Development of Regionally Calibrated Land Cover Impervious Surface Coefficients

Basic Information

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Principal Investigors: Michael (Sandy) Prisloe and Daniel Civco, University of Connecticut

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Statement of Critical Regional or State Water Problem: Nonpoint source pollution (NPS) has been cited as the nation's number one water quality problem and, in coastal areas, urban runoff is the pollutant of greatest concern (U. S. EPA, 1994). A number of researchers have found that the amount of urban runoff and its impacts on stream conditions and water quality are linked to the percent area of impervious surfaces within a watershed (Schueler, 1994; Arnold and Gibbons, 1996; Schueler, 2002). Research also indicates that the percent imperviousness threshold, above which impacts on stream health are noticeable, is quite low, being around 10 percent or less (Schueler, 1994).

Limiting the amount of impervious surface in a watershed is an important component of overall watershed management. Water resource and land use managers need to be able to determine the existing percent imperviousness in order to develop appropriate watershed management and/or NPS mitigation plans. While much research has focused on determining the relationship between watershed impervious surface coverage and water resource impacts, little work has been done to develop methods to measure impervious surfaces at the watershed scale (Cappiella and Brown, 2001). Past efforts to determine watershed imperviousness have been hampered by inconsistent methods and outdated or unavailable data. There is a need for easy to use tools to calculate watershed imperviousness that use well-documented methods and that achieve an acceptable level of accuracy.

Statement of Results or Benefits: This research will result in the formulation of regionally calibrated land-cover-specific impervious surface coefficients that will be used in an ArcView GIS-based impervious surface model. The model is being developed by the PIs and technical staff at NOAA's Coastal Services Center, Charleston, SC. The model will use NOAA's Coastal Change Analysis Program (C-CAP) land cover data and/or the federal government's Multi-Resolution Land Characteristics (MRLC) data, both interpreted from Landsat Thematic Mapper satellite imagery, and will calculate watershed imperviousness by multiplying the area of each land cover category by regional impervious surface coefficients calibrated for each land cover type. Furthermore, the model has been designed to accept a variety of land use and land cover source information, as well as locally-calibrated impervious cover coefficients. The model is based on a prototype developed by researchers at the University of Connecticut (Prisloe, Lei and Hurd, 2001).

The direct beneficiaries of the research will include two distinct groups; a national network of more than twenty Nonpoint Education for Municipal Officials (NEMO) Projects and water resource and land use managers at the local, regional and state levels of government. The use of the impervious surface model with data calibrated to the users' geographic region will greatly improve the model outputs and will provide officials with information that otherwise likely would be unavailable. Recognizing that there are differences in impervious cover among land use types, either because of category definition or geography, this study will examine land use information from both C-CAP and MRLC from study sites selected from within the coverage of the National NEMO Network. Metrics and estimates of variability for watershed imperviousness will provide the users with information necessary to design watershed management plans to control future increases in impervious surfaces or to mitigate its impacts in locations where large percentages already exist.

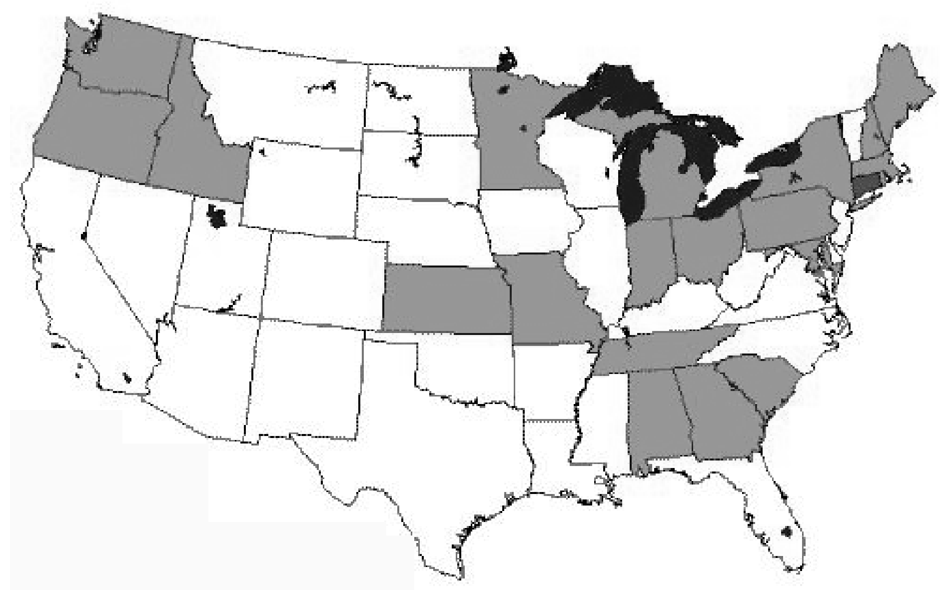

Figure 1.National NEMO Network Member States

Nature, Scope and Objectives of the Research: The objective of the research is to develop regionally calibrated impervious surface coefficients to be used with nationally available land cover data to calculate imperviousness for watersheds at locations throughout the country. The coefficients will be derived from high-resolution digital planimetric datasets that include building outlines, road pavement, driveways, parking lots and other impervious features. To our knowledge, this will be the first such set of regional impervious surface coefficients developed using a consistent and documented methodology. Calibration data will be collected from members of the National NEMO Network who possess planimetric data meeting the standards set forth by these investigators, most notably in terms of precision, polygon closure, and contemporaneousness with existing land cover data.

Analyses will be conducted by a graduate assistant under the supervision of the PIs. Tasks to be performed will require a working knowledge of remote sensing data, familiarity with image processing techniques to interpret land cover data from satellite imagery, and expertise in the field of geographic information systems. The graduate student will be responsible for acquiring and verifying the calibration data, preparing the data sets for analysis, developing the impervious surface coefficients, preparing project metadata and preparing informational and instructional materials to support use of the data in the impervious surface model.

Methods, Procedures and Facilities: Contemporary digital planimetric impervious surface data will be acquired from selected regions of the United States. Regions, although subject to change, likely will include the northeast, mid-Atlantic, southeast, Great Lakes and Pacific-northwest, coinciding with the geography of the National NEMO network and coverage of both C-CAP and MRLC land use datasets. Within each region, multiple samples each of rural, suburban and urban planimetric data will be sought. Sample areas will include towns, townships and cities; or portions thereof if complete areal coverage is unavailable. These planimetric data will be supplemented by impervious calibration data being developed in a parallel effort through on-screen, heads-up digitizing from digital orthophotographs[1]. Planimetric impervious surface data will include building footprints, road pavement, driveways, parking lots, sidewalks, tennis courts, patios and other impervious landscape features as shown in Figure 2.

Figure 2. Example of impervious cover calibration data

Digital planimetric impervious surface data will be solicited through the National NEMO Network, which is coordinated by NEMO staff at the Middlesex Cooperative Extension Office. A set of specifications will be prepared to define data requirements, content and accuracy. NEMO Project staff in each of the regions will

[1] *Concerted development and evaluation of techniques for impervious surface area estimation.* US Geological Survey, National Mapping Division and Water Resource Division. (John Jones, USGS, Reston, VA, Principal Investigator).

be tasked with locating and acquiring appropriate datasets. For information about the NEMO project, see http://nemo.uconn.edu.

Based on previous impervious surface research (Sleavin, 1999) supervised by the PIs, and observed also by cooperators at NOAA's Coastal Services Center[2], it is likely that significant spatial variations in land use patterns will exist within the acquired datasets. Sleavin's research, based on planimetric impervious surface data from four towns in Connecticut, found that within a single land cover class the percent of impervious surface varied based on the degree of urbanization (population density) of the town. For example, the amount of impervious surface found in the residential land use class was significantly lower in rural towns than it was in urban towns that were studied. Additionally, a great deal of variability in land use patterns was found within study towns. West Hartford, an urban town included in the research, had areas that ranged from densely developed to completely undeveloped.

Land use specific impervious surface coefficients will be derived using a method developed at the University of Connecticut (Sleavin, 1999; Prisloe, *et al*., 2000). With this method, land cover data (C-CAP and MRLC) are converted to a GIS polygon format and are overlaid on impervious surface calibration data, also polygon features. The area of imperviousness within each land cover class is calculated as

$$LULC_{ISarea} / LULC_{Area} * 100 = \text{LULC coefficient}$$

where $LULC_{ISarea}$ is the total area of impervious surface for a LULC class, and $LULC_{Area}$ is the total area for the same LULC class

This process will be repeated for each land use type from each urbanization class within each of the geographic regions (as discussed in the following) resulting in a set of regionally calibrated impervious surface coefficients.

Given the nature of definitions for land use and land cover, methods for its derivation, and its geographic dependency (*i.e.*, single family residential in the Northeast US has different characteristics from the same category in the Southeast), it is apparent that there will be a range of degree of imperviousness for a given land use class or set of related land use categories. It is essential that impervious coefficients derived from land use, whether the source be C-CAP, MRLC, or other, contain an expression of variability. Therefore, planimetric data for a large sample (n > 100) of impervious calibration sites will be acquired, through either the aforementioned National NEMO Network or the parallel USGS study[3]. This extensive data set will be partitioned into calibration and validation data sets, the former from which to develop impervious

[2] Eslinger, David, NOAA Coastal Services Center, Charleston, SC. Personal Communication, January 30, 2002.
[3] In this parallel study there are more than 150 sites measuring 510 meters on a side from areas within Massachusetts-New Hampshire, Maryland, and Florida, mapped from 1-meter digital orthoimagery, and covering a wide range of impervious surface densities and land use types.

cover coefficients and the latter to test their accuracy. The large sample of calibration data will enable the construction of error (variability) estimates for percent imperviousness for each land use class (likely μ +/- 1σ).

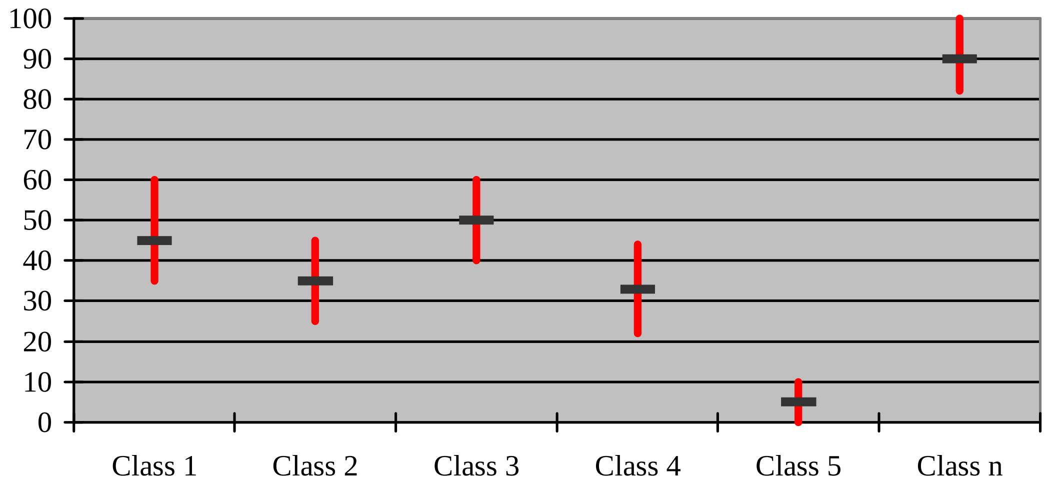

Figure 3. Hypothetical impervious cover means and ranges

It is recognized by the PIs that the relationship between population density and imperviousness is not linear for all land cover classes and that conditions exist where population density is low and imperviousness is high, such as within industrial areas. To account for the variability of impervious cover estimates as a function of development intensity class, a methodology to stratify the data into urban, suburban and rural classes will be developed. The urbanization classes will be independent of town geographies and may be based on Census blocks and population density or a modeled spatial property or set of properties of the land cover data (*e.g.* mean patch size, fractal dimension, proximity index). Stratification of the data will produce calibration datasets that accurately depict the degree of urbanization for which impervious surface coefficients will be developed.

The capability to estimate percent imperviousness under different urban intensity scenarios (*e.g.*, urban, suburban, rural) has been enabled within the ArcView extension tool being co-developed with NOAA CSC (Figure 4). Additionally, the tool provides the capacity to specify a dataset, such as Census tracts or a user defined geography, from which population density may be calculated. It is the intention of these PIs to maintain an updated library of impervious cover coefficients from which users can draw in order to fit specific land use characteristics.

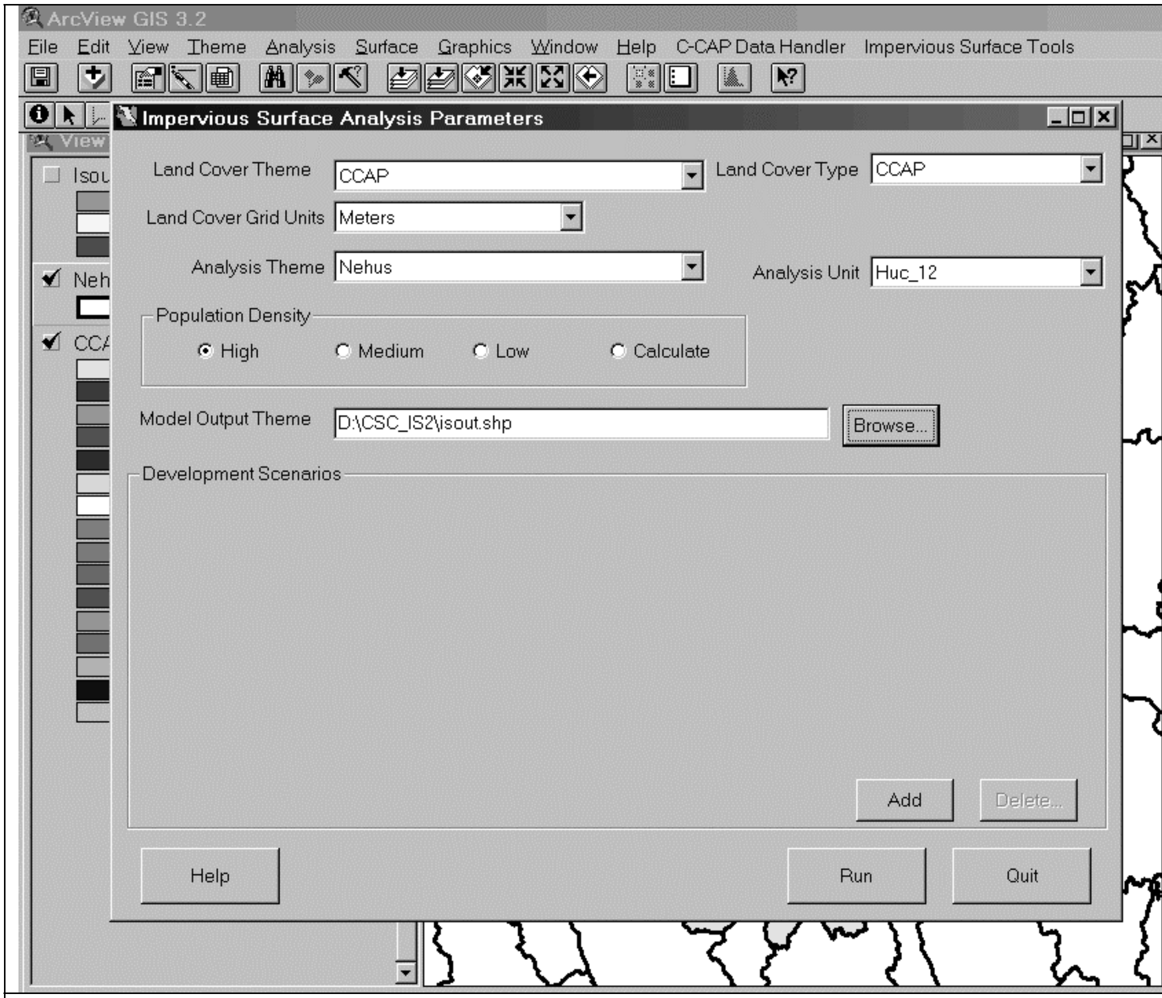

Figure 4. Parameter input box from the impervious cover tool ArcView extension.

Work on the project will be conducted at the Laboratory for Earth Resource Information Systems (LERIS) located within the College of Agriculture and Natural Resources. LERIS is the principal center at UConn for conducting geospatial data processing and research oriented toward natural resources and the environment. In 1997, LERIS was designated a *NASA Center of Excellence in Applications of Remote Sensing to Regional and Global Integrated Environmental Assessments***.** LERIS has conducted comprehensive remote sensing-based land use and land cover inventories for the state of Connecticut and neighboring portions of New York, Massachusetts, and Rhode Island using satellite based Landsat Thematic Mapper (TM) imagery (Civco and Hurd, 1991; Civco *et al.*, 1991; Civco *et al.*, 1998). The laboratory has multiple copies of ERDAS, ER Mapper and eCognition image processing software and participates in the University's site for ESRI's complete suite of GIS software.

Related Research: As stated above, the PIs have investigated the relationship between imperviousness and satellite derived land cover data for four towns in Connecticut (Sleavin, 1999). A hypothesis, that imperviousness is a function of land cover, was found to be partially true; however, the results of the research suggest that imperviousness is a function of land cover AND population density of some other variable such as land cover class density. This will be explored further through the proposed research.

The PIs also are collaborating on a study with the USGS to develop impervious surface calibration data for the New England Coastal Basin. These data are being interpreted from digital orthophoto quadrangles for a set of 450-meter by 450-meter sites through out the basin. Resulting impervious surface data will be used to test several methodologies for estimating imperviousness. These include several image processing techniques that use raw satellite imagery, spectral linear unmixing and sub-pixel classification and a technique similar to that proposed here.

The Center for Watershed Protection has summarized a number of methods that have been used by organizations to estimate watershed imperviousness that include using surrogate measures such as road densities, population density and other metrics (Cappiella and Brown, 2001).

The later two investigations are related to the proposed research but involve either a high degree of image processing expertise or surrogate measures to generate imperviousness estimates.

The proposed research, unlike the above, will result in impervious surface coefficients that easily can be used with readily available national datasets.

Progress

Planimetric, land use, and census data have been collected and analyzed for seven towns in Connecticut: Marlborough, Milford, Stamford, Suffield, Waterford, West Hartford, and Woodbridge. Data for other towns in the state (Groton, East Haddam, Killingly, Stonington and New London) as well as in neighboring portions of Massachusetts (Amherst) and New York (several Westchester County towns) are in the process of being collected and pre-processed. Preliminary analyses have been conducted at the census tract level, however, these are being extended to the finer scale block level as well as local watershed.

Two different sets of land use data have been used: those developed by the Laboratory for Earth Resources Information Systems (LERIS) using *circa* 1994-96 satellite remote sensing data[4],[5], and those from the National Land Cover Data (NLCD) program, based principally on *circa* 1992 satellite remote sensing data[6]. Whereas the land cover data developed by LERIS are more current, more spatially and thematically detailed, more

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[4] Hurd, J.D. and D.L. Civco. 1996. Land use and land cover mapping for the state of Connecticut and portions of New York state in the Long Island Sound Watershed. in Proc. GIS/LIS'96 Convention, Denver, CO. pp. 564-572.
[5] Civco, D.L. and J.D. Hurd. 1999. A hierarchical approach to land use and land cover mapping using multiple image types. Proc. 1999 ASPRS Annual Convention, Portland, OR. pp. 687-698.
[6] http://landcover.usgs.gov/natllandcover.html

accurate, and produced superior impervious surface estimates, the decision was made to proceed with the NLCD land cover because they are nationally-consistent data and are in the process of being updated[7]. The use of NLCD and the Census Bureau data enable the development of a geographically-extensible model.

A regression model estimating percent imperviousness has been developed for the 64 census tracts constituting the seven towns studied thus far. The general form of the tract-based regression is:

$$\%IS = (a + b*PopDen + c_i*\%LU_i)$$

where,

- %IS = the estimated percent imperviousness per tract
- PopDen = the population density (persons mi^{-2})
- Lu_i = the percentage of the tract occupied by land use "i"

The 64 tracts studied were divided into two sets of 32 with 30 randomized replications. The calibration and validation data were the town planimetric data (building footprints, roads, driveways, parking lots, sidewalks, etc.).

The specific form of the linear regression developed thus far, and under refinement, is:

$$Percent\_IS = a + b_1*Population\ Density + c_1*Low\ Intensity\ Residential + c_2*High\ Intensity\ Residential + c_3*Commercial + c_4*Deciduous\ Forest + c_5*Coniferous\ Forest + c_6*Mixed\ Forest + c_7*Crops + c_8*Recreational\ Grass + c_9*Wooded\ Wetland$$

Using the set of mean coefficients from the 30 independent regressions, impervious surface was estimated for the 64 tracts with a root mean square error (RMSE) of 3.33 percent, with maximum overestimations and underestimations of +/- 8 percent. It is expected that this model will evolve, and improve, with the addition of other calibration data from other towns, as well as the investigation into interaction models.

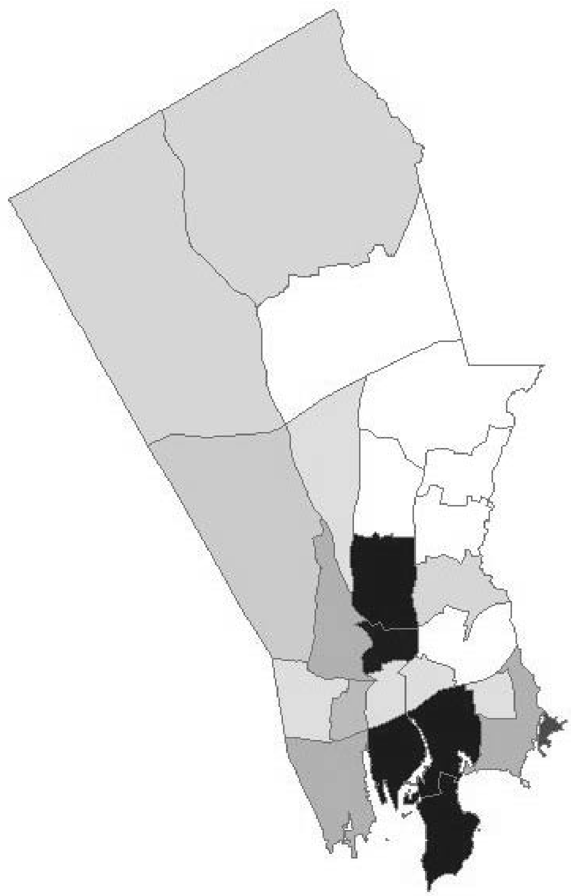
The generalized equation is being applied also at the census block level to provide a finer granularity in impervious surface prediction. Further, it is being applied at the local watershed level, a more meaningful geographic unit in terms of water quality and non-point source pollution. Because there is a strong relationship between impervious cover and not only land use but also population density, and since population data exist only for census measurement units (*e.g.*., tracts, blocks), a method had to be devised to interpolate population for local watersheds. Block population data were rasterized into the same grid space as the NLCD land use data and were summarized (averaged) over intersecting local watersheds. Divided by the area of the watershed, this provides an estimate of population

[7] http://landcover.usgs.gov/natlandcover_2000.html

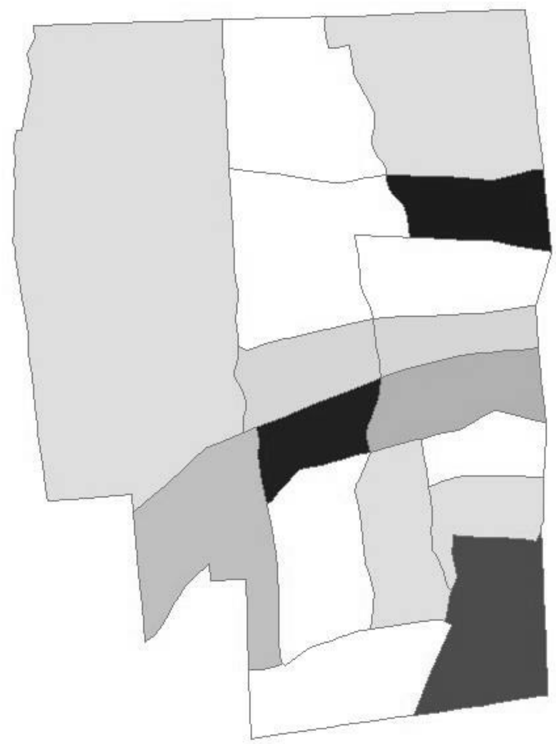
density. Likewise, percent of each land use in each watershed was determined by intersecting the two data layers. The same preliminary regression was applied to estimate percent imperviousness at the watershed level.

One independent variable not previously considered is committed open space – lands upon which little or no development occurs, such as state forests, parks, trust lands, and other forms of conservation areas. Future regressions will incorporate this predictor variable.

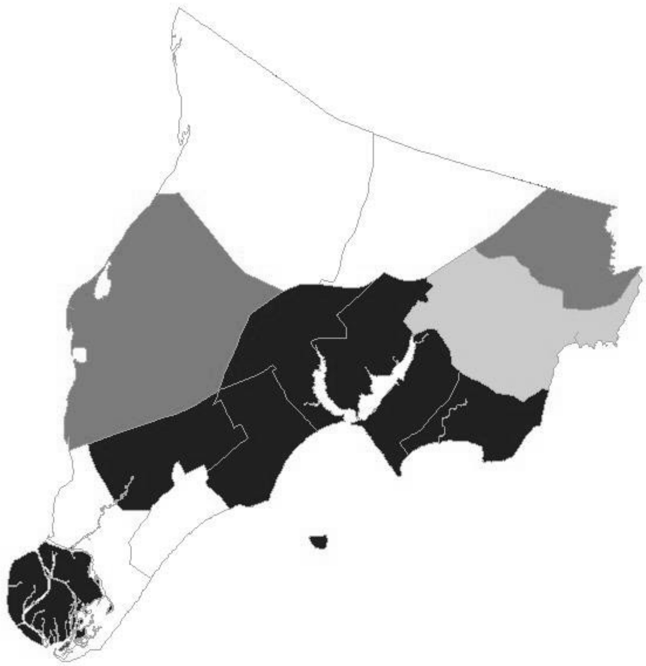
Examples of results to date are shown in Figure 1 which depicts the difference between actual imperviousness per tract and that predicted by the preliminary regression model for three study towns.



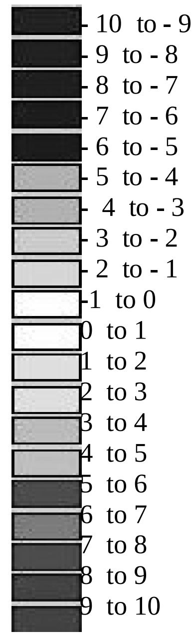
Stamford, Connecticut



West Hartford, Connecticut



Milford, Connecticut



Legend (% Difference)

Figure 1. Actual minus predicted impervious surface for three Connecticut towns.

Note: Maps are portrayed at different scales.

Student Support

Funds from this project have been used to support an MS-degree student, Anna Chabaeva, concentrating in earth resources information systems within the Department of Natural Resources Management and Engineering. Ms. Chabaeva has been the analyst largely responsible for data reformatting and analysis.

Publications

There have been no publications from this research as of yet. However, given the promising results thus far, it is expected that an abstract for a paper and presentation will be submitted for the ASPRS 2004 Annual Convention[8]. Also, there are plans for at least one peer-reviewed article. Ms. Chabaeva's Master's thesis will be yet another outlet for the results. And lastly, the results of this research will form the basis of a chapter of a manual on methodologies for impervious surface measurement.

Information Transfer

Once the impervious surface prediction model has been finalized, it will be applied to spatial data for the entire state of Connecticut and made available on the Internet by way of ArcGIS Server and ArcIMS. FGDC-compliant metadata[9] will accompany the map data. These products will become part of a website on impervious surface and located on the NAUTILUS[10] server (http://resac.uconn.edu).

Submitted 27 June 2003

[8] American Society for Photogrammetry and Remote Sensing, http://www.asprs.org/denver2004call.pdf
[9] Federal Geographic Data Committee, http://www.fgdc.gov/metadata/meta_stand.html
[10] Northeast Applications of Usable Technology In Land planning for Urban Sprawl, a NASA Regional Earth Science Applications Center (RESAC).

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