applies to areas of dense impervious surfaces where, due to missing training data or other phenomena, pixels were omitted from detection by any of the four sub-pixel classifications.

Step 3, Combine Averaged Data and Inclusion of IS Pixels from Developed Land Cover: This step combines previously processed data layers and includes a new IS class based on developed land cover. It contains two parts. The first combines the result from Step 2 (above) and with the original IS by replacing zero-value pixels in the original IS estimate with a pixel value greater than zero from the averaged IS layer. The second part takes all pixels that are identified as non-developed in each respective land cover and masks those pixels from the corresponding IS layer. Pixels that are considered developed in the land cover are then assigned an IS value if such a value exists for a corresponding developed pixel. Otherwise, if no IS value existed for a corresponding developed pixel, a new impervious value is assigned that represents 10 -19 percent impervious. Instead of containing classes 1-8 (10 percent increments starting at 20 percent IS), the IS layer now contains classes 1-9 (10 percent increments starting at 10 percent impervious). It is assumed that if the sub-pixel classifier was unable to detect a level of imperviousness for a given pixel, but the pixel was classified as developed, then it should contain a minimal imperviousness value, as such, a new IS level was created with this assumed imperviousness of 10 – 19 percent.

Step 4, Adjust for Consistency: This step reassigns pixels to assure that pixel values do not inaccurately fluctuate among the 4 dates of impervious surfaces. The model compares two adjacent dates of IS derived in Step 3, identifies those pixels that are different between the two dates, then assigns the pixel value from the most recent date of IS to the earlier date. Ultimately this prevents a pixel from increasing and decreasing in imperviousness over time thus making the dates more consistent.

Step 5, Update Imperviousness Based on Previous IS Date: This step compares the IS layers derived in Step 4 with their corresponding IS layer from Step 3 and replaces values for select pixels from Step 4 with values from Step 3. It is assumed that imperviousness will not change in pixels that are surrounded by other pixels of imperviousness. This model identifies edge pixels of

imperviousness (impervious pixels within two pixels of a zero value pixel) using a search procedure and changes the values of these pixels only if appropriate. If the impervious value is lower in the IS layer from Step 3 then it becomes the new pixel value. The result is that for each successive date of IS, increases in imperviousness occur in the likely fringe of developed areas and not within an already impervious region.

Step 6, On-screen Editing: Some areas, most notably in eastern Long Island, showed a high level of imperviousness for roads where the roads passed through non-vegetated agricultural areas. This is due to the similar reflectance characteristics of the developed and bare soil pixels which resulted in levels of impervious surfaces being higher than they actually are. Such areas were visually identified and edited on-screen to depict a more realistic level of imperviousness.

Step 7, Adjust roads from Class 1 to Class 2 imperviousness: Due to the difficulty of the Sub-pixel Classifier to detect levels of imperviousness for roads, a majority of the roads were identified as impervious due to the inclusion of the land cover information. This resulted in most roads being classified as containing 10-19 percent imperviousness (class 1). It is believed that this level of imperviousness *underestimates* the true level of imperviousness derived from roads. A final model was developed that searches all impervious pixels, identifies those pixels with a class value of 1 (10-19 percent) and are also connected to form a road network, then changes those pixels from a value of 1 (10 to 19 percent impervious) to a class value of 2 (20 to 29 percent impervious). Due to the manner in which the model is setup using the search option, isolated pixels and pixels adjacent to larger clumps of impervious pixels are not changed from class 1 to class 2. The result is a final impervious layer that more realistically depicts the true impervious conditions of roads in the landscape. Figure 6 provides examples of the final impervious surface estimate for each of the four dates.

Validation

To assess the accuracy of the percent impervious estimates derived from the Sub-pixel Classifier and post-processing steps, the results of the estimations were compared to high-accuracy planimetric data for nine Connecticut towns (West Hartford for *circa* 1990, Marlborough, Waterford, and Woodbridge for *circa* 1995, and Groton, Milford, Stamford, Stonington and Suffield for *circa* 2002). These reference data were derived from aerial photographs collected within a couple years of the Landsat image data used to derive the percent impervious surface estimates. Planimetric data were not available for the 1985 time frame. The planimetric data consist of anthropogenic impervious surfaces such as buildings, roads, sidewalks, driveways, and parking lots. The towns with available planimetric data represent a range of different development densities from more rural for Marlborough Stonington, and Suffield to suburban for Waterford and Woodbridge, to urbanized for Groton, Milford, Stamford, and West Hartford. To assess the accuracy of the impervious estimates, two validation procedures were conducted.

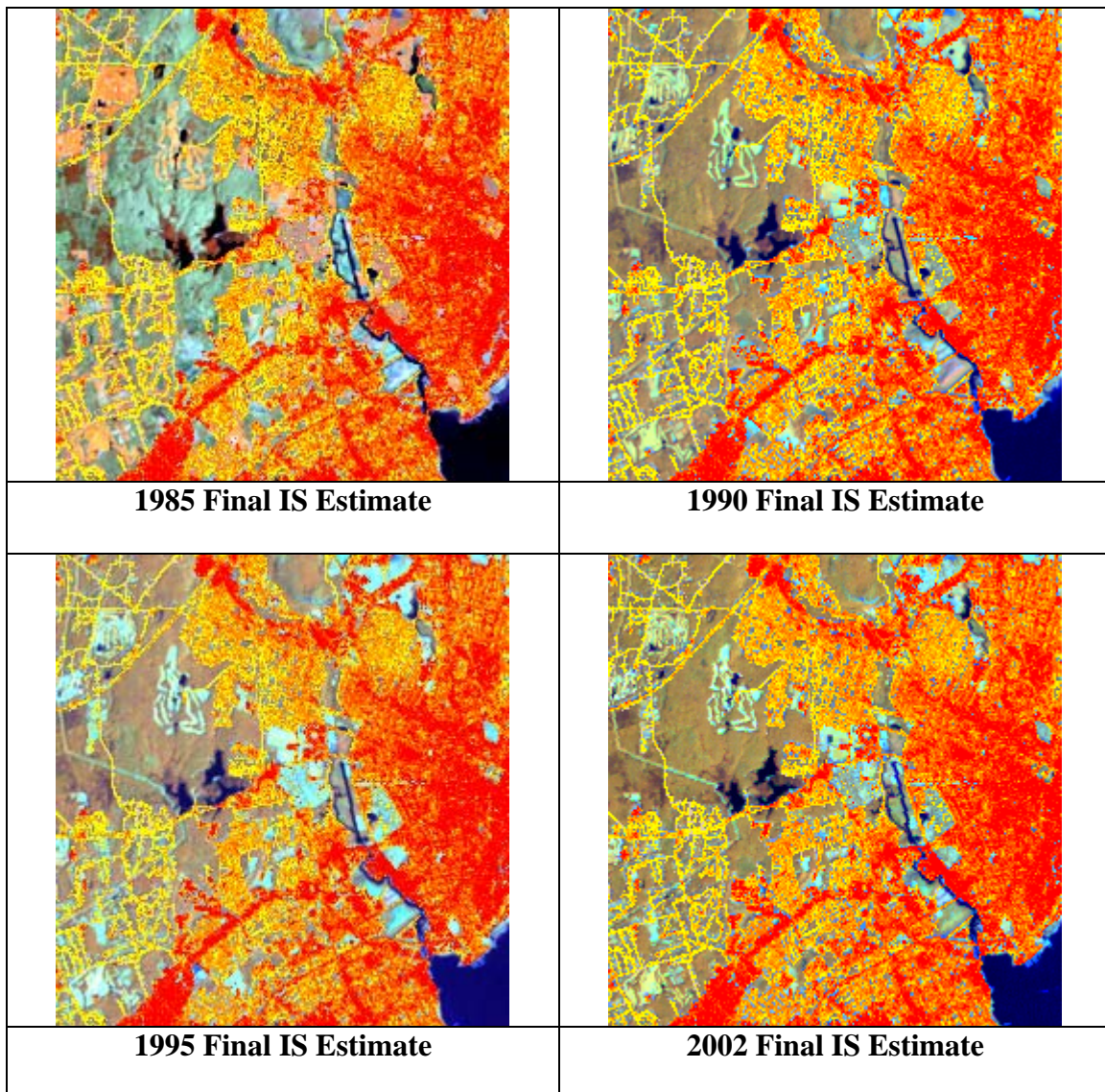


Figure 6. Examples of the final sub-pixel impervious surface estimates overlaid on the Landsat Thematic Mapper image for each of the four dates for the New Haven, Connecticut area. Colors range from yellow for low imperviousness to red for high imperviousness.

The first system of validation compared the planimetric reference data with the estimated data at the pixel level (100 foot spatial resolution). The planimetric data were co-registered to the corresponding Landsat TM image as precisely as possible. A grid corresponding to the 100 foot pixel space of the Landsat TM image was then generated for a rectangular area within each town. The grid was then *unioned* to the planimetric data for each town. From these *unioned* images, database tables were generated from which the percentage of impervious surfaces (on a continuous scale from 0 – 100% impervious) was calculated for each grid cell. These tables were *joined* with the grid file to generate images that represent percent imperviousness for each 100 foot grid cell. The images were recoded into the nine interval classes whose values correspond to the output from the sub-pixel estimation. This final, recoded layer for each of the towns comprised the validation data that were compared to the IS estimate on a per pixel basis. Visual comparisons between the planimetric derived impervious surface and sub-pixel impervious surface estimate, along with bar graphs showing the difference between impervious surfaces for

each image are provided in Appendix A. Additionally, accuracy assessment tables are provided that represent the potential per-pixel accuracy of the impervious surface estimate with the planimetric reference data. These tables provide overall classification accuracy with levels of classification omission and commission.

From a scientific perspective, how well the sub-pixel estimate predicted actual percent imperviousness at the sub-pixel level, compared to the planimetric reference data, is of principal interest. However, even slight mis-registration between the reference planimetric data and Landsat TM data could result in potentially large differences between actual and predicted values. Also, from a management perspective, the assessment of impervious surfaces is more meaningful when reported on a landscape management unit. To provide some validation as to the accuracy of the impervious surface estimation over larger analysis areas, a second validation procedure was conducted. This method compares the planimetric reference data with the estimated impervious surface data over regions of various grid sizes ranging from 500 foot grid cells to 3500 foot grid cells at 500 foot intervals (a total of seven grid sizes) for each of the nine towns. For each town, grids of each size were generated. Any grid cell fully contained within each town boundary was then extracted. The amount of impervious surfaces for each grid cell was calculated for both the planimetric reference data and for the sub-pixel estimated data. Scatter plots were generated for each town for each grid cell size to show the distribution of the expected impervious surface (reference) and estimated impervious surface for each grid cell. A best fit trend line was calculated with the intercept forced to zero and slope calculated, in addition to the root mean square error (RMSE) for each town for each grid size. Examples of these data for West Hartford and Woodbridge can be found in Appendix B. In addition, data for all nine towns were combined into a single scatter plot (one plot per grid size) with a best fit trend line, slope, and RMSE calculated. These scatter plots also can be found in Appendix B.

Results and Discussion

The final results of the impervious surface estimate provide a consistent set of impervious data for the Connecticut and New York portions of the Long Island Sound watershed. As reported in Appendix A, the overall accuracy results⁴ appear to vary for each year. For the years 1990, 1995, and 2002, the overall accuracy was 40.96 percent, 76.00 percent and 53.03 percent respectively. These percent accuracies increased substantially when the number of pixels in adjacent percent impervious surface coverage classes was included in the assessment (light green cells in Tables A1 – A3). The overall accuracies in these cases increased to 62.53 percent, 85.79 percent, and 67.54 percent for the years 1990, 1995, and 2002 indicating that a significant number of estimated pixels are within 10 percent of the reference data. The higher accuracy for the 1995 IS estimate was due to the existence of a large number of zero impervious pixels. Out of 121,140 pixels used in the assessment, 88,237 were correctly classified as containing no impervious

⁴ *It should be noted that the accuracy of impervious surface estimates at the pixel level (i.e., 100 feet) compared to reference data is subject to the quality of the geometric registration of the source data (Landsat TM and ETM) with those reference data (high resolution planimetric maps). Accuracy assessments conducted at this fine scale will represent not only the thematic accuracy of the impervious surface estimates, but also the misregistration between source and reference data, as well as the contemporaneity of those two datasets. A caveat should be placed on the use of data at the pixel level, and instead, a more appropriate, larger scale is suggested.*

surfaces (72.84 percent of the total). While this could be considered a minor success by not erroneously identifying impervious pixels where no imperviousness existed, the accuracy of pixels actually detecting the nine classes of imperviousness remained relatively low (see user's and producer's accuracy for each impervious class in Tables A1 – A3). The 1990 assessment used a total of 37,416 pixels with 10,868 pixels being correctly classified as containing no impervious surfaces (29.05 percent), and the 2002 assessment used 30,182 pixels with 13,783 being correctly classified as having no impervious surfaces (45.67 percent). As mentioned previously, it is difficult to compare these results on a per pixel basis due to possible misalignment issues between the planimetric reference and estimate impervious results. Also, since different towns and areas were used in the assessment for each analysis year, it is difficult to directly compare the different dates of impervious surface estimates.

Examining the accuracy of the impervious surface estimates over grid cells of various size (larger than the 100 foot pixel resolution of the estimate) provides a more meaningful assessment of the accuracy of the data for two reasons. First, misalignment between the spatially-generalized planimetric data and the sub-pixel estimation is greatly minimized. Second, although knowing the specific location of impervious surfaces, use of these data in a management framework will likely be summarized over a larger analysis area, such as a watershed. As such, reporting the accuracy at various grid sizes, users of the data will be provided a better assessment as to the accuracy of the data. An overall assessment shows that the smaller the grid cell or analysis unit the larger the potential error. Comparing the reference data to the estimated data for all nine towns together, a user could expect the average error in IS estimates to be approximately plus/minus 8.0 percent at a grid cell size of 500 feet. This value drops to plus/minus 4.0 percent once the grid cell increases to 3,500 feet (see Appendix B).

There is a noticeable trend in accuracy in terms of regions containing lower levels of impervious surfaces versus those containing higher levels of imperviousness. For those towns having overall lower levels of impervious surfaces (*i.e.*, more rural development densities), the IS estimate tends to under-estimate the overall actual impervious level, plus the overall error tends to be lower. The reverse is found for the higher impervious areas (*i.e.*, more of an urban development density) with the IS estimate over-estimating the amount of impervious surfaces present and the error level is higher. The under-estimation for the rural areas is most likely a function of both the Sub-pixel Classifier not being able to detect levels of MOIs below a 20 percent threshold and the inability of the land cover classification to detect smaller impervious features prominent in the rural landscape due to the moderate resolution of the Landsat TM sensor. The lower error level is due to the high number of areas with no impervious surfaces. The over-estimation of the more urbanized areas is likely the result of the post-processing procedures used to combine the final IS estimates, which may inflate the amount of impervious surfaces present at the pixel level. In addition, the higher level of error is due to the fact that there are more pixels that contain some level of impervious surfaces creating a higher likelihood of error.

Despite the apparent per-pixel inaccuracies of the sub-pixel impervious surface estimate, the Sub-pixel Classifier is capable of producing adequate results when compared to actual impervious surfaces derived from planimetric reference data. It has been shown that the level of error decreases as the size of the summary area increases. An advantage of this technique are the ability to identify the location and level of imperviousness within an analysis unit such as a watershed. A limitation of the Sub-pixel Classifier, however, is that it does not detect MOIs below a 20 percent threshold increasing potential error in regions of lower imperviousness.

Inclusion of land cover information for developed pixels to derive a 10 percent impervious class and also to mask erroneously detected impervious surfaces (*i.e.*, bare fields and barren land) was a necessary step to generate a more representative estimate of impervious surfaces and to force the impervious surface information to be compatible with the land cover data. Used together, these data will improve the ability of coastal resource and land use managers to be able to identify the location and change in land cover (summarized by land cover category in Table 2) and estimated impervious surfaces information summarized over a given analysis unit (summarized over geographic areas in Table 3 and by watershed in Appendix C) and will provide a significant advantage for the monitoring and protection of the coastal resources within Long Island Sound.

Table 2. Summary of land cover category by area for each of the four dates covering the Connecticut and New York portions of the Long island Sound watershed.

Long Island Sound Watershed Land Cover (Connecticut and New York region)								
	1985		1990		1995		2002	
	acres	hectares	acres	hectares	acres	hectares	acres	hectares
Developed	686,039	277,630	730,111	295,466	745,015	301,497	768,747	311,101
Turf & Grass	186,823	75,605	186,304	75,395	187,231	75,770	187,895	76,038
Other Grasses & Agriculture	376,780	152,478	387,030	156,626	395,675	160,124	406,065	164,329
Deciduous Forest	1,719,196	695,735	1,668,723	675,309	1,643,059	664,923	1,610,906	651,911
Coniferous Forest	321,722	130,196	317,074	128,316	314,449	127,253	310,998	125,857
Water	934,305	378,100	933,637	377,830	930,878	376,713	926,003	374,740
Non-forest Wetland	7,958	3,220	12,235	4,951	13,608	5,507	15,942	6,451
Forested Wetland	124,277	50,293	118,960	48,142	116,683	47,220	115,623	46,791
Tidal Wetland	18,893	7,646	18,878	7,640	18,893	7,646	19,050	7,709
Barren	31,296	12,665	34,484	13,955	41,927	16,967	46,284	18,731
Utility ROW	10,281	4,161	10,132	4,100	10,152	4,108	10,057	4,070
TOTAL	4,417,569	1,787,729	4,417,569	1,787,729	4,417,569	1,787,729	4,417,569	1,787,729

Table 3. Summary of the level of impervious surfaces for each of the four dates for the Connecticut and New York portions of the Long island Sound watershed.

Long Island Sound Watershed Percent Impervious Surfaces (Connecticut and New York region)				
	1985	1990	1995	2002
LIS Watershed	8.304	8.953	9.287	9.729
Connecticut Portion	6.134	6.750	7.056	7.460
New York Portion	31.677	32.680	33.310	34.171

References

- Arnold, C.L and C.J. Gibbons. 1996. Impervious surface coverage: the emergence of a key environmental indicator. *Journal of the American Planning Association*. 62(2):3243-258.
- Beach, D. 2002. Coastal Sprawl: The Effects of Urban Design on Aquatic Ecosystems in the United States. Pew Oceans Commission, Arlington, Virginia.
- Bird, S.L., S.W. Alberty, L.R. Exum. 2000. Generating high quality impervious cover data. *Quality Assurance*. 8(9):1-103.
- Bird, S., J. Harrison, L. Exum, S. Alberty and C. Perkins. 2002. "Screening to Identify and Prevent Urban Storm Water Problems: Estimating Impervious Area Accurately and Inexpensively." *Proceedings for National Water Quality Monitoring Conference*, May 20-23, 2002, Madison, WI.
- Booth, D.B., and L.E. Reinfelt. 1993. Consequences of urbanization on aquatic systems – measured effects, degradation thresholds, and corrective strategies. *Proceedings of Watershed 1993: A National Conference on Watershed Management*. March 21-24, Alexandria, VA. pp. 545-550.
- Boyer, E.W., C.L. Goodale, N.A. Jaworssk, and R.W. Howarth. 2002. Anthropogenic nitrogen sources and relationships to riverine nitrogen export in the northeastern USA. *Biogeochemistry*. 57(1):137-169.
- Brabec, E., S. Schulte, and P.L. Richards. 2002. Impervious surfaces and water quality; A review of current literature and its implications for watershed planning. *J. of Planning Literature*. 16(4): 499-514.
- Carpenter, S. R., N. F. Caraco, D. L. Correll, R. W. Howarth, A. N. Sharpley, and V. H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Applications* 8(3): 559–568.
- Clausen, J.C., G. Warner, D. Civco and M. Hood. 2003. Nonpoint Education for Municipal Officials Impervious Surface Research: Final Report. Connecticut DEP. 18p.
- Flanagan, M. and D.L. Civco. 2001a. Subpixel impervious surface mapping. *Proceedings 2001 ASPRS Annual Convention*, St. Louis, MO. 13 p.
- Flanagan, M and D.L. Civco. 2001b. Imagine Subpixel Classifier Version 8.4: Software Review. *Photogrammetric Engineering and Remote Sensing*. 67(1):23-28.
- Hall, M.J. 1984. Urban Hydrology, Elsevier Applied Science Publishers, Northern Ireland. 299p.
- Herlihy, A.T., J.L. Stoddard, and C.B. Johnson. 1998. The relationship between stream chemistry and watershed land cover data in the mid-Atlantic region, U.S. *Water Air and Soil Pollution*. 105(1-2):377-386.

- Huguenin, R.L., M.H. Wang, R. Biehl, S. Stoodley, and J. N. Rogers 2004. Automated subpixel photobathymetry and water quality mapping. *Photogrammetric Engineering and Remote Sensing*. 70(1):111-123.
- Hurd, J.D., D.L. Civco, E.H. Wilson, S. Prisloe and C. Arnold. 2003. Temporal characterization of Connecticut's landscape: methods, results, and applications. *Proceedings. 2003 ASPRS Annual Convention*, Anchorage, AK. 12 p.
- Ji, M.H., and Jensen, J.R. 1999. Effectiveness of subpixel analysis in detecting and quantifying urban imperviousness from Landsat Thematic Mapper imagery. *Geocarto International*, 14(4):31-39.
- Justice, D. and F. Rubin. 2003. Developing impervious surface estimates for coastal New Hampshire. *A Final Report to the New Hampshire Estuaries Project*. The University of New Hampshire, Durham, NH. 25 p.
- Koeln, G. and J. Bissonnette. 2000. Cross-correlation analysis: mapping landcover change with a historic landcover database and a recent, single-date multispectral image. *Proceedings 2000 ASPRS Annual Convention*, Washington, D.C.
- Roy, H.A., D.A. Rosemond, J.M. Paul, D.S. Leign, and B.J. Wallace. 2003. Stream macroinvertebrate response to catchment urbanization. *Freshwater Biology*. 48:329-346.
- Schueler, T. R., 1994. The importance of imperviousness. *Watershed Protection Techniques*, 1(3):100-111.
- Smith, F.G.F, N. Herold, T Jones and C. Sheffield. 2002. Evaluation of cross-correlation analysis, a semi-automated cChange detection, for updating of an existing landcover classification. In Proc. 2002 ASPRS Annual Convention, Washington D.C.
- U.S. Environmental Protection Agency (EPA). 1994. The Quality of Our Nation's Water: 1992 Report. EPA-841-S-94-002. Office of Water Quality. U.S. Environmental Protection Agency. Washington D.C. 20460.
- U.S. Environmental Protection Agency (EPA). 1996. The National Water Quality Inventory Report to Congress, 1996. Office of Water Quality. U.S. Environmental Protection Agency. Washington, D.C., 200 p.
- U.S. Environmental Protection Agency (EPA). 2002. National Water Quality Inventory. 2000 Report. EPA-841-R-02-001. Office of Water. Washington D.C. 20460.
- Wang, Y.Q., Zhang, X. and W. Lampa. 2000. "Improvement of Spatial Accuracy in Natural resources Mapping using Multisensor Remote Sensing and Multisource Spatial Data", in *Proceedings 4th International Symposium on Spatial Accuracy Assessment in natural Resources and environmental Sciences*, Amsterdam, Netherlands, July, 2000. pp. 723-730.
- Ward, D., Phinn, S.R. and A.T. Murry. 2000. Monitoring growth in rapidly urbanized areas using remotely sensed data", *Professional Geographer*, Vol. 52(3):371-386.

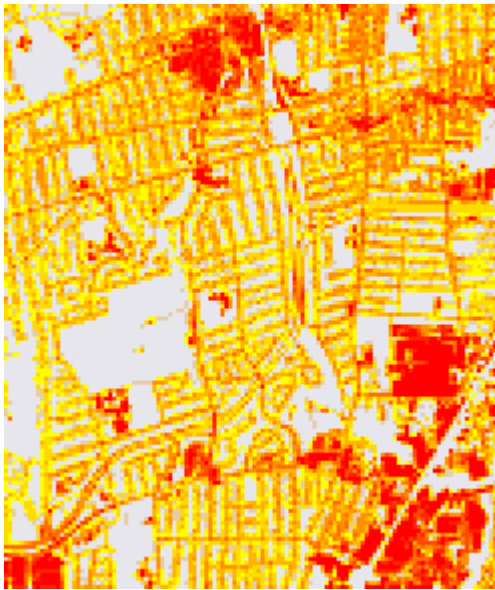
Wickham, J.D., R.V. O'Neill, K.H. Riitters, E.R. Smith, T.G. Wade and K.B. Jones. 2002. Geographic targeting of increases in nutrient export due to future urbanization. *Ecological Applications* 12(1):93-106.

Yang, L., G. Xian, J.M. Klaver and B. Deal. 2003. Urban land-cover change detection through sub-pixel imperviousness mapping using remotely sensed data. *Photogrammetric Engineering and Remote Sensing* 9(9):1003-1010.

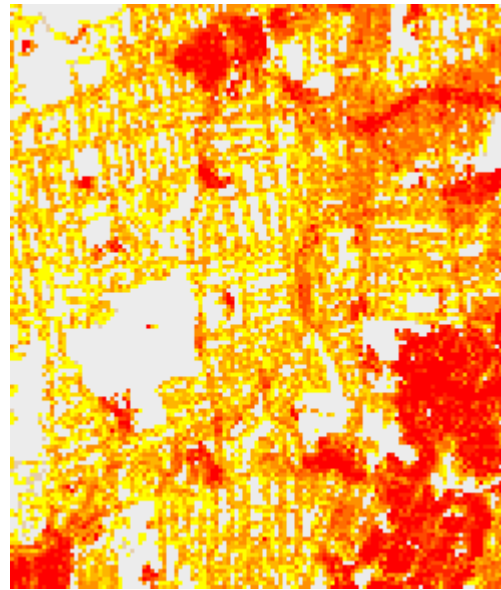
Appendix A

Per-pixel Comparison of Planimetric and Estimated Percent Impervious Surfaces at 10 percent Increments

Circa 1990 West Hartford Validation Area 1



Planimetric Reference Data
% IS total area = 35.96



Impervious Surface Estimate
% IS total area = 39.80

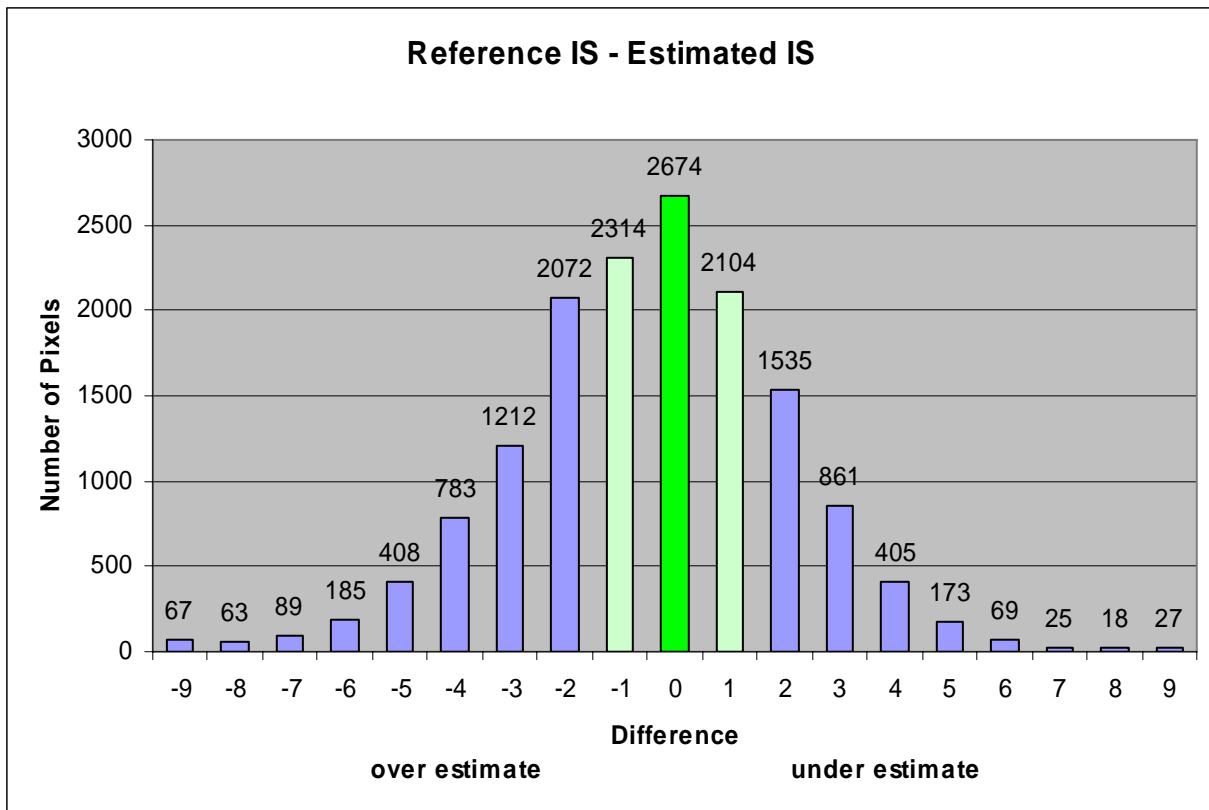
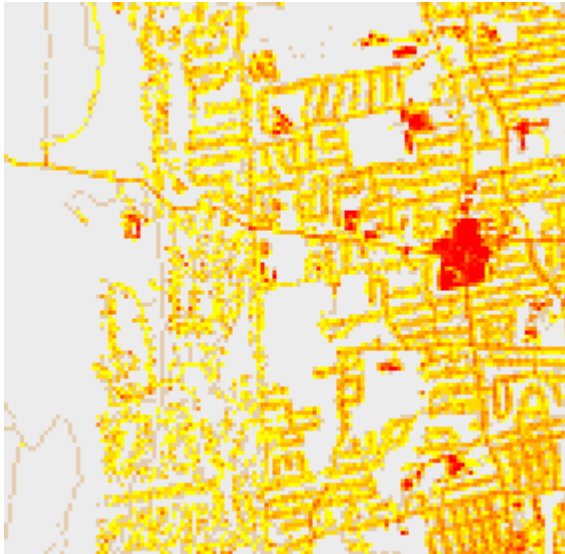
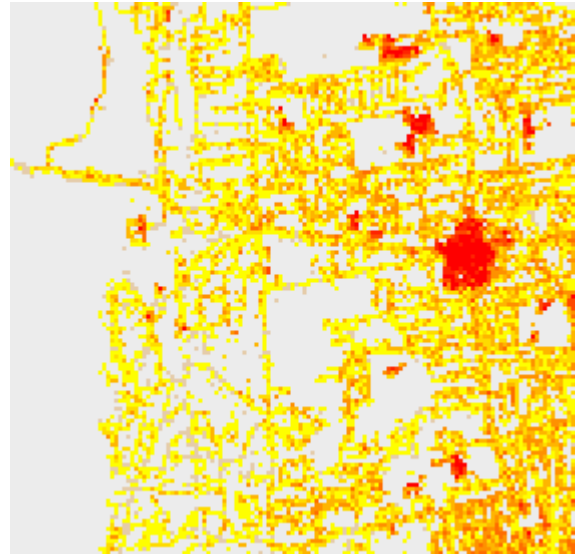


Figure A-1. Comparison of planimetric impervious data to the 1990 impervious surface estimate for a portion of West Hartford, Connecticut. The bar graph displays the pixel value difference between both data sets excluding pixels that contained a zero value of imperviousness in both datasets.

Circa 1990 West Hartford Validation Area 2



Planimetric Reference Data
% IS total area = 20.01



Impervious Surface Estimate
% IS total area = 19.02

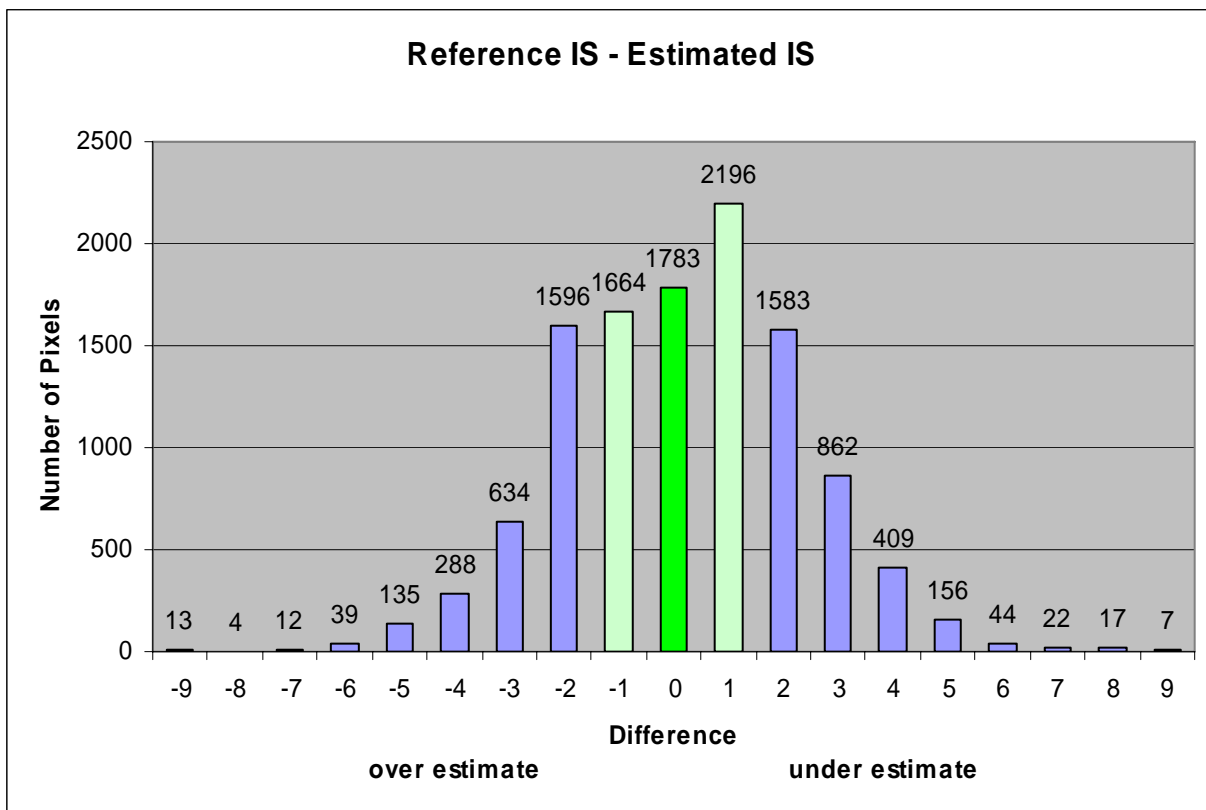
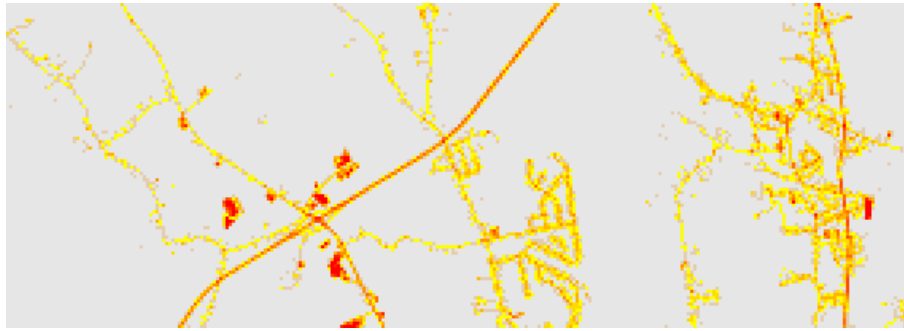
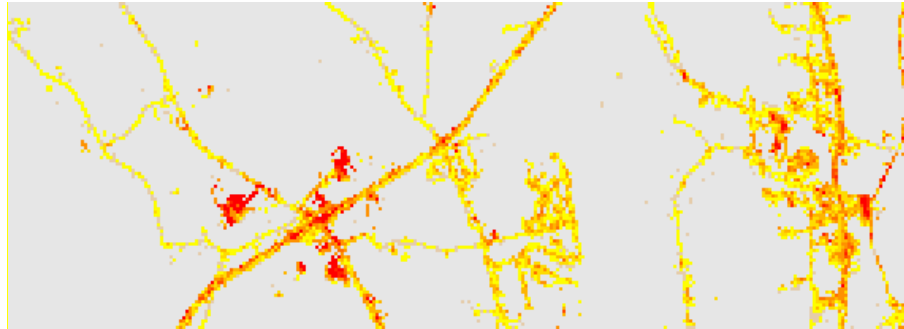


Figure A-2. Comparison of planimetric impervious data to the 1990 impervious surface estimate for a portion of West Hartford, Connecticut. The bar graph displays the pixel value difference between both data sets excluding pixels that contained a zero value of imperviousness in both datasets.

Circa 1995 Waterford Validation Area 1



Planimetric Reference Data % IS total area = 8.70



Impervious Surface Estimate % IS total area = 9.89

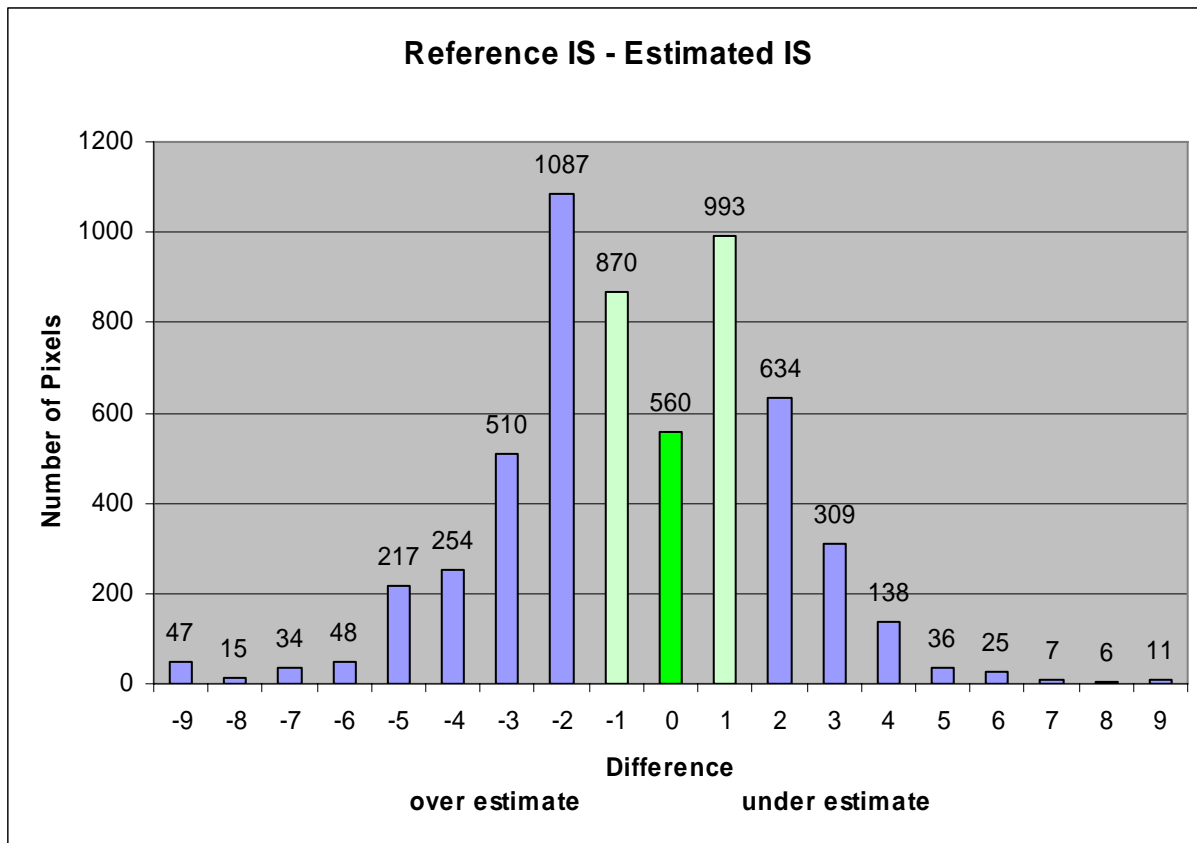
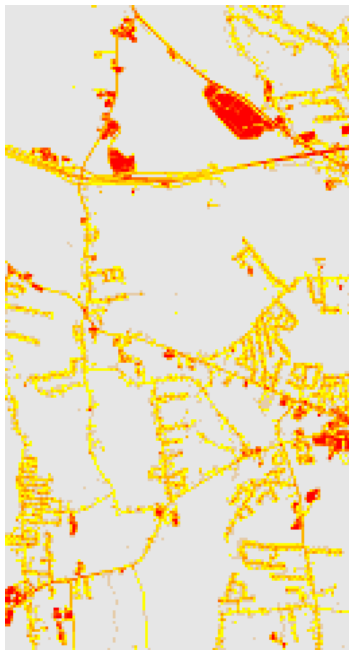
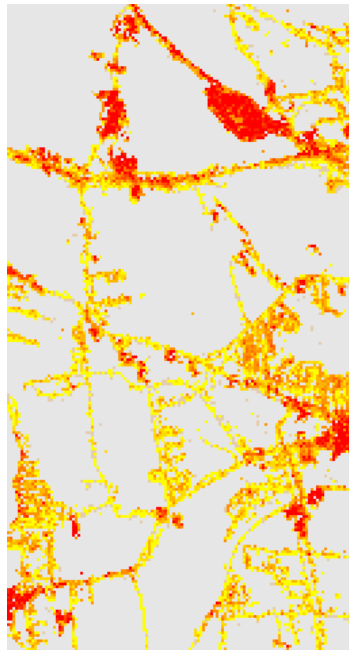


Figure A-4. Comparison of planimetric impervious data to the 1995 impervious surface estimate for a portion of Waterford, Connecticut. The bar graph displays the pixel value difference between both data sets excluding pixels that contained a zero value of imperviousness in both datasets.

Circa 1995 Waterford Validation Area 2



Planimetric Reference Data
% IS total area = 12.82



Impervious Surface Estimate
% IS total area = 15.70

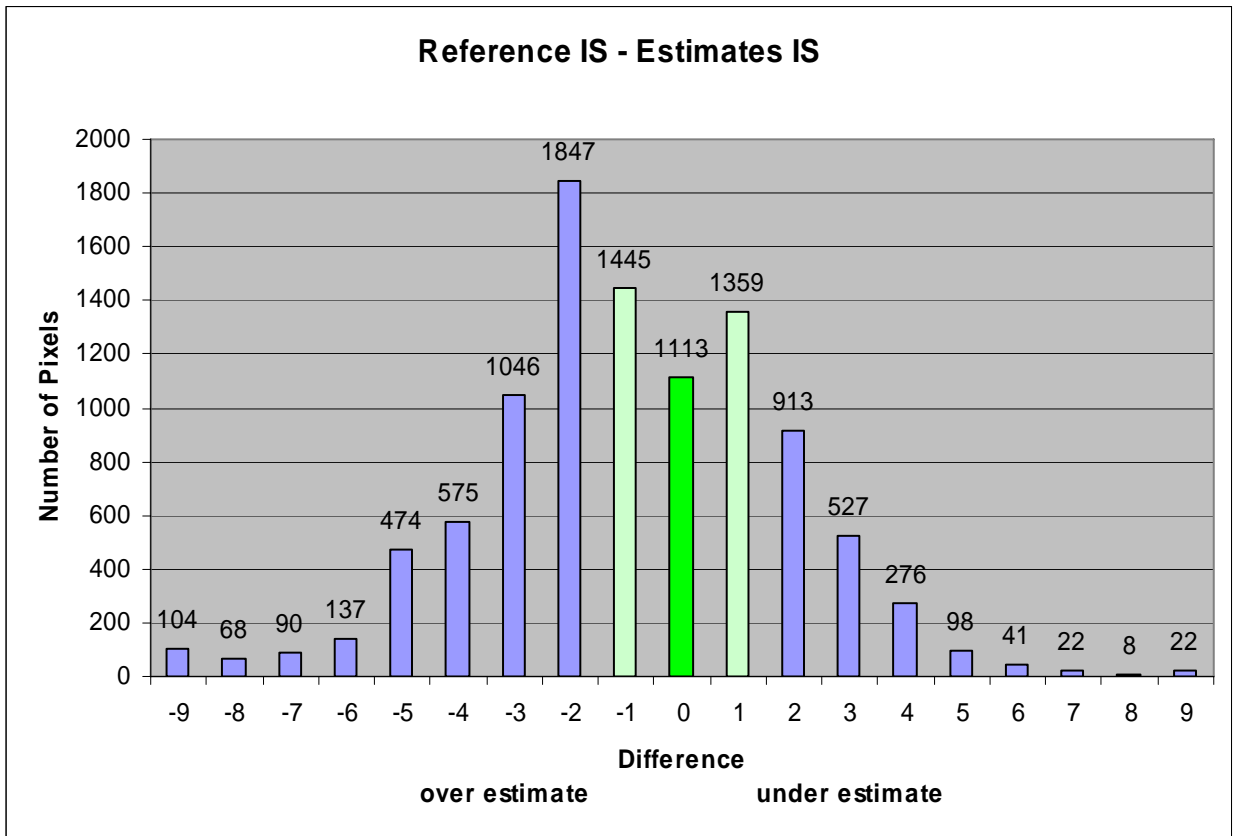
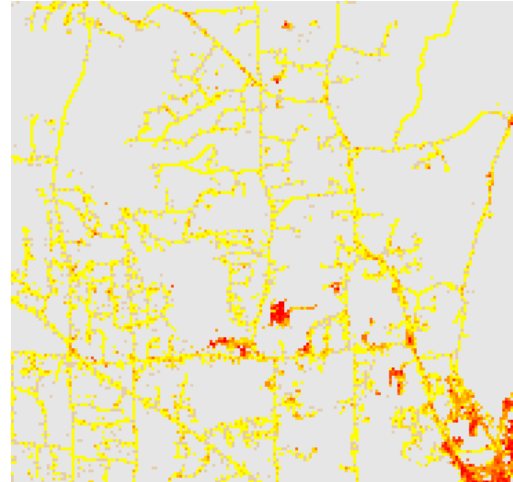


Figure A-6. Comparison of planimetric impervious data to the 1995 impervious surface estimate for a portion of Waterford, Connecticut. The bar graph displays the pixel value difference between both data sets excluding pixels that contained a zero value of imperviousness in both datasets.

Circa 1995 Woodbridge Validation Area



Planimetric Reference Data
% IS total area = 11.13



Impervious Surface Estimate
% IS total area = 9.85

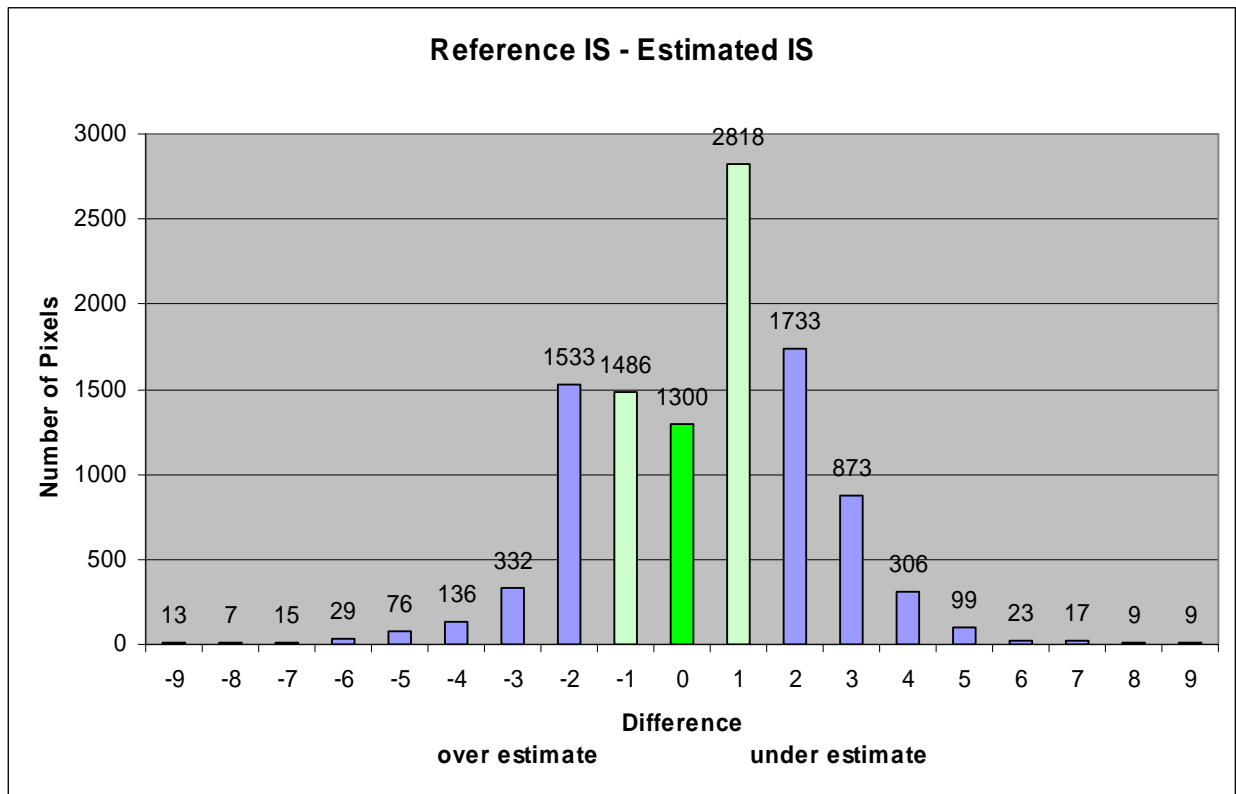
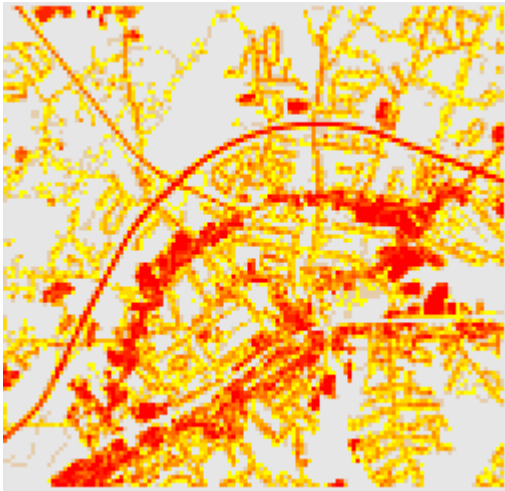
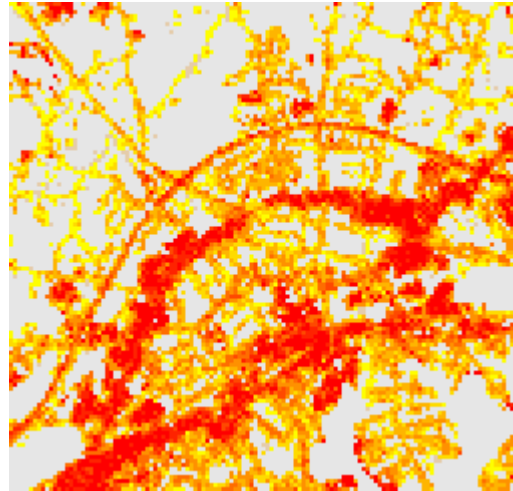


Figure A-7 Comparison of planimetric impervious data to the 1995 impervious surface estimate for a portion of Woodbridge, Connecticut. The bar graph displays the pixel value difference between both data sets excluding pixels that contained a zero value of imperviousness in both datasets.

Circa 2002 Milford Validation Area



Planimetric Reference Data
% IS total area = 27.36



Impervious Surface Estimate
% IS total area = 33.70

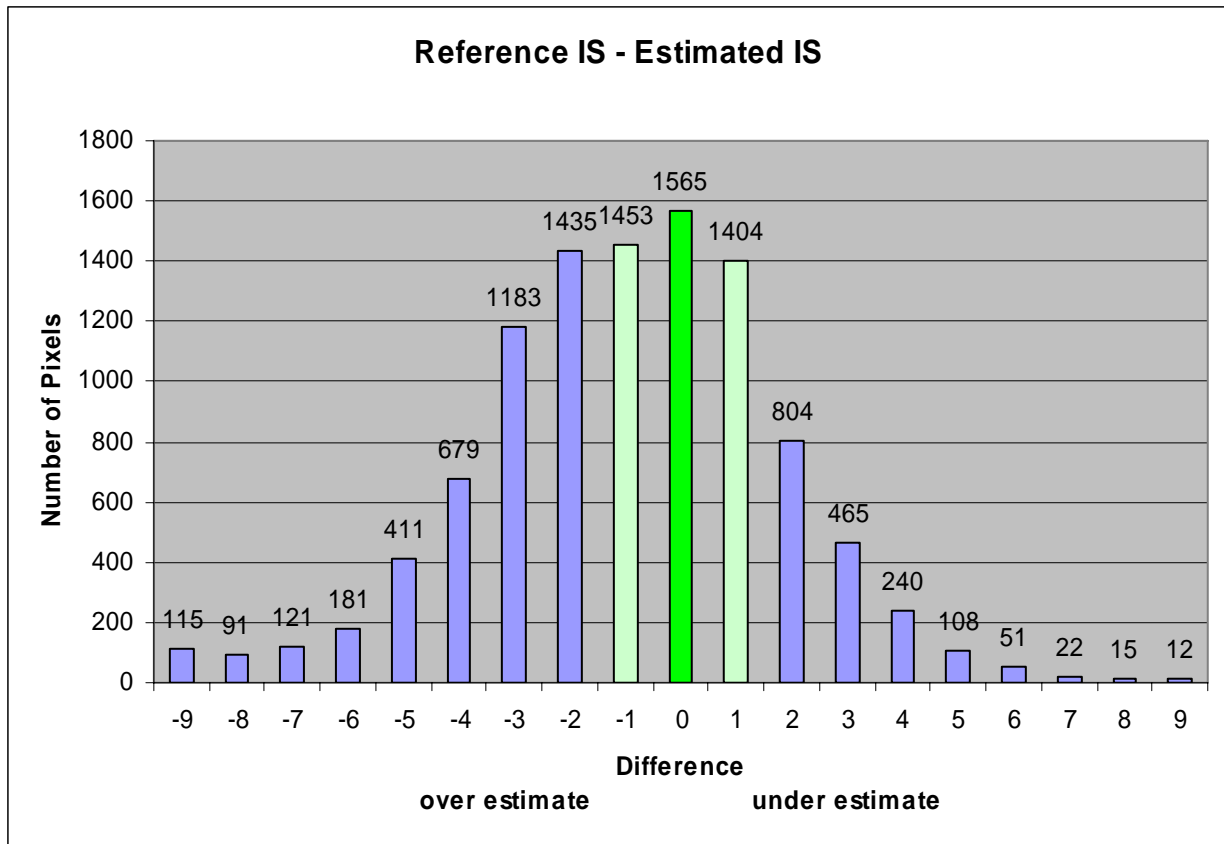
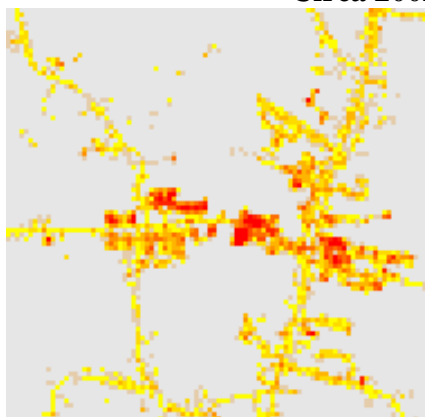
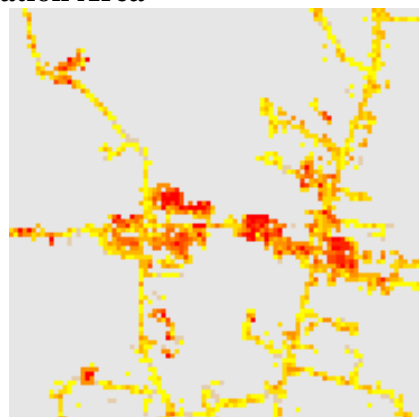


Figure A-7 Comparison of planimetric impervious data to the 2002 impervious surface estimate for a portion of Milford, Connecticut. The bar graph displays the pixel value difference between both data sets excluding pixels that contained a zero value of imperviousness in both datasets.

Circa 2002 Suffield Validation Area



Planimetric Reference Data
% IS total area = 11.78



Impervious Surface Estimate
% IS total area = 11.38

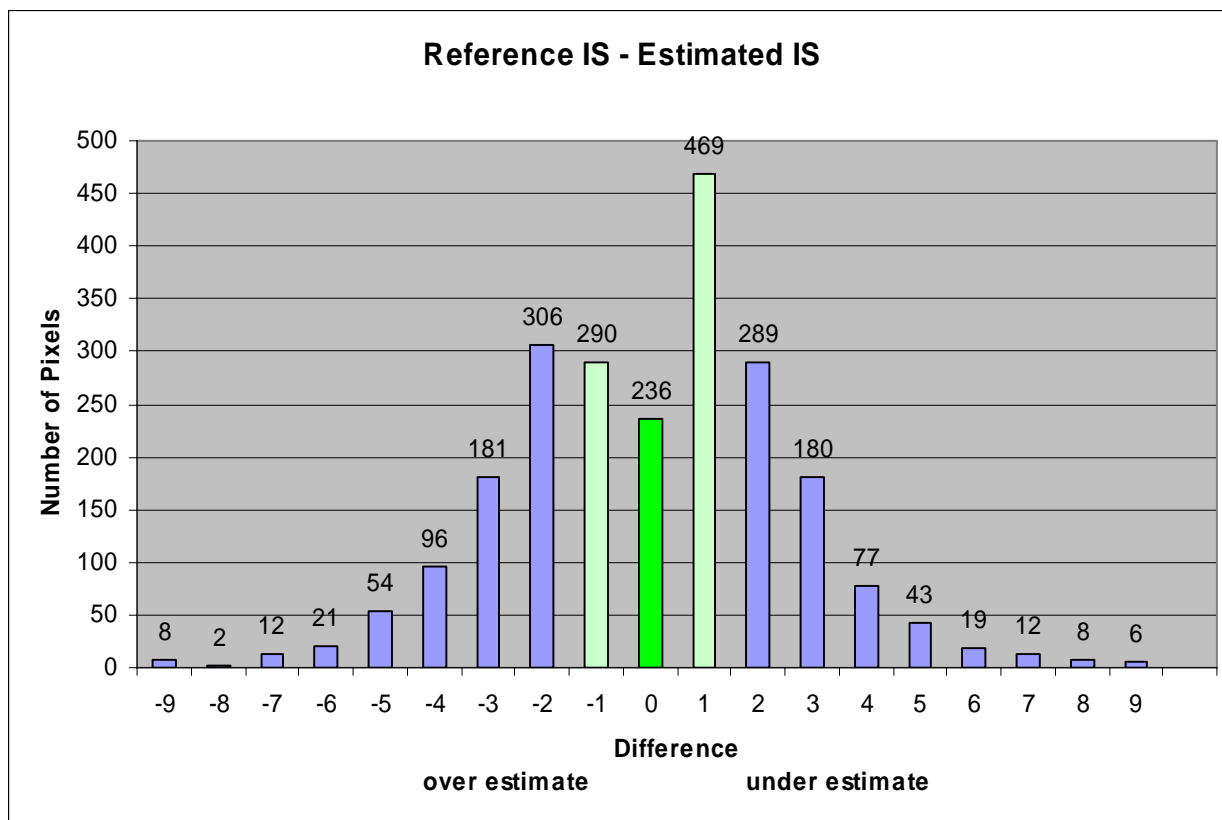
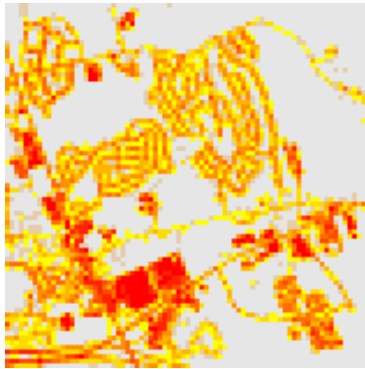
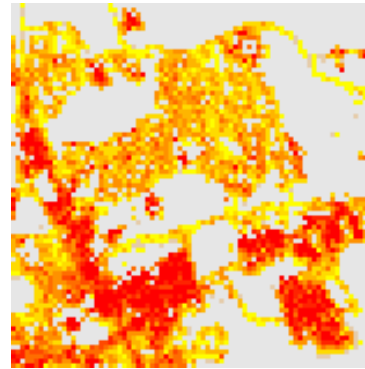


Figure A-8. Comparison of planimetric impervious data to the 2002 impervious surface estimate for a portion of Suffield, Connecticut. The bar graph displays the pixel value difference between both data sets excluding pixels that contained a zero value of imperviousness in both datasets.

Circa 2002 Groton Validation Area



Planimetric Reference Data
% IS total area = 24.71



Impervious Surface Estimate
% IS total area = 31.42

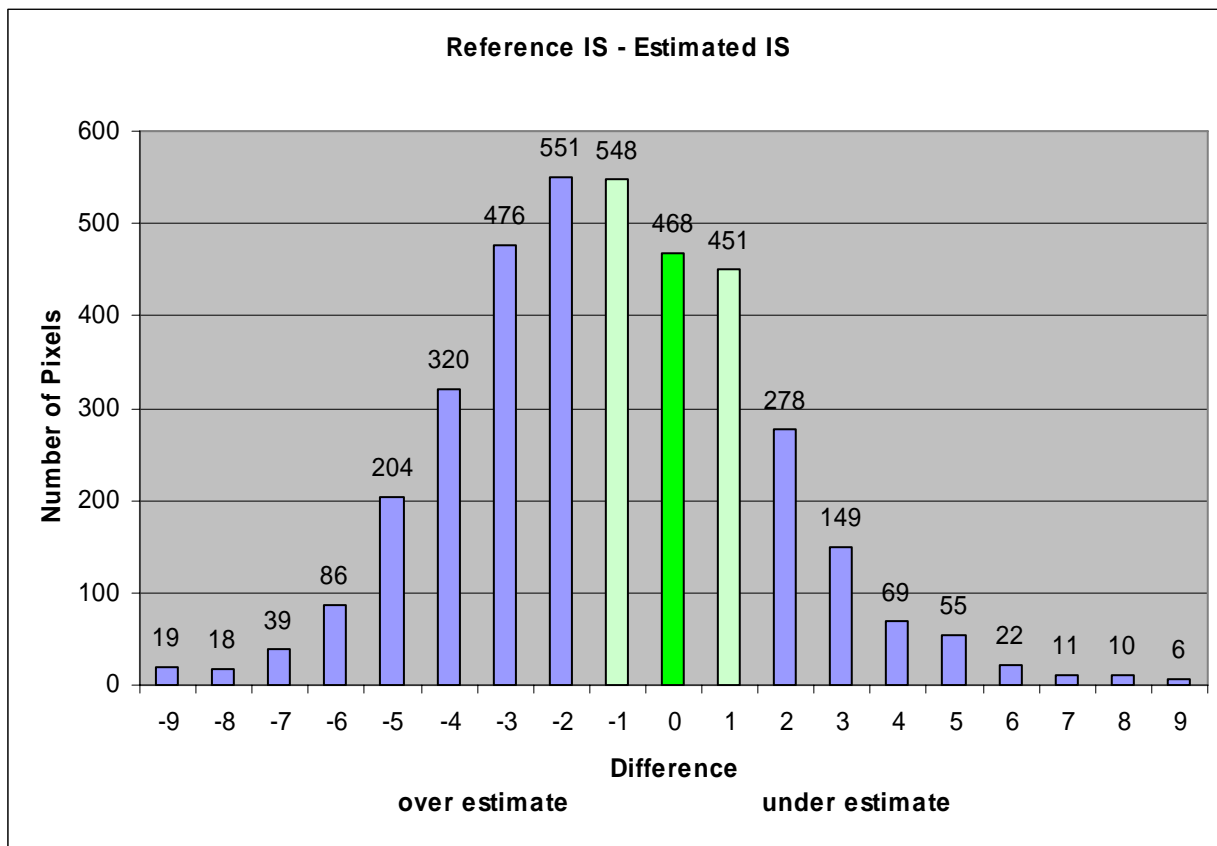


Figure A-9. Comparison of planimetric impervious data to the 2002 impervious surface estimate for a portion of Groton, Connecticut. The bar graph displays the pixel value difference between both data sets excluding pixels that contained a zero value of imperviousness in both datasets.

Table A-1. Error matrix for the 1990 impervious surface estimate based on data from the town of West Hartford

		REFERENCE											
ESTIMATE	CLASS	0	1	2	3	4	5	6	7	8	9	Commission	User's Accuracy
	0	10868	1499	1412	1115	675	290	103	43	35	34	5206	67.61
	1	236	69	71	44	16	3	2	0	0	0	372	15.65
	2	1480	731	1101	1053	917	389	70	14	4	4	4662	19.10
	3	552	309	515	592	568	343	106	21	8	6	2428	19.60
	4	437	353	586	864	930	477	157	26	12	15	2927	24.11
	5	289	229	392	619	825	686	261	81	33	33	2762	19.90
	6	106	70	127	235	288	347	202	65	45	38	1321	13.26
	7	39	33	44	93	99	164	154	118	81	119	944	12.50
	8	29	25	26	53	78	91	78	99	91	225	704	11.45
	9	80	38	37	59	87	107	124	144	207	668	883	43.07
Omission		3248	3287	3210	4135	3553	2211	1055	493	425	474		
Producer's Accuracy		76.99	2.06	25.54	12.52	20.75	23.68	16.07	19.31	17.64	58.49		<i>Overall 40.96</i>

n = 37,416 pixels

Correctly classified = 15,325 pixels (green cells)

Overall accuracy = 40.96% (green cells)

Overall accuracy combining {-10%, 0%, and +10} ΔIS classes = 62.53% (green and light green cells)

Table A-2. Error matrix for the 1995 impervious surface estimate based on data from the towns of Marlborough, Waterford, and Woodbridge

		REFERENCE											
ESTIMATE	CLASS	0	1	2	3	4	5	6	7	8	9	Commission	User's Accuracy
	0	88237	4506	2890	1610	654	224	85	49	23	44	10085	89.74
	1	1426	620	542	294	77	18	1	1	0	0	2359	20.81
	2	3501	1824	1724	1186	460	121	35	3	4	0	7134	19.46
	3	1205	633	583	514	338	129	51	16	4	5	2964	14.78
	4	591	341	411	476	373	160	53	24	9	7	2072	15.26
	5	635	259	286	389	324	177	110	41	21	38	2103	7.76
	6	105	67	66	105	104	97	66	38	26	28	636	9.40
	7	84	35	50	51	60	63	69	40	30	35	517	7.74
	8	42	10	19	22	33	42	50	58	44	100	376	10.48
	9	171	57	55	79	105	101	91	93	120	267	872	23.44
		Omission	7760	7732	4902	4212	2155	955	545	323	237	257	
	Producer's Accuracy	91.92	7.42	26.02	10.88	14.75	15.64	10.80	11.02	15.66	50.95		<i>Overall 76.00</i>

n = 121,140 pixels

Correctly classified = 92,062 pixels (green cells)

Overall accuracy = 76.00% (green cells)

Overall accuracy combining {-10%, 0%, and +10} ΔIS classes = 85.79% (green and light green cells)

Table A-3. Error matrix for the 2002 impervious surface estimate based on data from the towns of Groton, Suffield, and Milford.

		REFERENCE												
ESTIMATE	CLASS	0	1	2	3	4	5	6	7	8	9	Commission	User's Accuracy	
	0	13738	1024	761	551	303	182	85	45	33	24	3008	82.04	
	1	165	24	24	16	5	0	1	1	0	0	212	10.17	
	2	671	241	255	179	117	51	16	6	1	0	1282	16.59	
	3	797	336	406	386	300	174	69	11	6	5	2104	15.50	
	4	508	261	371	443	408	295	116	37	15	11	2057	16.55	
	5	418	208	286	310	364	341	190	60	31	41	1908	15.16	
	6	130	72	115	139	196	200	158	68	52	50	1022	13.39	
	7	93	41	56	87	118	117	116	100	92	75	895	11.17	
	8	49	23	37	42	54	75	101	118	116	152	651	15.12	
	9	142	62	56	80	81	123	164	190	238	481	1136	29.75	
	Omission		2973	2268	2112	1847	1538	1217	858	536	468	358		
Producer's Accuracy		82.21	1.05	10.77	17.29	20.97	21.89	15.55	15.72	19.86	57.33		<i>Overall</i> 53.03	

n = 30,182 pixels

Correctly classified = 16,007 pixels (green cells)

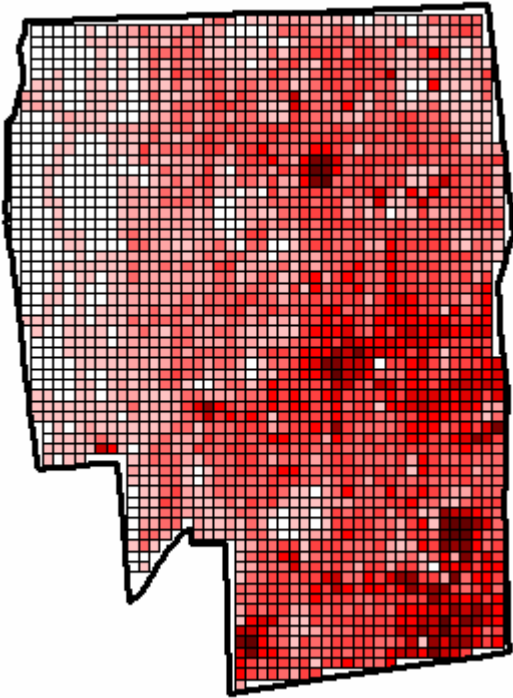
Overall accuracy = 53.03% (green cells)

Overall accuracy combining {-10%, 0%, and +10} ΔIS classes = 67.54% (green and light green cells)

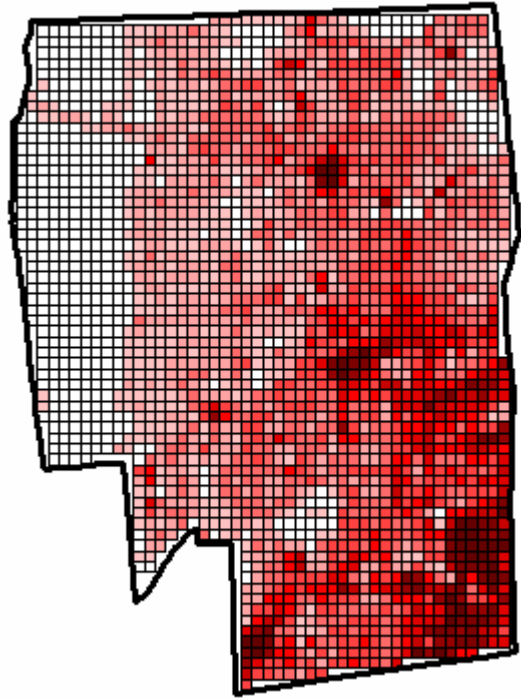
Appendix B

A Sampling of the Results of Comparing Reference and Estimated Impervious Surface Results Summarized Over Grid Cells of Various Sizes for West Hartford and Woodbridge Connecticut

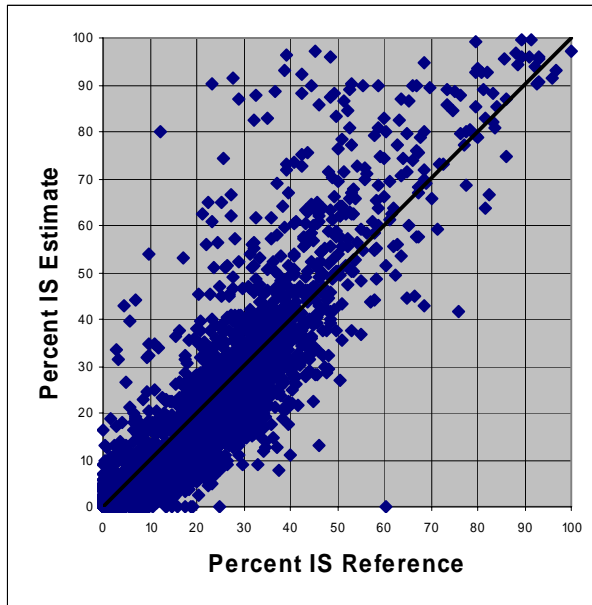
Circa 1990 West Hartford Impervious Surfaces, 500 foot Grid Cells



Planimetric Reference Data at 500 foot Grid Cells



Sub-Pixel Estimated Data at 500 foot Grid Cells



Number of Grid Cells = 2,379

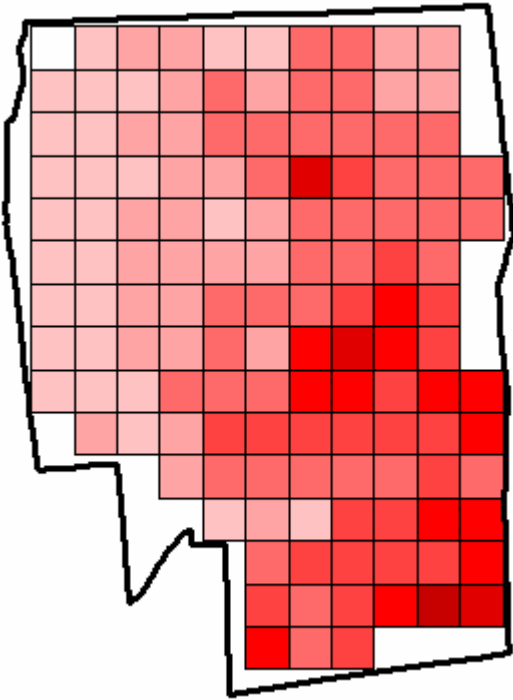
Slope = 1.003x

$R^2 = 0.7725$

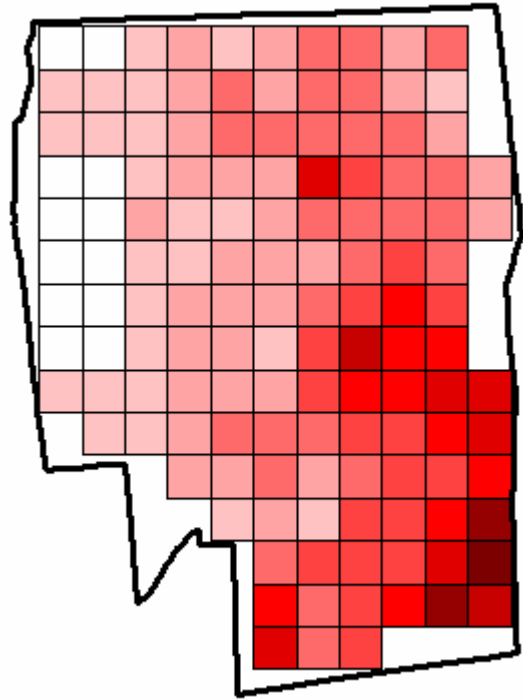
RMSE = 10.18046

Figure B-1. Comparison of the planimetric IS reference data to the 1990 sub-pixel IS estimate data summarized over 500 foot grid cells for West Hartford, Connecticut. The scatter plot displays the location of each grid cell in terms of the reference IS data plotted against the estimated IS data. The number of grid cells, best fit linear trend line slope (intercept = 0), R-square (reflects the extent of the linear relationship), and the root mean square error (RMSE) are provided.

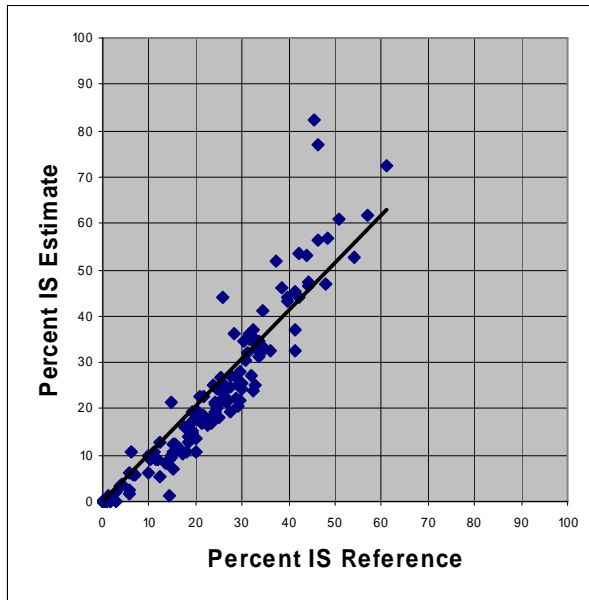
Circa 1990 West Hartford Impervious Surfaces, 2000 foot Grid Cells



Planimetric Reference Data at 2000 foot Grid Cells



Sub-Pixel Estimated Data at 2000 foot Grid Cells



Number of Grid Cells = 133

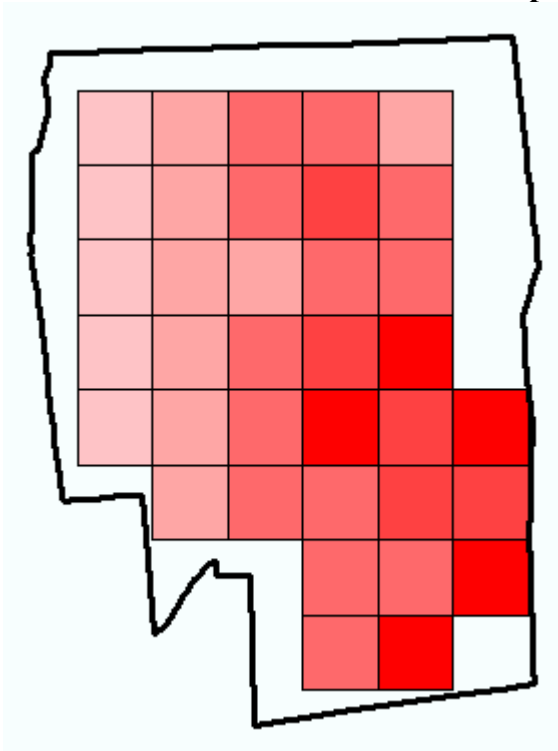
Slope $y = 1.0286x$

$R^2 = 0.8631$

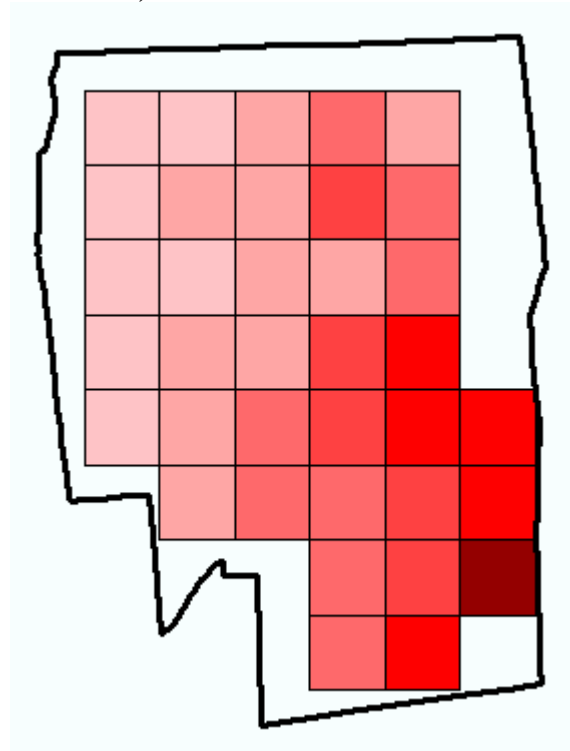
RMSE = 6.5409

Figure B-2. Comparison of the planimetric IS reference data to the 1990 sub-pixel IS estimate data summarized over 2000 foot grid cells for West Hartford, Connecticut. The scatter plot displays the location of each grid cell in terms of the reference IS data plotted against the estimated IS data. The number of grid cells, best fit linear trend line slope (intercept = 0), R-square (reflects the extent of the linear relationship), and the root mean square error (RMSE) are provided.

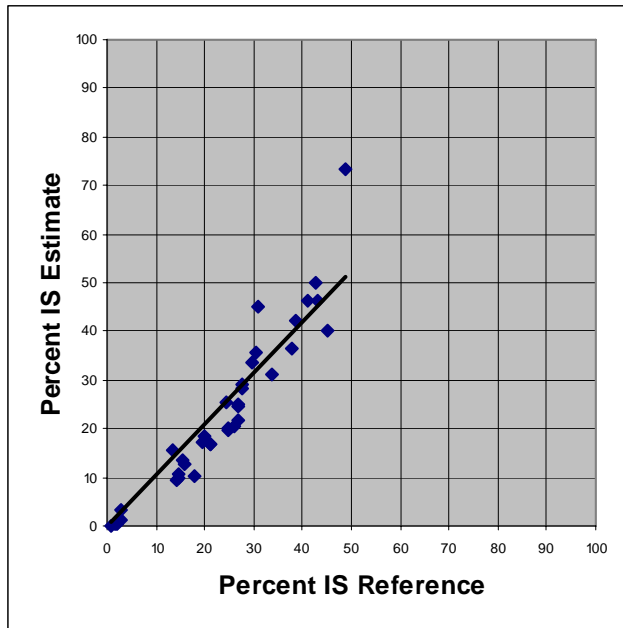
Circa 1990 West Hartford Impervious Surfaces, 3500 foot Grid Cells



Planimetric Reference Data at 3500 foot Grid Cells



Sub-Pixel Estimated Data at 3500 foot Grid Cells



Number of Grid Cells = 36

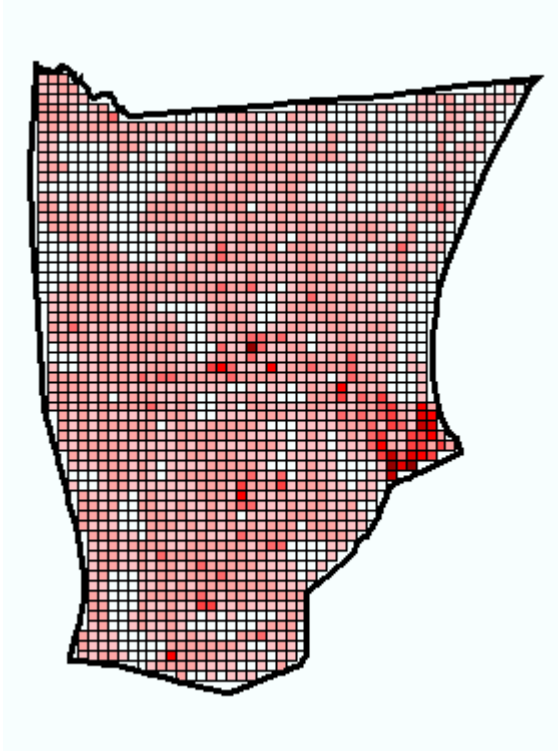
Slope $y = 1.0436X$

$R^2 = 0.8704$

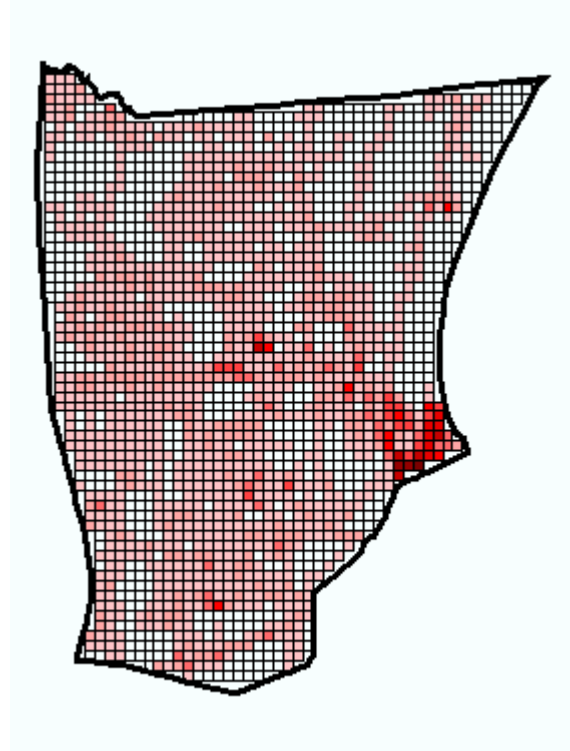
RMSE = 5.9893

Figure B-3. Comparison of the planimetric IS reference data to the 1990 sub-pixel IS estimate data summarized over 3500 foot grid cells for West Hartford, Connecticut. The scatter plot displays the location of each grid cell in terms of the reference IS data plotted against the estimated IS data. The number of grid cells, best fit linear trend line slope (intercept = 0), R-square (reflects the extent of the linear relationship), and the root mean square error (RMSE) are provided.

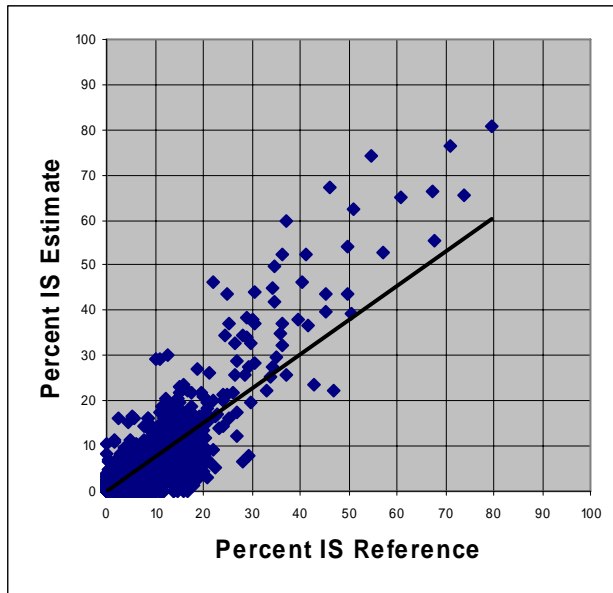
Circa 1995 Woodbridge Impervious Surfaces, 500 foot Grid Cells



Planimetric Reference Data at 500 foot Grid Cells



Sub-Pixel Estimated Data at 500 foot Grid Cells



Number of Grid Cells = 2020

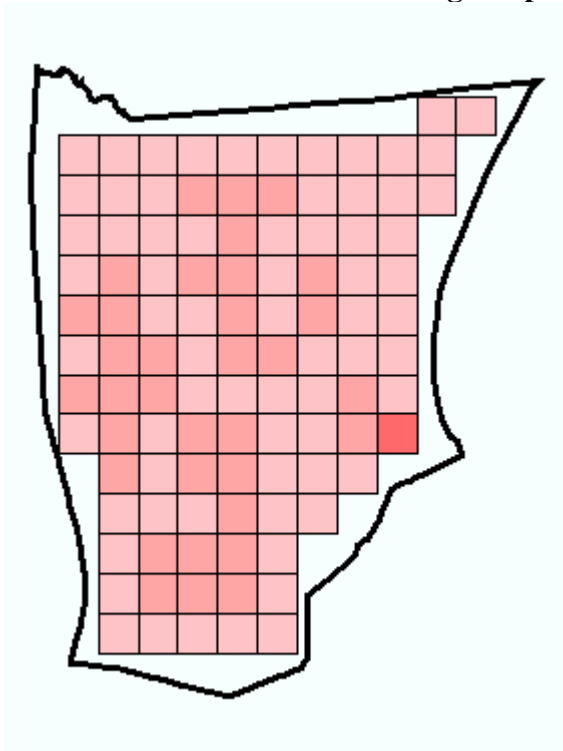
Slope $y = 0.757x$

$R^2 = 0.7178$

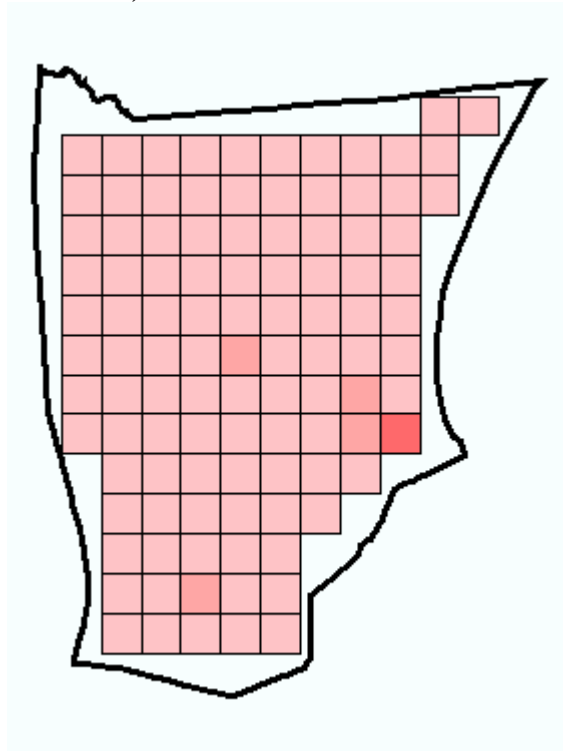
RMSE = 5.1073

Figure B-4. Comparison of the planimetric IS reference data to the 1990 sub-pixel IS estimate data summarized over 500 foot grid cells for Woodbridge, Connecticut. The scatter plot displays the location of each grid cell in terms of the reference IS data plotted against the estimated IS data. The number of grid cells, best fit linear trend line slope (intercept = 0), R-square (reflects the extent of the linear relationship), and the root mean square error (RMSE) are provided.

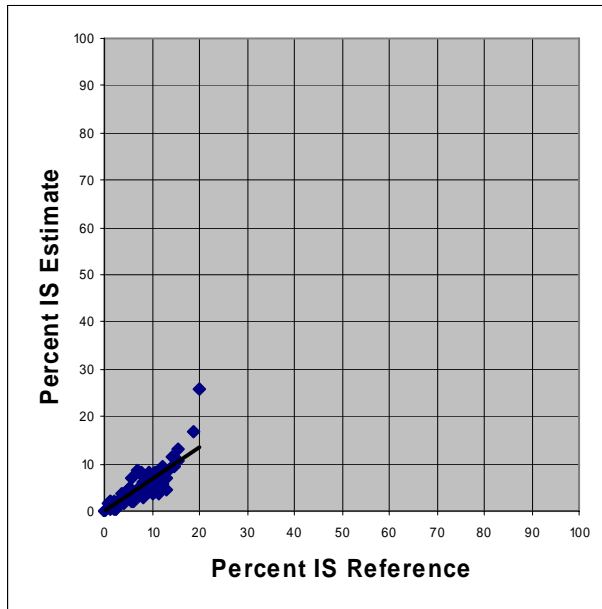
Circa 1995 Woodbridge Impervious Surfaces, 2000 foot Grid Cells



Planimetric Reference Data at 2000 foot Grid Cells



Sub-Pixel Estimated Data at 2000 foot Grid Cells



Number of Grid Cells = 104

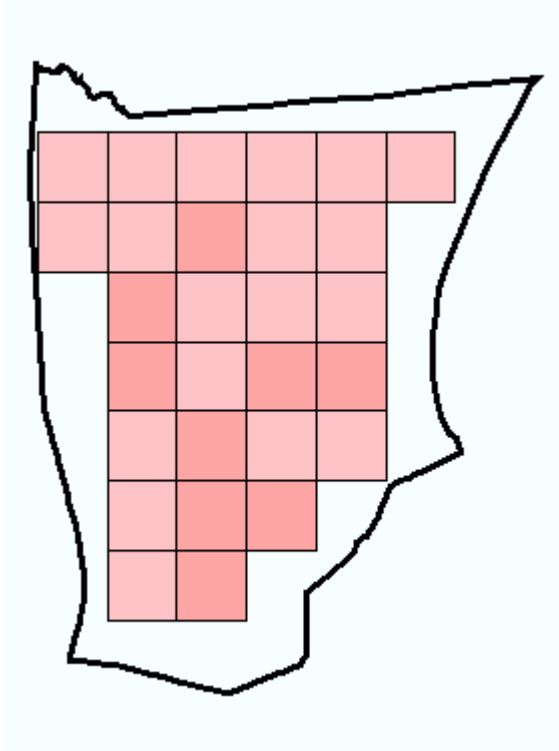
Slope $y = 0.6604x$

$R^2 = 0.6939$

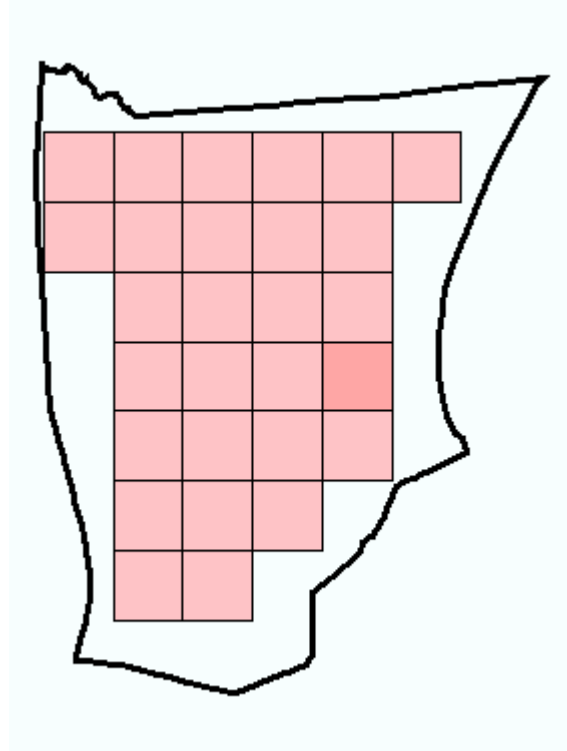
RMSE = 3.5852

Figure B-5. Comparison of the planimetric IS reference data to the 1990 sub-pixel IS estimate data summarized over 2000 foot grid cells for Woodbridge, Connecticut. The scatter plot displays the location of each grid cell in terms of the reference IS data plotted against the estimated IS data. The number of grid cells, best fit linear trend line slope (intercept = 0), R-square (reflects the extent of the linear relationship), and the root mean square error (RMSE) are provided.

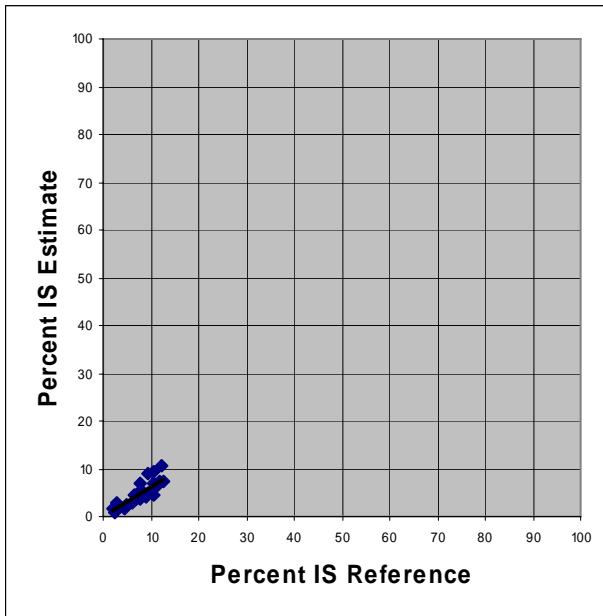
Circa 1995 Woodbridge Impervious Surfaces, 3500 foot Grid Cells



Planimetric Reference Data at 3500 foot Grid Cells



Sub-Pixel Estimated Data at 3500 foot Grid Cells



Number of Grid Cells = 28

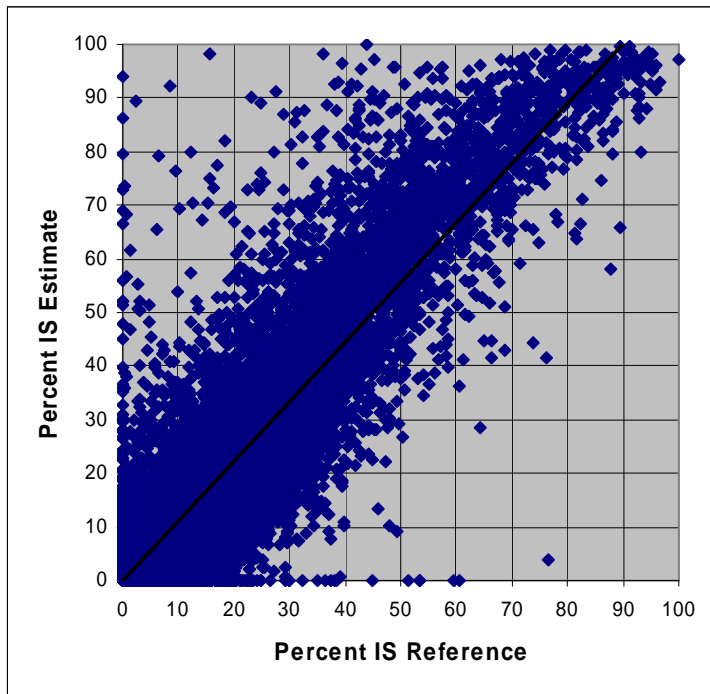
Slope $y = 0.6309x$

$R^2 = 0.710$

RMSE = 3.4132

Figure B-6. Comparison of the planimetric IS reference data to the 1990 sub-pixel IS estimate data summarized over 3500 foot grid cells for Woodbridge, Connecticut. The scatter plot displays the location of each grid cell in terms of the reference IS data plotted against the estimated IS data. The number of grid cells, best fit linear trend line slope (intercept = 0), R-square (reflects the extent of the linear relationship), and the root mean square error (RMSE) are provided.

All Towns, 500 foot Grid Cells



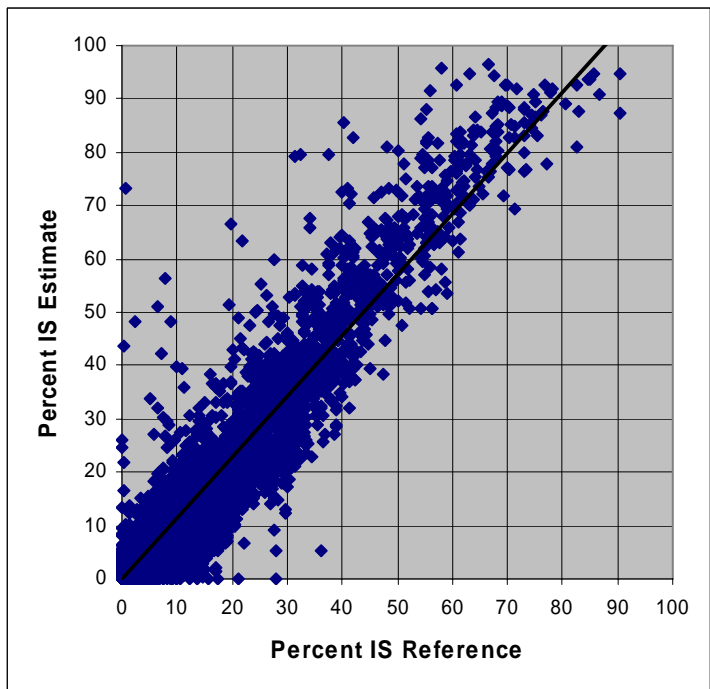
Number of Grid Cells = 28,606

Slope $y = 1.1159x$

$R^2 = 0.8494$

RMSE = 7.9710

All Towns, 1000 foot Grid Cells



Number of Grid Cells = 6,720

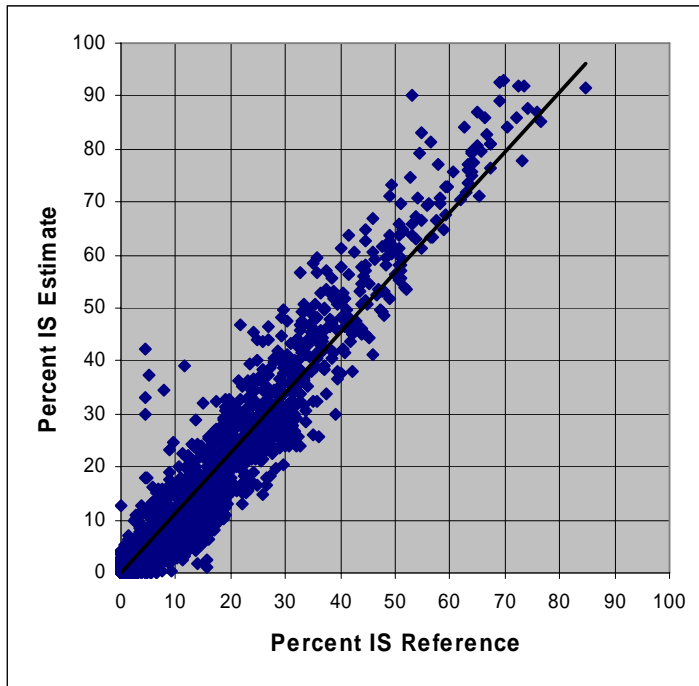
Slope $y = 1.1411x$

$R^2 = 0.9001$

RMSE = 6.2027

Figure B-7. Comparison of the planimetric IS reference data to the sub-pixel IS estimate data summarized over 500 foot and 1000 foot grid cells for all nine analysis towns. The scatter plot displays the location of each grid cell in terms of the reference IS data plotted against the estimated IS data. The number of grid cells, best fit linear trend line slope (intercept = 0), R-square (reflects the extent of the linear relationship), and the root mean square error (RMSE) are provided.

All Towns, 1500 foot Grid Cells



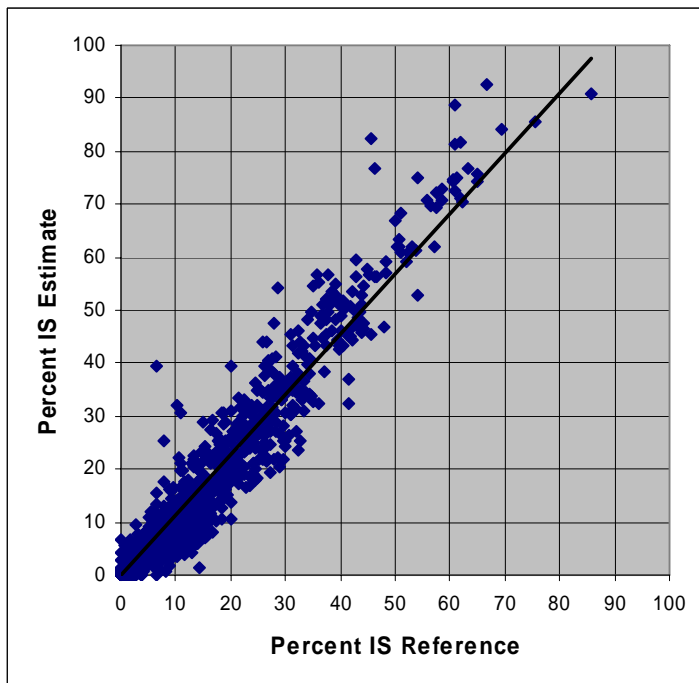
Number of Grid Cells = 2,824

Slope $y = 1.1361$

$R^2 = 0.9221$

RMSE = 5.2005

All Towns, 2000 foot Grid Cells



Number of Grid Cells = 1,496

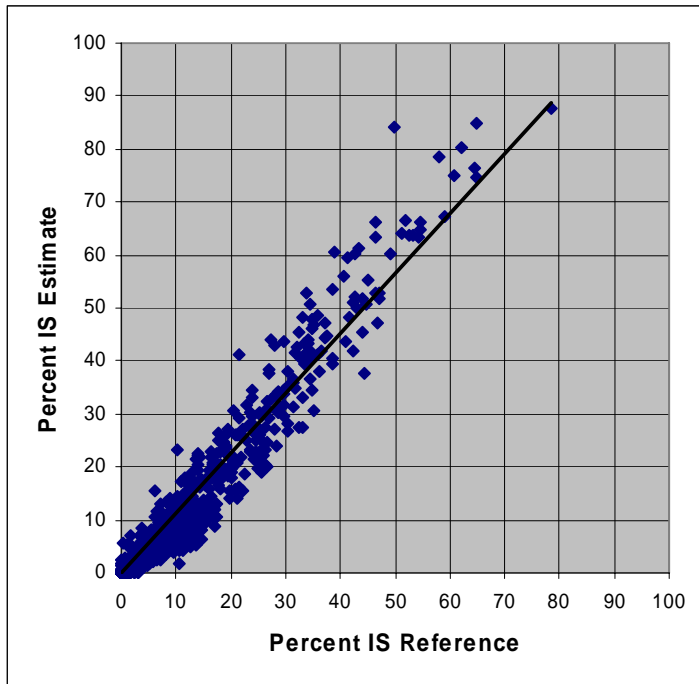
Slope $y = 1.1375x$

$R^2 = 0.9243$

RMSE = 5.0212

Figure B-8. Comparison of the planimetric IS reference data to the sub-pixel IS estimate data summarized over 1500 foot and 2000 foot grid cells for all nine analysis towns. The scatter plot displays the location of each grid cell in terms of the reference IS data plotted against the estimated IS data. The number of grid cells, best fit linear trend line slope (intercept = 0), R-square (reflects the extent of the linear relationship), and the root mean square error (RMSE) are provided.

All Towns, 2500 foot Grid Cells



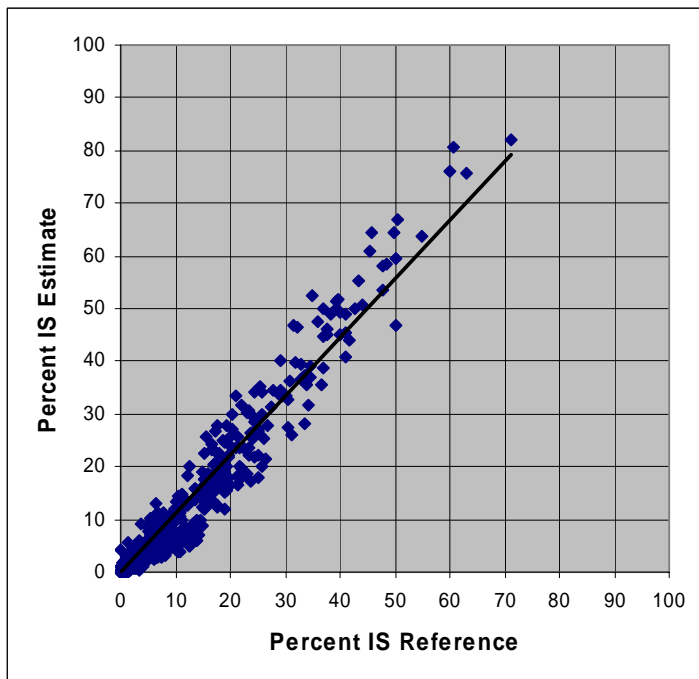
Number of Grid Cells = 900

Slope $y = 1.1313$

$R^2 = 0.9328$

RMSE = 4.5029

All Towns, 3000 foot Grid Cells



Number of Grid Cells = 591

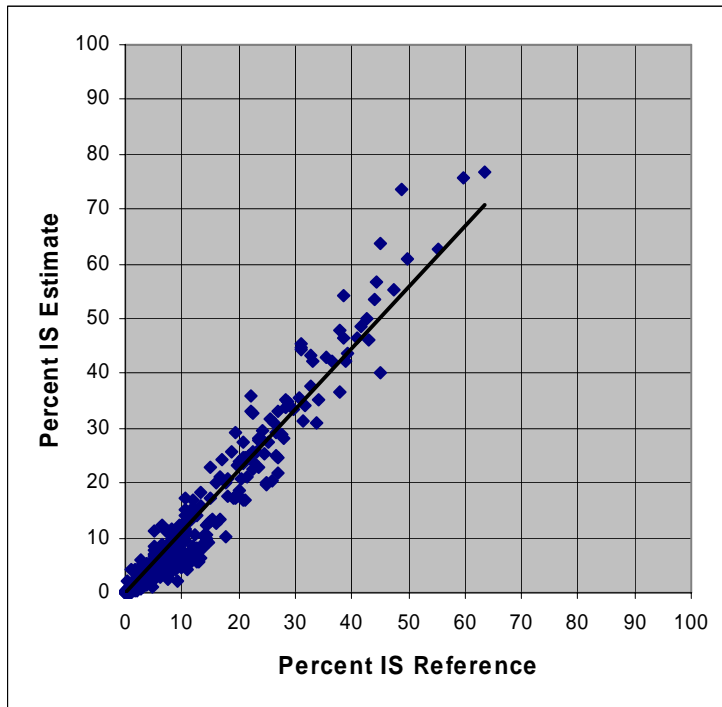
Slope $y = 1.1165x$

$R^2 = 0.9367$

RMSE = 4.0787

Figure B-9. Comparison of the planimetric IS reference data to the sub-pixel IS estimate data summarized over 2500 foot and 3000 foot grid cells for all nine analysis towns. The scatter plot displays the location of each grid cell in terms of the reference IS data plotted against the estimated IS data. The number of grid cells, best fit linear trend line slope (intercept = 0), R-square (reflects the extent of the linear relationship), and the root mean square error (RMSE) are provided.

All Towns, 3500 foot Grid Cells



Number of Grid Cells = 404

Slope $y = 1.117x$

$R^2 = 0.9346$

RMSE = 4.0278

Figure B-10. Comparison of the planimetric IS reference data to the sub-pixel IS estimate data summarized over 3500 foot grid cells for all nine analysis towns. The scatter plot displays the location of each grid cell in terms of the reference IS data plotted against the estimated IS data. The number of grid cells, best fit linear trend line slope (intercept = 0), R-square (reflects the extent of the linear relationship), and the root mean square error (RMSE) are provided.

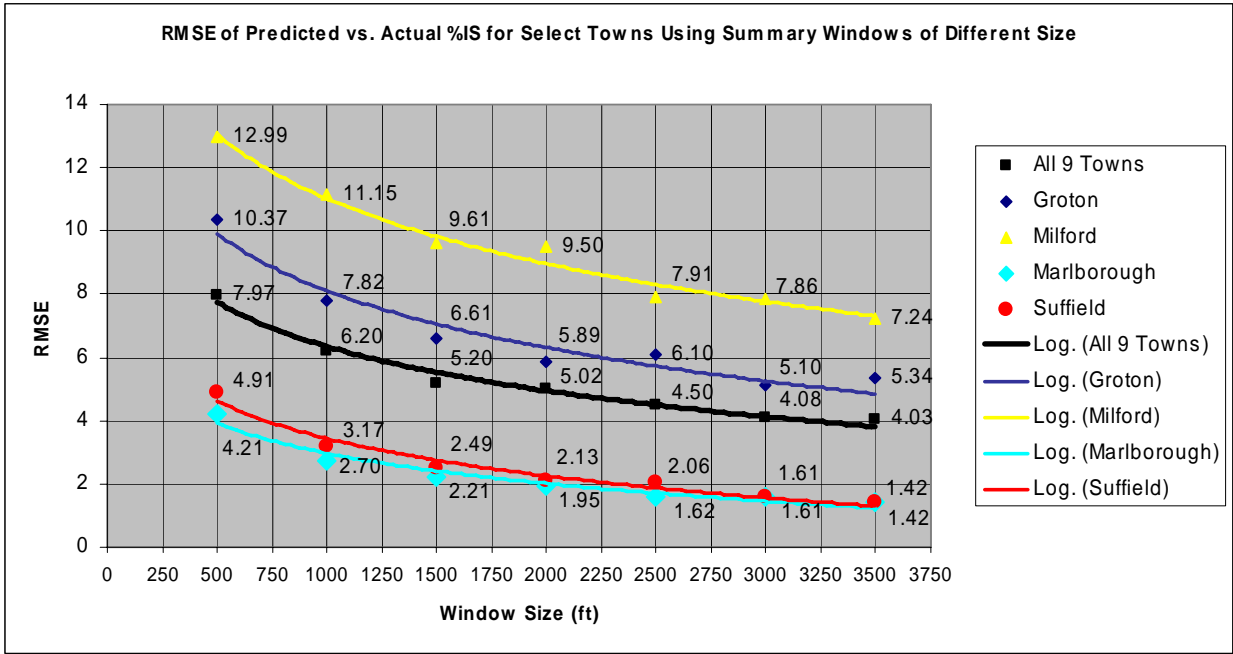


Figure B-11. Scatter plot with logarithmic trend line superimposed showing the relationship between grid cell size and RMSE for all nine towns combined in addition to two urbanized towns (Groton and Milford) and two rural towns (Marlborough and Suffield).

Appendix C

Summary of Impervious Surfaces of Sub-regional Watersheds for 1985, 1990, 1995 and 2002

CONNECTICUT WATERSHEDS						
Name	Number	Acres	1985 %IS	1990 %IS	1995 %IS	2002 %IS
ABBEY BROOK	4204	4,927.62	2.32	2.64	2.76	3.02
ALLYN BROOK	4605	3,506.46	2.99	3.30	3.50	3.96
ANDRUS BROOK	6003	1,373.02	1.03	1.04	1.05	1.09
ANGUILLA BROOK	2101	7,891.33	3.13	3.50	3.78	4.29
ASH CREEK	7106	9,813.00	34.15	35.49	36.34	37.47
ASHAWAY RIVER	1003	3,283.88	3.89	4.17	4.41	4.96
ASPETUCK RIVER	7202	14,754.18	2.97	3.17	3.31	3.61
BALL POND BROOK	6402	4,850.50	3.98	4.67	4.87	5.10
BANTAM RIVER	6705	25,732.28	2.22	2.40	2.46	2.55
BARTLETT BROOK	3902	5,956.12	1.31	1.41	1.45	1.49
BASS BROOK	4401	6,659.35	19.10	20.97	21.72	22.77
BEACON HILL BROOK	6918	6,537.60	4.24	5.18	5.46	6.14
BEAVER BROOK	3802	5,008.24	1.13	1.22	1.24	1.27
BEAVER BROOK	3804	7,252.67	2.18	2.38	2.52	2.67
BEAVER BROOK	4803	5,343.77	0.88	0.93	0.94	0.95
BEAVER POND BROOK	6913	3,572.59	16.11	19.23	20.76	21.79
BELCHER BROOK	4601	5,305.22	6.74	8.05	8.39	9.36
BIGELOW BROOK	3203	18,734.99	1.40	1.46	1.51	1.54
BILLINGS BROOK	3605	3,790.12	1.33	1.48	1.51	1.56
BLACK HALL RIVER	4021	3,532.28	3.47	3.82	4.04	4.26
BLACKBERRY RIVER	6100	17,341.03	2.51	2.73	2.83	3.00
BLACKLEDGE RIVER	4707	16,680.11	2.82	3.02	3.16	3.34
BLACKWELL BROOK	3711	18,011.26	1.53	1.65	1.70	1.77
BLADENS RIVER	6919	6,874.43	4.70	5.57	5.79	6.32
BOG HOLLOW BROOK	6014	4,189.36	0.46	0.49	0.50	0.51
BOGGS POND BROOK	6602	4,184.91	7.22	7.78	8.41	8.89
BOOTH HILL BROOK	7104	3,257.81	8.54	9.36	10.02	10.55
BRANCH BROOK	6910	14,494.87	2.05	2.34	2.39	2.48
BRANFORD RIVER	5111	15,586.31	8.03	8.94	9.33	9.74
BREAKNECK BROOK	3702	2,796.79	0.35	0.41	0.43	0.44
BRIDE BROOK	2206	3,191.15	4.46	5.18	5.57	6.23
BROAD BROOK	4206	10,099.24	2.81	3.24	3.43	3.72
BROAD BROOK	3716	10,478.21	1.07	1.23	1.27	1.34
BROAD BROOK	5204	3,080.09	2.13	2.47	2.73	2.89
BROWN BROOK	6201	3,567.30	0.10	0.10	0.11	0.11
BRUCE BROOK	7102	2,199.40	47.25	48.74	49.79	50.89
BRUSHY BROOK	1101	8,394.77	0.49	0.49	0.51	0.53
BUCKHORN BROOK	4205	3,163.88	3.18	3.81	4.14	4.41
BUNGEE BROOK	3201	10,729.15	1.63	1.69	1.73	1.77
BURLINGTON BROOK	4311	5,922.45	2.63	3.13	3.26	3.58
BURNAP BROOK	3107	4,680.00	2.37	2.50	2.60	2.70
BUTTERNUT BROOK	6704	3,854.19	1.68	1.82	1.84	1.89
BYRAM RIVER	7411	11,948.41	11.47	12.33	12.89	13.68
CADY BROOK	3403	5,434.70	0.86	1.20	1.25	1.51
CARR BROOK	4012	4,335.63	2.37	2.54	2.61	2.74
CARSE BROOK	6009	3,459.22	0.97	0.99	0.99	1.00
CHARTERS BROOK	4501	7,430.77	1.64	1.81	1.91	1.99
CHATFIELD HOLLOW BROOK	5105	7,283.11	1.65	1.74	1.76	1.84
CHERRY BROOK	4309	8,847.84	1.27	1.48	1.52	1.59
CHESTER CREEK	4017	9,255.28	2.87	3.10	3.23	3.45

CONNECTICUT WATERSHEDS Continued						
Name	Number	Acres	1985 %IS	1990 %IS	1995 %IS	2002 %IS
CHOATE BROOK	3717	3,303.30	1.45	1.59	1.66	1.73
COBBLE BROOK	6013	2,906.65	1.16	1.23	1.24	1.31
COGINCHAUG RIVER	4607	18,128.74	4.36	4.72	4.90	5.14
COHASSE BROOK	3704	2,720.59	0.45	0.48	0.49	0.50
COLD BROOK	4008	4,786.70	1.62	1.87	1.93	2.10
COMSTOCK BROOK	7301	4,698.60	3.50	3.74	3.82	3.89
CONNECTICUT RIVER	4000	102,613.55	8.78	9.88	10.37	11.04
COPPER MINE BROOK	4314	11,916.14	9.01	10.12	10.55	11.22
COPPS BROOK	2102	4,825.78	2.29	2.43	2.52	2.89
CORY BROOK	3715	4,977.21	1.44	1.56	1.61	1.66
CRICKER BROOK	7107	4,564.91	3.70	3.93	4.14	4.56
DARIEN RIVER	7402	3,976.05	15.74	16.30	16.80	17.44
DEEP BROOK	6019	3,422.19	6.58	7.23	7.45	7.76
DEEP RIVER	3904	5,674.14	1.48	1.66	1.71	1.88
DEEP RIVER	4018	4,589.88	4.42	4.72	5.01	5.36
DENISON BROOK	3603	2,569.87	1.13	1.22	1.25	1.38
DEUEL HOLLOW BROOK	6304	3,995.83	1.11	1.15	1.20	1.23
DICKINSON CREEK	4708	9,613.44	2.48	2.66	2.79	2.99
EAST ASPETUCK RIVER	6502	16,169.24	2.35	2.51	2.58	2.71
EAST BRANCH BYRAM RIVER	7410	7,227.02	3.57	3.96	4.16	4.38
EAST BRANCH EIGHTMILE RIVER	4802	10,478.45	1.82	2.09	2.16	2.27
EAST BRANCH FARMINGTON RIVER	4308	24,183.09	1.13	1.18	1.19	1.20
EAST BRANCH MIANUS RIVER	7406	3,448.98	4.32	4.60	4.67	4.90
EAST BRANCH NAUGATUCK RIVER	6905	9,040.89	8.94	9.58	9.88	10.26
EAST RIVER	5108	12,830.09	2.39	2.55	2.69	2.95
EAST SPRING BROOK	6801	3,742.06	2.14	2.24	2.30	2.40
EAST SWAMP BROOK	6605	3,273.28	5.34	6.40	6.64	7.34
EDSON BROOK	3101	11,271.17	1.49	1.72	1.79	1.95
EIGHTMILE BROOK	6023	11,162.95	3.04	3.55	3.74	4.17
EIGHTMILE RIVER	5201	9,441.40	5.76	8.11	8.42	9.37
EIGHTMILE RIVER	4800	20,170.17	1.29	1.34	1.41	1.48
EKONK BROOK	3503	3,409.76	1.16	1.21	1.25	1.31
ENGLISH NEIGHBORHOOD BROOK	3706	3,088.31	1.49	1.55	1.58	1.60
EXETER BROOK	3901	3,554.30	1.25	1.36	1.38	1.50
FACTORY BROOK	6005	10,044.89	1.97	2.06	2.12	2.22
FALLS RIVER	4019	11,347.95	3.68	4.16	4.63	5.13
FARM RIVER	5112	16,359.03	8.33	9.34	9.74	10.37
FARMILL RIVER	6025	9,657.46	10.49	12.23	12.98	13.79
FARMINGTON RIVER	4300	136,702.31	4.93	5.76	6.04	6.41
FAWN BROOK	4706	8,194.55	1.57	1.71	1.83	1.91
FENTON RIVER	3207	21,988.47	2.39	2.55	2.70	2.81
FIVEMILE RIVER	3400	24,943.67	3.73	4.17	4.38	4.66
FIVEMILE RIVER	7401	7,993.72	16.33	16.99	17.60	18.31
FOLLY BROOK	4005	3,922.30	43.16	44.91	45.98	47.09
FOURMILE RIVER	2207	4,198.29	2.32	2.78	2.96	3.32
FRENCH RIVER	3300	64,663.30	4.30	4.87	5.17	5.51

CONNECTICUT WATERSHEDS Continued						
Name	Number	Acres	1985 %IS	1990 %IS	1995 %IS	2002 %IS
FRESHWATER BROOK	4003	7,420.60	12.40	15.35	17.35	18.63
FRY BROOK	3712	4,217.08	5.70	6.62	6.94	7.38
FULLING MILL BROOK	6915	3,441.37	8.30	11.19	12.70	13.87
FURNACE BROOK	3103	10,420.38	1.81	2.00	2.06	2.16
FURNACE BROOK	6010	8,506.04	1.34	1.41	1.43	1.45
GARDNER BROOK	3906	8,859.74	1.75	1.91	1.98	2.06
GIFFORDS BROOK	3109	3,785.38	1.48	1.83	1.93	2.01
GILLETTES BROOK	4202	3,376.62	1.89	2.12	2.31	2.44
GOFF BROOK	4010	7,882.90	15.93	17.02	17.85	18.84
GREAT BROOK	4001	15,580.69	4.39	4.60	4.74	4.97
GREAT BROOK	2107	10,039.97	6.33	7.53	8.49	9.22
GREAT MEADOW BROOK	3601	4,039.58	1.17	1.19	1.20	1.22
GREEN FALL RIVER	1002	7,113.08	0.72	0.73	0.74	0.80
GREENWICH CREEK	7408	5,692.59	7.05	7.37	7.70	8.05
GUINEA BROOK	6011	5,729.41	1.18	1.22	1.22	1.24
GULF STREAM	4203	2,824.78	3.06	3.42	3.56	3.72
HALEYS BROOK	2105	4,835.42	2.61	2.93	3.14	3.71
HALFWAY RIVER	6022	6,832.26	3.36	4.30	4.66	5.72
HALL MEADOW BROOK	6901	7,901.64	1.03	1.08	1.09	1.09
HAMILTON RESERVOIR BROOK	3701	13,014.74	1.98	2.10	2.14	2.20
HAMMONASSET RIVER	5106	22,885.72	2.71	3.06	3.24	3.54
HANCOCK BROOK	6911	9,850.64	5.58	6.30	6.78	7.11
HARBOR BROOK	5206	7,751.26	21.09	22.70	23.54	24.85
HARRIS BROOK	4801	3,942.90	1.53	1.82	1.90	2.05
HART BROOK	6902	4,312.75	0.49	0.51	0.51	0.52
HATCHET BROOK	3703	2,520.60	0.59	0.72	0.76	0.81
HESSEKY BROOK	6805	3,982.04	1.84	2.01	2.05	2.22
HIGGANUM CREEK	4014	12,633.70	2.60	2.89	2.98	3.13
HOCKANUM RIVER	4500	22,578.54	17.00	18.98	20.09	21.41
HOLLENBECK RIVER	6200	17,048.20	1.01	1.06	1.08	1.11
HOP BROOK	4318	8,715.61	4.10	4.63	4.84	5.10
HOP BROOK	6916	11,135.63	6.46	7.37	7.66	8.05
HOP RIVER	3108	26,706.56	2.12	2.34	2.46	2.61
HORSENECK BROOK	7409	4,173.26	13.20	13.66	14.15	14.63
HOUSATONIC RIVER	6000	399,065.34	5.50	6.04	6.35	6.76
HUBBARD BROOK	4307	13,276.07	0.64	0.77	0.77	0.77
HUBBARD BROOK	4307	13,276.07	0.64	0.77	0.77	0.77
HUBBARD BROOK	4007	5,063.58	9.85	10.96	11.53	12.35
HUNTS BROOK	3006	8,369.23	2.75	3.08	3.32	3.57
INDIAN HOLLOW BROOK	3801	2,823.07	1.83	2.03	2.10	2.16
INDIAN LAKE CREEK	6301	12,115.34	2.19	2.27	2.36	2.45
INDIAN RIVER	5104	4,767.05	5.25	6.27	6.70	7.50
INDIAN RIVER	5306	7,797.28	20.60	21.70	23.09	24.19
JACKS BROOK	6706	5,037.14	1.20	1.24	1.25	1.29
JEREMY RIVER	4705	8,239.02	2.57	2.91	2.98	3.18
JORDAN BROOK	2201	4,841.37	9.12	10.78	11.56	12.83
JUDD BROOK	4702	3,270.96	3.41	3.87	4.41	4.79
KENT FALLS BROOK	6012	3,748.70	1.04	1.09	1.11	1.12
KETCH BROOK	4207	4,411.36	2.21	2.45	2.56	2.78
KETTLETOWN BROOK	6021	3,114.99	1.95	2.34	2.57	2.78

CONNECTICUT WATERSHEDS Continued						
Name	Number	Acres	1985 %IS	1990 %IS	1995 %IS	2002 %IS
KITT BROOK	3714	7,976.67	1.36	1.55	1.68	1.80
KONKAPOT RIVER	6004	39,416.96	1.74	2.13	2.28	2.43
LAKE CANDLEWOOD	6400	17,719.31	3.58	3.76	3.95	4.14
LATIMER BROOK	2202	11,352.81	2.20	2.79	3.00	3.33
LEADMINE BROOK	6908	10,308.29	3.40	3.84	4.03	4.36
LEBANON BROOK	3705	6,301.76	0.55	0.59	0.60	0.63
LEWIS GUT	7101	2,548.32	37.72	39.08	39.98	40.64
LIEUTENANT RIVER	4020	7,780.69	3.10	3.32	3.46	3.70
LIMEKILN BROOK	6606	5,611.17	8.71	10.00	10.49	11.57
LITTLE RIVER	3708	17,528.46	2.24	2.44	2.54	2.73
LITTLE RIVER	3805	27,699.07	1.70	1.82	1.89	1.95
LITTLE RIVER	6920	9,917.23	3.23	4.04	4.34	4.92
LITTLE RIVER	7201	3,805.97	1.99	2.17	2.20	2.41
LONG MEADOW POND BROOK	6917	5,420.79	6.10	6.65	7.11	7.63
MACEDONIA BROOK	6015	7,039.79	1.02	1.05	1.05	1.06
MAD RIVER	4302	20,318.17	2.55	2.70	2.75	2.82
MAD RIVER	6914	13,023.67	14.33	15.93	16.54	17.45
MARSH BROOK	4502	3,489.60	3.93	4.50	4.68	5.39
MARSHEPAUG RIVER	6701	7,291.86	2.07	2.20	2.25	2.27
MARY BROWN BROOK	3402	5,536.47	1.05	1.28	1.34	1.44
MASHAMOQUET BROOK	3710	18,027.61	1.33	1.43	1.47	1.54
MATTABESSET RIVER	4600	24,844.86	9.05	10.77	11.39	12.28
MEADOW BROOK	4703	7,118.32	6.99	7.74	8.08	8.51
MEANS BROOK	6024	7,007.92	5.40	6.72	7.13	7.55
MENUNKETESUCK RIVER	5103	11,128.77	2.57	2.81	3.02	3.27
MERRICK BROOK	3803	8,311.51	1.28	1.35	1.44	1.50
MERRYALL BROOK	6501	3,762.24	1.22	1.26	1.28	1.33
MIANUS RIVER	7407	18,331.88	5.27	5.72	5.92	6.25
MIDDLE RIVER	3102	10,450.97	2.69	3.23	3.40	3.62
MILL BROOK	3301	7,074.00	7.69	8.95	9.60	10.16
MILL BROOK	3707	4,435.18	1.98	2.08	2.14	2.20
MILL BROOK	6008	3,648.35	1.41	1.45	1.46	1.51
MILL BROOK	4321	4,118.49	10.67	12.76	13.44	14.60
MILL BROOK	6302	7,629.44	1.27	1.33	1.35	1.36
MILL BROOK	3105	3,397.03	4.62	4.94	5.06	5.31
MILL BROOK	3713	7,171.21	2.80	3.30	3.65	3.96
MILL CREEK	4015	4,529.32	2.75	2.97	3.04	3.13
MILL RIVER	5302	16,286.40	16.12	17.24	17.89	18.69
MILL RIVER	7108	15,927.58	7.14	7.73	8.14	8.70
MILL RIVER	7404	8,544.64	3.24	3.47	3.58	3.74
MIRY BROOK	6601	3,219.87	5.32	7.37	7.76	8.62
MISERY BROOK	5203	3,993.23	7.85	8.78	9.19	9.80
MOODUS RIVER	4710	11,270.39	2.66	2.79	2.89	3.03
MOOSUP RIVER	3500	34,150.65	3.71	4.21	4.48	4.78
MORGAN BROOK	4305	5,795.08	2.50	3.20	3.30	3.44
MORRISSEY BROOK	6017	4,645.63	1.37	1.67	1.71	1.86
MOUNT HOPE RIVER	3206	17,966.85	1.56	1.65	1.73	1.77
MOUNT MISERY BROOK	3602	5,456.10	1.12	1.15	1.15	1.18
MUDDY BROOK	4101	12,870.31	2.55	3.30	3.67	3.94
MUDDY RIVER	5208	13,947.15	5.96	6.84	7.19	7.68

CONNECTICUT WATERSHEDS Continued						
Name	Number	Acres	1985 %IS	1990 %IS	1995 %IS	2002 %IS
MYRON KINNEY BROOK	3604	3,895.41	0.76	0.78	0.78	0.81
MYSTIC RIVER	2106	2,666.93	14.47	15.68	16.77	18.08
NATCHAUG RIVER	3200	18,732.71	3.03	3.56	3.93	4.19
NAUGATUCK RIVER	6900	49,515.44	12.85	13.90	14.35	15.00
NECK RIVER	5107	4,343.22	4.96	5.49	5.82	6.28
NEPAUG RIVER	4310	20,464.31	1.52	1.73	1.84	1.95
NIANTIC RIVER	2204	4,666.11	7.46	8.44	9.01	9.81
NICKEL MINE BROOK	6903	3,563.26	1.41	1.57	1.64	1.70
NOD BROOK	4317	3,936.61	8.74	9.63	10.22	10.74
NONEWAUG RIVER	6802	13,605.20	1.98	2.29	2.35	2.59
NOROTON RIVER	7403	7,058.04	15.88	16.46	16.89	17.55
NORTH BRANCH PARK RIVER	4404	18,437.36	12.10	13.43	13.95	14.66
NORTHFIELD BROOK	6909	4,238.25	2.80	3.03	3.10	3.43
NORWALK RIVER	7300	20,828.93	14.99	16.09	16.52	17.15
OIL MILL BROOK	2203	3,333.44	3.12	3.50	3.66	3.96
OXOBOXO BROOK	3004	7,744.31	4.60	5.02	5.31	5.76
OYSTER RIVER	5101	3,668.85	5.82	7.06	7.39	7.90
PACHAUG RIVER	3600	20,574.73	2.74	3.22	3.43	3.67
PADANARAM BROOK	6603	4,650.91	10.56	11.39	11.83	12.54
PARK RIVER	4400	5,630.08	47.46	49.04	49.80	50.83
PATCHOGUE RIVER	5102	5,062.33	5.66	6.57	6.98	7.56
PATTAGANSETT RIVER	2205	5,662.83	6.24	7.08	7.74	8.65
PAWCATUCK RIVER	1000	109,607.70	11.30	12.26	13.00	14.33
PEASE BROOK	3905	7,880.48	1.38	1.50	1.62	1.70
PEQUABUCK RIVER	4315	18,575.98	15.31	17.18	17.85	18.83
PEQUONNOCK RIVER	7105	15,381.42	20.33	21.91	22.68	23.96
PINE BROOK	4709	9,966.08	3.90	4.17	4.26	4.44
PINE BROOK	4704	3,211.01	1.83	1.92	1.96	2.01
PIPER BROOK	4402	7,334.41	30.69	32.67	33.56	34.93
PODUNK RIVER	4004	12,997.79	12.73	15.27	16.71	18.01
POLAND RIVER	4313	6,482.39	1.65	1.84	1.92	2.07
POMPERAUG RIVER	6800	13,691.31	4.67	5.80	6.11	6.41
POND BROOK	6018	8,898.06	3.42	3.87	4.25	4.65
POOTATUCK RIVER	6020	13,297.08	4.47	5.08	5.43	5.97
POQUETANUCK BROOK	3003	8,926.74	2.61	2.97	3.11	3.30
PUMPKIN GROUND BROOK	6026	3,798.87	9.85	11.19	12.02	12.70
QUANDUCK BROOK	3501	12,542.31	1.37	1.51	1.55	1.64
QUINEBAUG RIVER	3700	124,816.03	3.66	4.22	4.55	4.98
QUINNIPIAC RIVER	5200	46,499.46	18.58	20.45	21.22	22.08
RAYMOND BROOK	4701	5,790.97	3.04	3.15	3.25	3.34
RESERVOIR BROOK	4011	4,470.02	0.84	0.99	1.09	1.18
RIPPOWAM RIVER	7405	15,060.80	13.08	13.64	14.02	14.60
ROARING BROOK	3104	14,088.19	1.89	2.03	2.26	2.39
ROARING BROOK	4312	4,834.95	5.19	5.88	6.27	7.04
ROARING BROOK	4009	11,826.33	2.59	2.96	3.20	3.48
ROCK BROOK	6907	5,522.38	1.21	1.45	1.50	1.63
ROCKY BROOK	3401	3,912.36	0.99	1.08	1.55	1.60
SAGES RAVINE BROOK	6001	2,265.44	0.33	0.33	0.33	0.33
SALMON BROOK	4320	29,267.69	1.99	2.23	2.36	2.57
SALMON BROOK	4006	12,908.91	13.32	15.32	15.93	17.15

CONNECTICUT WATERSHEDS Continued						
Name	Number	Acres	1985 %IS	1990 %IS	1995 %IS	2002 %IS
SALMON CREEK	6007	7,546.27	1.51	1.54	1.57	1.59
SALMON RIVER	4700	11,994.24	1.43	1.54	1.59	1.70
SANDY BROOK	4304	24,774.31	0.97	1.03	1.04	1.07
SARGENT RIVER	5303	3,655.64	2.45	2.96	3.05	3.22
SASCO BROOK	7109	6,533.78	7.84	8.30	8.64	8.92
SAUGATUCK RIVER	7200	31,074.68	5.01	5.28	5.40	5.61
SAWMILL BROOK	3208	4,647.11	5.31	6.25	6.52	7.13
SAWMILL BROOK	6401	3,364.13	1.29	1.34	1.39	1.68
SAWMILL BROOK	4604	4,466.57	5.53	6.20	6.66	7.23
SAWMILL BROOK	4606	3,285.04	1.70	2.39	2.44	2.78
SCANTIC RIVER	4200	38,433.29	3.61	4.22	4.56	4.96
SCHENOB BROOK	6002	13,402.62	1.98	2.02	2.06	2.14
SHEPAUG RIVER	6700	45,400.46	1.39	1.50	1.54	1.59
SHERMAN BROOK	3903	5,233.06	2.00	2.46	2.92	3.11
SHETUCKET RIVER	3800	28,867.83	4.67	5.15	5.50	5.79
SHEWVILLE BROOK	3002	9,254.31	1.70	2.10	3.41	3.69
SHUNOCK RIVER	1004	10,590.93	1.89	2.03	2.27	2.50
SILVERMINE RIVER	7302	14,414.92	5.70	6.10	6.22	6.40
SKUNGAMAUG RIVER	3106	19,667.67	2.31	2.69	2.83	3.06
SLOCUM BROOK	4301	5,361.41	0.57	0.60	0.60	0.60
SLUICE CREEK	5109	1,436.69	14.54	15.80	16.76	17.98
SNAKE MEADOW BROOK	3502	6,913.86	2.37	2.59	2.69	2.82
SODOM BROOK	5205	3,377.14	15.30	16.66	17.45	18.76
SOUTH CENTRAL SHORELINE	5000	37,748.07	23.66	25.32	26.26	27.35
SOUTH FORK HOCKANUM RIVER	4504	7,633.52	13.17	14.17	14.85	15.67
SOUTHEAST SHORELINE	2000	27,389.64	10.78	11.56	12.26	13.44
SOUTHWEST SHORELINE	7000	25,221.06	34.78	35.69	36.44	37.41
SPRAIN BROOK	6803	7,011.12	1.38	1.43	1.46	1.52
SPRUCE BROOK	6906	3,597.89	1.29	1.34	1.35	1.37
SPRUCE SWAMP CREEK	6006	6,736.73	1.23	1.30	1.33	1.36
SQUAW HOLLOW BROOK	3205	5,468.32	1.49	1.61	1.64	1.70
STEELE BROOK	6912	10,905.89	11.22	13.24	14.17	15.05
STILL RIVER	3202	10,218.88	1.72	1.80	1.84	1.97
STILL RIVER	4303	10,315.10	4.69	5.82	6.14	6.91
STILL RIVER	6600	20,071.29	14.38	16.67	17.33	18.35
STONEHOUSE BROOK	3204	4,045.94	1.05	1.09	1.22	1.25
STONY BROOK	4100	15,670.55	5.20	6.30	6.67	7.07
STONY BROOK	3005	6,362.38	3.94	4.32	4.51	4.93
SUMNER BROOK	4013	8,216.61	9.30	9.97	10.30	10.81
SUSQUETONSCUT BROOK	3907	9,825.92	1.96	2.16	2.27	2.42
SYMPAUG BROOK	6604	4,638.24	12.04	14.42	15.22	16.15
TANKERHOOSER RIVER	4503	8,225.91	7.62	8.66	9.24	9.80
TENMILE RIVER	6300	46,107.07	0.46	0.48	0.49	0.49
TENMILE RIVER	3110	7,081.37	1.22	1.38	1.43	1.47
TENMILE RIVER	5202	12,966.85	6.20	7.56	8.32	9.01
THAMES RIVER	3000	19,446.94	16.95	18.28	19.02	20.32
THOMPSON BROOK	4316	3,009.60	4.28	5.10	5.35	5.80
THREEMILE BROOK	4002	6,151.60	2.36	3.23	3.41	3.65
TRADING COVE BROOK	3001	8,825.07	5.45	6.17	6.47	7.18

CONNECTICUT WATERSHEDS Continued						
Name	Number	Acres	1985 %IS	1990 %IS	1995 %IS	2002 %IS
TRANSYLVANIA BROOK	6806	4,615.83	1.74	2.19	2.47	2.69
TROUT BROOK	4403	11,357.29	17.95	19.06	19.70	20.66
VALLEY BROOK	4306	4,763.23	0.23	0.23	0.23	0.23
WANGUM LAKE BROOK	6202	6,841.13	0.67	0.67	0.70	0.70
WAPPOQUIA BROOK	3709	3,684.70	2.06	2.14	2.23	2.33
WATCHAUG BROOK	4201	5,554.53	1.62	2.54	2.80	3.24
WEBATUCK CREEK	6303	33,766.53	1.19	1.25	1.28	1.34
WEBATUCK CREEK	6303	33,766.53	1.19	1.25	1.28	1.34
WEBATUCK CREEK	6303	33,766.53	1.19	1.25	1.28	1.34
WEBSTER BROOK	4603	3,445.31	25.71	28.86	29.87	31.37
WEEKEEPEEMEE RIVER	6804	10,312.70	1.65	1.74	1.82	1.93
WEPAWAUG RIVER	5307	12,782.25	9.08	9.58	10.03	10.48
WEST ASPETUCK RIVER	6500	12,543.07	1.53	1.67	1.71	1.78
WEST BRANCH BANTAM RIVER	6703	5,460.98	1.95	2.10	2.15	2.24
WEST BRANCH NAUGATUCK RIVER	6904	5,965.51	8.35	8.81	9.02	9.30
WEST BRANCH SALMON BROOK	4319	17,018.53	1.40	1.53	1.59	1.72
WEST BRANCH SAUGATUCK RIVER	7203	7,629.06	4.10	4.38	4.56	4.86
WEST BRANCH SHEPAUG RIVER	6702	6,702.84	0.88	0.91	0.92	0.93
WEST RIVER	5305	11,690.42	16.89	17.48	17.91	18.29
WEST RIVER	5110	11,602.98	4.92	5.21	5.43	5.64
WHALEBONE CREEK	4016	9,361.80	1.41	1.52	1.58	1.64
WHARTON BROOK	5207	4,894.67	13.02	13.94	14.49	15.53
WHETSTONE BROOK	3404	9,049.44	2.09	2.30	2.41	2.52
WHITFORD BROOK	2104	5,715.11	1.76	1.89	2.07	2.19
WHITING RIVER	6101	12,464.23	1.21	1.24	1.26	1.29
WILLIAMS BROOK	2103	3,963.86	2.91	3.32	3.50	3.86
WILLIMANTIC RIVER	3100	32,773.56	4.67	5.32	5.62	6.06
WILLOW BROOK	4602	6,723.38	17.77	18.66	19.23	19.88
WILLOW BROOK	5301	8,298.55	4.91	5.63	5.92	6.36
WINTERGREEN BROOK	5304	6,730.30	18.72	19.51	20.03	20.74
WOMENSHENUK BROOK	6016	5,988.64	1.33	1.41	1.43	1.46
WOOD RIVER	1100	49,011.02	1.16	1.20	1.21	1.25
WYASSUP BROOK	1001	7,339.26	1.02	1.03	1.04	1.11
YANTIC RIVER	3900	15,615.39	6.43	7.18	7.61	8.21
YELLOW MILL CHANNEL	7103	2,894.79	40.76	41.99	42.67	43.69

NEW YORK WATERSHEDS					
Name	Acres	1985 %IS	1990 %IS	1995 %IS	2002 %IS
BAYVILLE to LLOYD PT	25,997.37	12.26	12.83	13.21	13.81
BEAVER SWAMP BROOK	1,962.19	16.56	17.13	18.01	18.71
BEAVER SWAMP BROOK WEST	1,129.20	24.90	25.53	26.25	27.14
BLIND BROOK BASIN	6,761.44	14.92	15.62	16.34	17.93
BRONX RIVER BASIN	23,897.30	38.49	39.87	40.68	41.70
BRONX RIVER to MAMARONECK RIVER	21,221.59	48.30	49.98	50.95	52.08
CITY ISLAND	288.71	63.37	64.86	65.62	66.32
CROTON RIVER to HARLEM RIVER	10,758.49	60.75	62.31	63.13	64.12
DAVIDS ISLAND	78.20	18.68	19.11	19.56	19.99
FISHERS ISLAND	2,720.46	4.05	4.14	4.34	4.43
GLEN ISLAND	65.80	28.33	30.60	31.67	32.17
GRASSY SPRAIN BASIN	5,471.62	22.78	24.19	25.34	26.33
HART ISLAND	101.49	18.62	19.81	20.53	21.37
HEN ISLAND	35.43	2.24	2.32	2.32	2.39
HUCKLEBERRY ISLAND	9.00	0.00	0.00	0.00	0.00
KENSICO BASIN	8,543.48	4.85	5.15	5.65	5.87
KINGS COUNTY	10,427.27	85.70	86.68	86.97	87.33
LARCHMONT HARBOR	1,200.57	32.16	33.22	34.16	35.55
LLOYD PT to NISSEQUOGUE RIVER	24,061.81	15.92	16.42	16.81	17.62
LOWER LONG ISLAND SOUND	1,066.24	17.75	18.22	18.68	19.31
MAMARONECK HARBOR	752.72	21.60	22.35	23.10	24.27
MAMARONECK RIVER BASIN	11,180.73	20.57	21.99	22.90	23.86
MANHATTAN ISLAND EAST	8,148.21	80.02	80.71	81.19	81.70
MILL ROCK	2.62	0.00	0.00	0.00	0.00
MILTON HARBOR BASIN	342.47	8.26	8.84	8.95	9.26
NASSAU-QUEENS CO to SAND POINT LIGHTHOUSE	12,984.17	25.48	26.50	27.23	28.45
NISSEQUOGUE RIVER BASIN	25,752.39	19.74	21.09	22.04	23.21
NISSEQUOGUE RIVER to ORIENT POINT	35,266.08	10.07	10.65	10.93	11.59

NEW YORK WATERSHEDS Continued					
Name	Acres	1985 %IS	1990 %IS	1995 %IS	2002 %IS
NORTH BROTHER ISLAND	5.15	3.83	3.83	3.83	3.83
NORTH QUEENS COUNTY	35,966.95	66.61	67.89	68.54	69.38
PEA ISLAND	3.37	0.00	0.00	0.00	0.00
PINE BROOK BASIN	1,334.14	34.85	35.91	36.83	38.46
PLUM ISLAND	846.02	5.18	5.32	5.39	5.48
PORT CHESTER HARBOR BASIN	717.28	38.78	39.47	39.91	40.50
RANDALLS ISLAND	539.48	33.21	35.63	37.77	38.35
RIKERS ISLAND	417.65	46.41	56.74	59.89	63.00
ROOSEVELT ISLAND	146.12	45.88	48.48	50.57	52.18
SAND PT LIGHTHOUSE to BAYVILLE	17,767.31	19.16	20.02	20.66	21.57
SCOTCH CAPS ISLAND	2.92	0.00	0.00	0.00	0.00
SHELDRAKE RIVER BASIN	3,910.44	21.03	21.75	22.50	23.53
SOUTH BROTHER ISLAND	6.98	0.00	0.00	0.00	3.90

Appendix D
Table of Deliverables

Table C-1. List of Deliverables.

File Name	Date	Format	Description
1985lc_lis	1985	ERDAS Imagine	Per-pixel Land Cover
1990lc_lis	1990	ERDAS Imagine	Per-pixel Land Cover
1995lc_lis	1995	ERDAS Imagine	Per-pixel Land Cover
2002lc_lis	2002	ERDAS Imagine	Per-pixel Land Cover
1985lc_lis	1985	ESRI Grid	Per-pixel Land Cover
1990lc_lis	1990	ESRI Grid	Per-pixel Land Cover
1995lc_lis	1995	ESRI Grid	Per-pixel Land Cover
2002lc_lis	2002	ESRI Grid	Per-pixel Land Cover
1985lis_lis	1985	ERDAS Imagine	Per-pixel Impervious Surfaces Estimate
1990is_lis	1990	ERDAS Imagine	Per-pixel Impervious Surfaces Estimate
1995is_lis	1995	ERDAS Imagine	Per-pixel Impervious Surfaces Estimate
2002is_lis	2002	ERDAS Imagine	Per-pixel Impervious Surfaces Estimate
1985is_lis	1985	ESRI Grid	Per-pixel Impervious Surfaces Estimate
1990is_lis	1990	ESRI Grid	Per-pixel Impervious Surfaces Estimate
1995is_lis	1995	ESRI Grid	Per-pixel Impervious Surfaces Estimate
2002is_lis	2002	ESRI Grid	Per-pixel Impervious Surfaces Estimate
lis_wtrshd_area	All four dates	ESRI Shapefile	Impervious surface estimate summarized over entire Long Island Sound watershed analysis area
ct_lis_wtrshd_area	All four dates	ESRI Shapefile	Impervious surface estimate summarized over the entire Connecticut portion of the Long Island Sound watershed area
ny_lis_wtrshd_area	All four dates	ESRI Shapefile	Impervious surface estimate summarized over the entire New York portion of the Long Island Sound watershed area
ct_sr_wtrshd	All four dates	ESRI Shapefile	Impervious surface estimate summarized over the sub-regional watersheds of the Connecticut portion of the Long Island Sound watershed area
ct_local_wtrshd	All four dates	ESRI Shapefile	Impervious surface estimate summarized over the local watersheds of the Connecticut portion of the Long Island Sound watershed area
ny_wtrshd	All four dates	ESRI Shapefile	Impervious surface estimate summarized over the sub-regional watersheds of the New York portion of the Long Island Sound watershed area