Remote-Sensing-Enhanced Outreach Education as a Decision Support System for Local Land-Use Officials

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Abstract

Technological advances in remote-sensing (RS) science and cultural changes brought about by the "digital revolution" are combining to bring the worlds of remote sensing and land-use planning closer together. The University of Connecticut is engaged in a series of three projects that investigate RS-based decision support systems (DSS) for local land-use officials. The NEMO Project is focused on town-level decisions, the Connecticut River Watersheds Project is focused on watershed-level decisions, and the NAUTILUS Project is working on specific tools addressing urban sprawl. Each DSS is built upon a delivery system of professional outreach educational programs, based on RS information, and enhanced through the use of geographic information systems (GIS). A review of this work demonstrates that, when integrated with applications and outreach to form tailored decision support systems, RS information can be a powerful force in assisting local officials to plan better the growth of their communities.

The Need for Better Land-Use Decisions

Land use is the common thread that runs through some of the most vital issues facing America's communities today — issues like economic growth, natural resource protection, and quality of life. The need for more informed land-use decisions has become a priority issue for agencies and organizations from the Environmental Protection Agency to the National Homebuilder's Association, and is manifested in new programs focused on topics such as "sprawl," "liveable communities," and "smart growth."

Evidence of the environmental, social, and economic impacts of poorly planned communities continues to mount. Nonpoint source pollution, or polluted runoff, which has its genesis in land use, is now the number one water quality problem in the United States (U.S. EPA, 2000). The Nature Conservancy reports that up to one-third of the country's animal and plant species are at risk of extinction, primarily due to habitat loss and degradation (Stein and Flack, 1997). The American Farmland Trust estimates that farmland is being lost to development at a rate of one million acres per year (Sorensen *et al.*, 1997). Urban "sprawl" — the attenuated, land-consumptive pattern of suburban development that has dominated the American landscape since the advent of the interstate highway system after World War II — is a major concern of financial institutions and environmental agencies alike (Bank of America, 1995; Sierra Club, 2000).

Confronting these problems, with few tools at their disposal, are local land-use decision makers in communities across the country. Land use in the United States is predominantly a local issue. Land-use policies are developed, and land-use decisions are made, by elected and appointed officials at the county and municipal or town level. Most of these volunteers have little or no training in land planning or natural resource protection, and many lack professional assistance. The decisions made by these local officials will determine the look and feel of the country's landscape for decades to come (Arnold, 1999).

The Potential Benefits of Remote Sensing

Because of the critical importance of their work, and because they deal with land-use planning and regulation on a daily basis, local officials are prime candidates to be the beneficiaries of information derived from remote sensing (RS) science and related geospatial technologies. There are, however, significant impediments to making geospatial information truly useful at the *local* level. Unlike federal and state natural resource management professionals, local officials are volunteers with limited access to geospatial data, and are constrained in their ability to develop uses for the data that are relevant to their operations. Simply providing data or maps is not enough. Impressive multi-layer maps created with geographic information systems (GIS) are becoming the digital age equivalent of the 300-page technical report that sits on a shelf, gathering dust. Land-use decision makers need both improved RS-derived information and *meaningful* access to this information.

The challenges posed in bringing "space science" to town hall are considerable, but the potential benefits are enormous. Geospatial information and tools can be critical assets for local and regional land-use decision makers as they plan and design their communities. Geospatial technologies can provide the key information that allows local natural resource managers to place their case-by-case land-use decisions within the broader context of the community, region, or watershed, assisting them to characterize and understand their landscape, identify and map priority natural resources, project land-use patterns and visualize alternative futures, educate their constituency, and

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share information and resources needed to reach consensus on a future course for their communities.

The key to realizing these benefits will be the development and dissemination of decision support system (DSS) models that successfully bridge the gap between the RS and planning worlds through the integration of research, applications, and outreach. The University of Connecticut has been conducting projects investigating such DSS models for the past nine years. The work is a collaboration between the Laboratory for Earth Resources Information Systems (LERIS) and the Cooperative Extension System (CES), two units of the University of Connecticut College of Agriculture and Natural Resources. This paper presents three case studies that demonstrate the evolution of our approach to a local land-use DSS. Each project involves the use of RS-derived information, and the manipulation and tailoring of that information through the use of GIS analyses. Based on our conviction that face-to-face educational interchange is the foundation of the decision support process, each depends on delivery of the information through the media of professional outreach education.

The NEMO Project: A Simple DSS for Town-Level Land-Use Decisions

Project Objectives

The Nonpoint Education for Municipal Officials (NEMO) project was created in 1991 to educate local land-use decision makers in Connecticut about the relationship between land use and water quality. The catalyst for NEMO was the creation of statewide land-cover information derived from Landsat Thematic Mapper (TM) imagery. Because the land-cover data have a 30-meter resolution, and local officials focus on the site-level scale of perhaps 1 to 10 meters, NEMO was developed in part to test the hypothesis that an outreach-based delivery system for RS and GIS data could bridge the "resolution gap" and serve as an effective DSS.

NEMO was developed around outreach education programs tailored for, and delivered at the convenience of, the target audience of town-level land-use commissioners. Local land-use decision makers comprise a challenging audience for any decision support effort. Local commission membership turns over rapidly, and commissioners are pressed for time and typically not well versed in technical matters. As a result, our assumption was that a DSS for this audience must be non-technical, highly interactive, not overly time-consuming, and presented within both the logistical and topical contexts of the world of local decision making.

Project Design

The initial NEMO effort focused on three pilot towns along Connecticut's coast. A one-hour educational program was developed. The first half of the presentation focuses on water resources, water quality issues, and the concept of watersheds. State natural resource GIS data such as watershed boundaries, simple hydrography, and town boundaries are used to help convey these concepts. The second half of the presentation addresses land-use patterns and their relationship to water resource protection. The TM-based land-cover data are the foundation for this part of the program (Arnold *et al.*, 1993). Presentations were tailored for each of the three pilot towns, and delivered to municipal audiences that included members of all land-use boards and commissions, as well as other town groups such as economic development commissions, land trust officials, and boards of finance.

GIS technology is critical to meeting NEMO's self-imposed stringent requirements for an effective local land-use DSS. Above and beyond analysis of data, GIS maps can convey a tremendous amount of information in a short period of time. However, the images must be well-crafted, and not simply extracted from a GIS or image-processing software package with all the potentially distracting and confusing "buttons and whistles." Presenting these tailored GIS images through the use of computer projection software has enabled us to convey geospatial information in an even more compelling way. Using computer projection and clipped GIS maps in combination allows the presenter to "build" GIS-derived maps without resorting to potentially confusing and problematic demonstrations of actual GIS operations. Computer projection has other distinct advantages, enabling the presenter to combine geospatial data with a wide range of other information, customize presentations quickly and easily, and use animation to direct the audience's attention.

The Role of Remote Sensing

NEMO is based upon a *circa* 1988/1990 land-cover data set produced by LERIS for the Long Island Sound Study National Estuary Program, commissioned for the purpose of estimating nonpoint source pollutant loadings to Long Island Sound. The land-cover map was created through independent classification of spring and summer Landsat Thematic Mapper satellite images utilizing a maximum-likelihood classification algorithm. A matrix was used to merge subjectively the spring and summer classifications, resulting in a single classification containing 22 categories of land-cover information; major roads from vector digital line graphs were added to form an additional category (Civco and Hurd, 1991).

NEMO presents these land-cover data in simplified form. The original 23 land-cover categories were reclassified into four grouped classes that best approximate the land-use designations familiar to local officials: residential; commercial and industrial; agriculture and open land; and forest and wetland. These generalized categories are then mapped separately and combined with local photographs to highlight the extent and distribution of each land use, and to introduce the water quality issues associated with each (Figure 1). The maps are displayed in order of increasing intensity of land use, highlighting the mounting impacts on water resources as urbanization occurs.

NEMO also uses RS land-cover data to estimate existing and future water quality conditions, through an analysis of impervious cover. Impervious land cover is a widely accepted indicator of urbanization and its impacts on water resources (Klein, 1979; Schueler, 1994; Arnold and Gibbons, 1996). Coefficients of impervious cover taken from the literature are applied to the aggregated land-cover categories to estimate the average level of

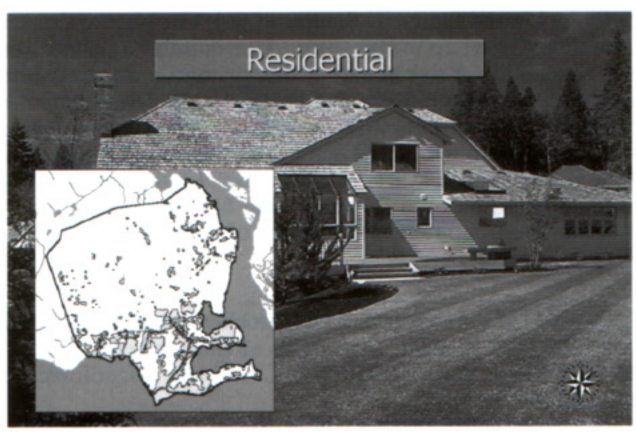

Figure 1. NEMO combines single-factor land-cover maps with local photos for maximum educational effect.

impervious coverage for small-order drainage basins (average size about 2 square kilometers). The map of current impervious cover is then compared with a zoning-based "build out" scenario, which assumes that all land zoned for a particular use will eventually be put to that use (unbuildable areas such as committed open space and wetlands are excluded) (Stocker *et al.*, 1999). In both scenarios, the percent impervious coverage is depicted in a "stoplight" color scheme corresponding to average values shown in the literature to protect (green), threaten (yellow), or degrade (red) water resources (Plate 1). The end result is a "back-of-the-envelope" estimate for local officials of the future ramifications of their current land-use regulations — not in the more traditional terms of population or housing density, but in terms of the amount of impervious cover and its implications for the health of their water resources.

Results and Discussion

Despite improvements to the hardware and software, the basic NEMO education program is not much different today from the original 1993 version. Seven years after the first NEMO presentation, project staff give approximately 150 presentations a year, all by request — a strong indication of the value that local officials place upon this DSS. The project has worked with well over half of the 169 municipalities in Connecticut. Project analyses and information have been incorporated into several regional and state plans. At the all-important local level, the project has documented many changes to town plans, policies, and practices catalyzed by the NEMO DSS. Type of impacts include changes to town comprehensive plans; changes to zoning and subdivision regulations; subdivision design criteria that promote infiltration and reduction of impervious surfaces; creation of open space plans and watershed management plans; initiation of scientific research projects and K-12 education projects; and increased cooperation and communication among land-use decision makers, both within towns and among towns.

Success can also be measured by the interest in NEMO from peers in other states. The NEMO model is being adapted around the country, with funded pilot projects in 16 states and a number of projects in the planning stage. Although these projects differ somewhat in topical focus, virtually all are concerned with the impacts of urbanization on water resources. All use land-use or land-cover data displayed using GIS maps as a foundation of their educational programs. The University of Connecticut is in the process of linking these adaptations into a National NEMO Network, through which member projects can share information, educational tools, and experiences (Rozum and Arnold, 2000).

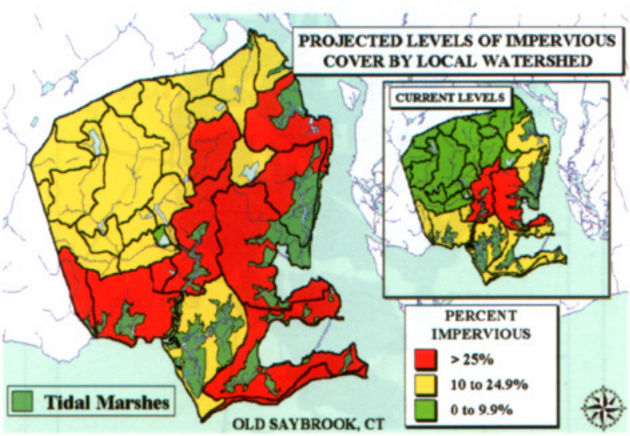

Plate 1. Impervious surface analysis for Old Saybrook, Connecticut, comparing current levels estimated from RS data (inset) to future levels projected from zoning.

Based on these successes, we conclude that the unique perspective provided by 30-meter RS data more than outweighs its shortcomings in resolution. The 30-meter resolution of the land-cover imagery does pose certain problems for its effective use. First of all, careful attention is needed to ensure that the target audience understands the limits of the data. Researchers and educators must sometimes walk a fine line between explaining such limitations, and undermining the perceived value of the information by detailing a long list of technical caveats. Second, resolution obviously imposes limits to what size area can be meaningfully examined within the DSS context, and to what extent the information presented can be quantified. For example, one persistent problem is that older residential neighborhoods with mature trees are often classified as forest cover. Therefore, without considerable ground-truthing, an analysis quantifying natural versus developed land for smaller jurisdictions may be suspect.

Despite these cautions, RS-derived land cover is in many ways a new and useful type of information for local officials. In dealing with issues of growth, nonpoint source pollution, forest fragmentation, etc., what physically comprises the land surface is an important piece of information to which few have access. Local officials are more familiar with maps that show *land use*: i.e., what types of activities or development are planned or permitted, such as zoning or parcel maps. These maps deal with cultural information and administrative zones, but may not convey what is actually happening on the land. Conversely, aerial photos — even digital orthophotos — show land cover in great detail, but cannot easily be used to extract statistics or perform quantitative analyses. Thus, the image of their town's RS-derived land cover can be a valuable and unique piece of information for local officials.

An essential aspect of making these data useful is simplicity. Local officials see many maps in the course of their work. However, after decades of outreach work with this audience, it is the firm conviction of the investigators that most people are not proficient at reading maps. The simpler the image can be rendered, the better. The simplicity of NEMO's most educationally powerful images of RS land cover, watershed boundaries, and waterways stands in direct contrast to the tendency of GIS practitioners to create maps with multiple overlays. NEMO has convinced us that complex multi-layered GIS maps are more likely to be effective as modern art than as a DSS component.

Within the framework of the NEMO DSS, the primary value of RS-derived information is educational rather than analytical. Our experience has shown that this education can be effective in creating the momentum for land-use policy change at the local level. However, because catalyzing change in local public policy takes time, an essential requirement of this type of DSS is a continuing presence by the DSS providers, in this case professional outreach staff.

Creating a Watershed Framework for Local Land-Use Planning

Project Objectives

NEMO demonstrates the power of geospatial technologies to enable local officials to visualize the relationship between their land-use decisions and resultant impacts on water resources. Just as important is another type of visualization — the ability to put town- and parcel-level land-use decisions into the more environmentally meaningful context of a regional watershed or ecosystem. The objective of the second case study was to test the hypothesis that the NEMO DSS model could be expanded to encompass a multi-town region (Arnold *et al.*, 1996).

The Connecticut River Watersheds Project, which began in 1993, is comprised of a series of three projects focused on regional subbasins of the lower Connecticut River. The lower Connecticut River region has been identified by state and federal environmental organizations as a critical habitat area. Water quality improvements to the river since the advent of the Clean Water Act in the early 1970s, coupled with a geological setting that has inhibited intensive development, have resulted in an area rich in high quality tidal marshes. The subject watersheds range in size and political jurisdiction from Chester Creek, about 15 square kilometers in area and involving two towns, to Salmon River, about 300 square kilometers in area and involving seven towns. For purposes of illustration, in this paper we focus on the Eightmile River Watershed, which is 100 square kilometers in area and involves three towns.

Project Design

The DSS in this case study differs in several ways from that of the NEMO Project. First, the educational programs target private landowners in addition to community decision makers. A successful DSS must have a clearly defined target audience. We believe that land-use patterns within the project area, and the target audiences that control them, must drive the program. The Eightmile River watershed is over 80 percent forested, most of which is controlled by non-industrial private land owners. This key target group was therefore added to our NEMO audience of community decision makers (Kane and Worthley, 2000).

Second, the watershed projects have an organizational structure that includes a Resource Team of University and other natural resource professionals, working with a Watershed Committee of local leaders. Watershed Committee members help establish project goals, and provide local knowledge and data to the Resource Team to help create the GIS analyses that are deemed most critical to reaching those goals. This iterative process is perhaps the most critical aspect of the watershed project DSS. The final products of the Resource Team/Watershed Committee collaboration, in the form of NEMO-style GIS-supported educational presentations, are delivered to various audiences in the watershed communities, sometimes by University of Connecticut CES professionals but often by the Watershed Committee members themselves.

Third, the watershed projects involve the development and deployment of many more digital data layers and analytical procedures than a standard NEMO town program. In addition to data related to water resources, these projects focus on cultural, historical, and upland natural resources. Vector data include

- publicly available basic and interpreted natural resource data (e.g., surficial materials, soils suitable for on-site septic systems, wetland soils, rare and endangered species, slope),
- infrastructure and administrative data (e.g., municipal boundaries, transportation, water and sewer infrastructure), and
- data layers digitized and/or developed especially for the project (developed land, parcels, archaeologically significant sites, active farmland, stream habitat quality, forest fragmentation).

Special project data layers were created using a number of techniques. For example, *important historical and archaeological sites* were digitized from paper maps and expert input from the State Archaeologist. Other data, such as the *developed land* layer, was created by on-screen digitizing of developed areas from scanned USGS quadrangle maps, which were then updated with digital orthophotographs and "windshield survey" field checking.

All data layers were assembled into an atlas of single-factor maps and placed on the project Web site for the use of all involved with the project. The data layers became the basis for a number of analyses devised by the combined Resource/Watershed team. After several iterations over the course of about two years, three final map series combining both single-factor and analytical maps were created: Land Resources, Water Resources, and Development/Community Resources. The final maps of each series were then combined to show the relationship of priority land, water, and cultural resources to the areas in the watershed best suited for development. The areas of conflict (and no conflict) have become the basis for discussion among land-use commissions and community leaders in the watershed towns.

The Eightmile River Land Resources series, the final map of which appears as Figure 2, helps to illustrate some of the key aspects of this case study. Forest fragmentation was identified by the Resource/Advisory team as the critical "upland" land-use issue in the watershed. Unfragmented areas were determined using RS land cover, state and specially acquired GIS data, best professional judgement by the Resource Team professionals, best local judgement by the Advisory Committee, and field verification. Each area was then evaluated and ranked based on such features as size, roundness (amount of interior forest habitat), percentage of productive forest and agricultural soils, amount and quality of water resources, and amount of permanently protected land. The results of this involved analytical process, however, were then "distilled" into a series of concise maps displayed using Powerpoint slides that often take less than a minute to present. Figure 2 is the last, and simplest, map.

The Role of Remote Sensing

The Watershed Projects use an updated and improved version of the original 1990 land-cover database used to develop NEMO. The 1997 Connecticut statewide land-cover mapping employed a hierarchical approach to land-cover classification, resulting in the generation of 28 categories of information (Civco *et al.*, unpublished report, 1998; Civco and Hurd, 1999). In this technique, a normalized difference vegetation index and Tasseled Cap transformation were applied to springtime and summertime

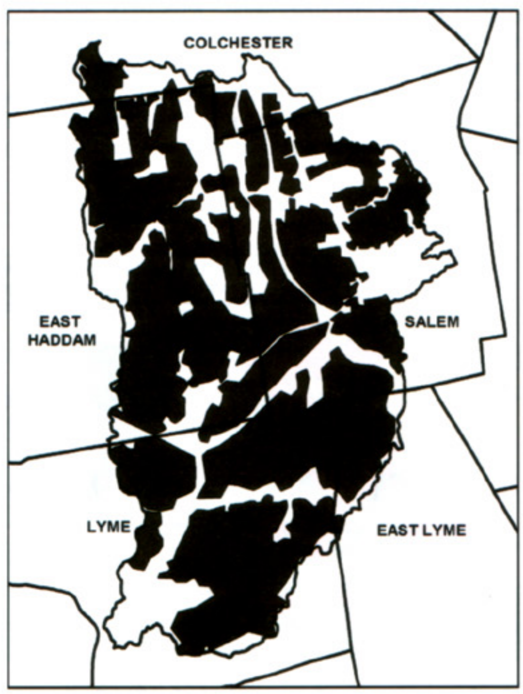

Figure 2. Unfragmented forest areas within the Eightmile River Watershed.

imagery to extract spectrally similar pixels from Landsat Thematic Mapper imagery. The spectrally similar pixels were grouped into images identifying vegetation, water, wetland, and urban and barren. Each of these image groupings were classified individually using a maximum likelihood classification algorithm, and then merged to create a single land-cover map.

To locate and identify isolated residential and commercial areas which tend to be too small to be resolved by the Landsat TM sensor yet are an important component of the Connecticut landscape, a TM/SPOT fused image was created. This fused image can be described as a 10-meter, six-band multispectral image. It was created by resampling the six reflective 30-meter TM bands (excluding the thermal band) to 10-meter pixels, performing principal components analysis (PCA), histogram matching the 10-meter-pixel resolution SPOT panchromatic image with the TM-derived principal components, and then performing inverse PCA to re-create six-band 10-meter-resolution image data. This image was closely examined, and thresholds were developed based on the spectral characteristics to derive a binary map which identifies urban structures and other features with spectral characteristics which are similar to the urban features (*e.g.*, barren land, bare soil, exposed rock, etc.). This 10-meter urban structure binary map was then resampled to a 30-meter dataset, and fused with the 30-meter TM-derived land-cover data. The resulting classification provided a more detailed discrimination of land-cover features in Connecticut, particularly in the suburban/urban fringe. A comparison of the 1990 and 1997 data for the same town in Connecticut demonstrates this improvement (Plate 2).

Results and Discussion

Educational workshops presenting the project information and draft recommendations are still being presented by both Resource Team and Watershed Committee members to a wide range of community groups and organizations. Even so, the Eightmile River Watershed project already has been very successful at fostering a watershed perspective for land-use decision makers, both at town hall and at the property owner level. For example, in December of 1997 the First Selectmen (chief elected officials) of each of the three towns in the Eightmile Watershed signed the Eightmile Watershed Conservation Compact, in which they agree to work together to guide their towns' growth in a way that preserves the natural resources and community character of the area. Based on our experience with NEMO and the Watersheds Project, CES staff have developed metrics for monitoring and evaluating changes to local land-use policies and practices. It should be emphasized that, while these changes are *catalyzed* by the DSS, they are *realized* by the local entities themselves, and often the result of a combination of many factors. Table 1 summarizes some of the key impacts, to date, that have occurred in the Eightmile River Watershed.

The Watersheds Project effectively demonstrates the utility of geospatial data and analyses in assisting local land-use decision makers to "remove the blinders" imposed by their immediate local concerns, and put land-use decisions within a watershed context. The DSS models for both the Watershed Project and NEMO are built upon the same foundation of education, informed and facilitated by geospatial technology. However, NEMO relies primarily on the educational power of RS information in presentation form, while the Watersheds Project adds the key component of the iterative mapping *process* between the Resource Team and Watershed Committee.

The Watersheds Project has also demonstrated to the investigators that plentiful digital data can be a mixed blessing. While more data allow more powerful analyses, their use demands more carefully planned and implemented delivery systems. Complicated issues like forest fragmentation, analyzed using complex geospatial technologies and data acquisition techniques, not only *can* be distilled into simple products, they *must* be — if they are to be relevant in the world of local land-use decisions. Detailed maps, analyses, and data can be relegated to CD or Web formats for those who choose to pursue more in-depth information.

The NAUTILUS Project: Next Step in Becoming Relevant to Local Decision Makers

Project Objectives

Based on experiences with the first two case studies, the authors felt that the next evolutionary step would be to investi-

Table 1. Summary Impact Metrics for the Eightmile River Watershed Project

Impact/Indicator	Results to Date
Changes to local plans & regulations	• Project maps and information have been incorporated into updates of all three town's comprehensive plans • One town is working on a Compatible Economic Development initiative
Changes to local land use administrative policies & organizational structure	• Two towns have created new Open Space Committees • One town has created an open space trust fund • Two towns are developing GIS capability and data • One town has created a Conservation Commission • One town has appropriated $150,000 for its existing open space fund
Initiation and/or increases to public or private stewardship of natural resources	• Over 1700 acres of land has been conserved as permanently protected open space • Over 500 acres of private forest land have been placed under Forest Stewardship plans • Over 2500 acres of private forest land are being managed using CES Forestry information and recommendations • A new land trust was created • Local high schools have begun an "Adopt a Salmon" fish restoration project • A fish passage was placed over a dam in the lower River, restoring high quality upstream stream habitat to several species
Changes to development design	• Conservation development designs are being discussed in all three towns
Increased cooperation & collaboration among towns	• Eightmile River Watershed Conservation Compact signed December 1997 by chief elected official of all three towns

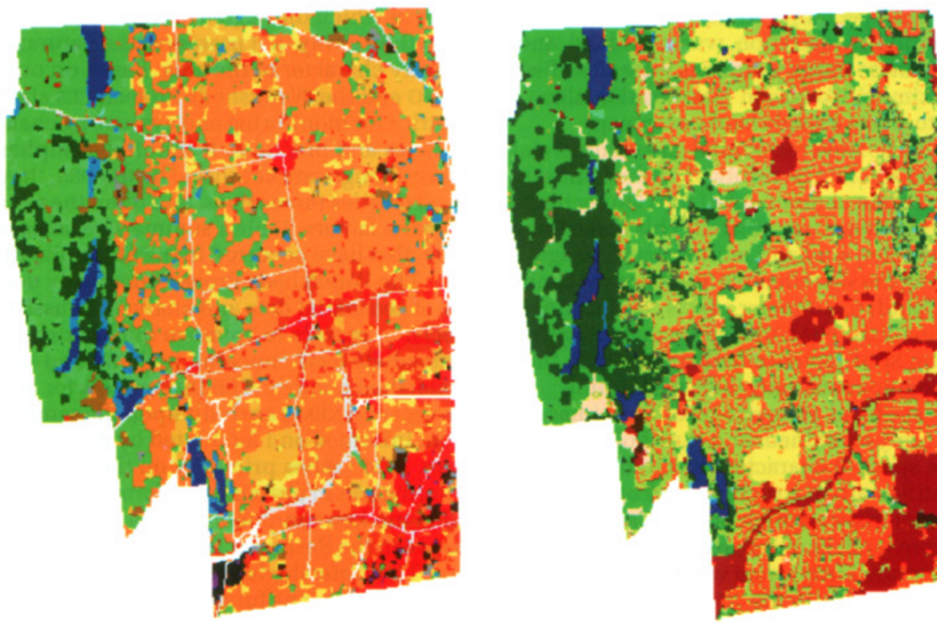

Plate 2. Comparison of 1990 (left) and 1997 (right) land-cover maps for the town of West Hartford, Connecticut. Improved discrimination in the suburban road/house/lawn complexes can be seen in the 1997 map.

gate whether more accurate RS data can enable local officials to go beyond broad land-use issues at the town and watershed levels, to deal with the specific problem of sprawl patterns of growth. Testing this hypothesis is the focus of the NAUTILUS Project, a new NASA Regional Earth Science Applications Center (RESAC) at the University of Connecticut. NAUTILUS stands for Northeast Applications of Useable Technology In Land planning for Urban Sprawl. The overall goal of the RESAC program is to develop new methods for bringing together the research, service, and user communities to apply NASA's research results to practical societal problems. The specific mission of the NAUTILUS Project is to advance further our DSS models, targeting local land-use decision makers, with particular emphasis on suburban/urban sprawl and its impacts on water and forest resources. Our intent is to go beyond the simple landscape characterization of previous models to develop specific metrics and tools that can be applied by local officials to community planning.

Project Design

NAUTILUS consists of a three-part work plan that involves remote sensing research, Web and CD-based applications, and on-the-ground educational outreach. Research techniques are initially being tested in the Salmon River watershed in Connecticut, with the most effective and cost-effective techniques to be applied to three additional pilot watersheds in Maine, New Jersey, and Massachusetts.

Information developed by the research side of NAUTILUS will become the basis for GIS-driven applications that will allow land-use decision makers to access and visualize the research results. Visualization tools will be made available to local officials (and others) through a multi-media approach that will include educational presentations, the World Wide Web, CD, and interactive kiosks placed in key locations in our Connecticut watershed. Interactive internet mapping technologies will play a large role in this work. Temporal characterizations of land-cover change will be compiled into animations that can be viewed over the Web, perhaps ending with different forecast options that can help the user visualize alternative futures.

Both RS and more detailed local data will be used. For example, planimetric data for one of the towns in the Salmon River watershed has been used to develop an animation of the growth of subdivisions over time. The program was created using Microsoft Visual Basic 6.0 and ESRI's MapObjects ActiveX control. Subdivision approval dates (as an approximation of the actual date of construction) were researched and linked to a base parcel layer provided by the town. The resulting interface can be animated and run with various options to show the growth of the town since the 1940s (Plate 3).

Interactive tutorials will also be used to refine and improve upon our NEMO build-out scenarios, enabling browsers to choose various development scenarios and see the implications for the health of their water resources. Three-dimensional visualization will improve our ability to have end users site and evaluate future development within a watershed framework. Early work has used ESRI ArcVIew 3D Analyst, and other packages such as ERDAS Imagine VirtualGIS are being evaluated.

The final and most important part of the NAUTILUS DSS will involve on-the-ground, NEMO-adapted educational projects in the four pilot watersheds in Maine, Massachusetts, Connecticut, and New Jersey. Watershed groups comprised of different combinations of state and nonprofits organizations have been formed in each watershed. These groups are kept involved in the research and applications phase of the project through a Watershed Partners Group. The local groups, supported by the applications developed by NAUTILUS, will be responsible for delivery of presentations in each watershed to local officials and other key groups.

The Role of Remote Sensing

A primary difference between NAUTILUS and its two predecessors is that the RS research is driven by, and fully integrated

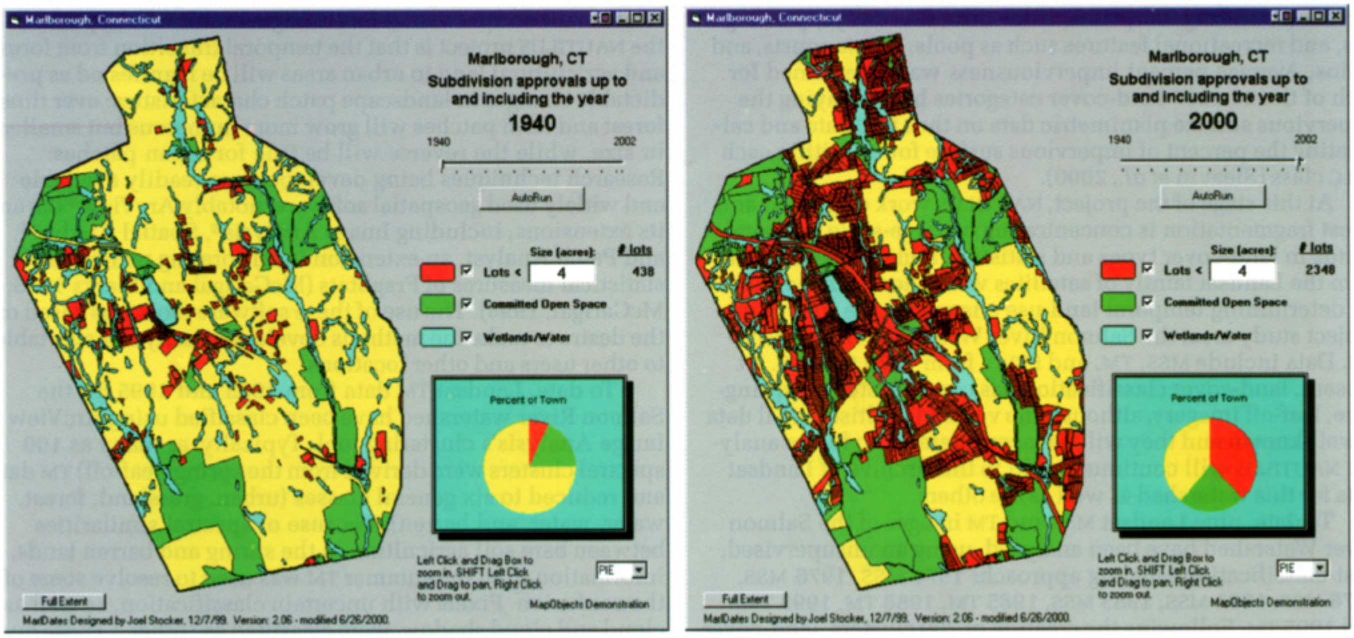

Plate 3. Interactive visualization tools, like this interface demonstrating the rate of subdivision growth in Marlborough, Connecticut, will be made accessible via the Web, CDs, and community kiosks. Red is developed land, yellow is land available to be developed, green is protected open space, and blue is water.

with, the applications and outreach components. The RS research agenda for NAUTILUS has three major components: (1) improved basic land-cover information, (2) improved impervious cover estimates, and (3) characterization of suburban sprawl and forest fragmentation.

The objective of the work on more accurate land cover is to produce as thematically rich and spatially detailed land-use information as possible from remote sensing and ancillary data. A goal is to approach, and even surpass, Anderson Level II categories, using principally (but not exclusively) satellite image data. Multisource, multispectral, multiresolution data, including Landsat TM and ETM+, SPOT Panchromatic, ADAR 5500, Ikonos, DOQQs, and others are being used for different levels of detail. Ancillary data include digital line graphs (DLGs) for hydrography and transportation, and digital elevation models (DEMs) and their derived products (slope, aspect, illumination). The need for measurements other than just spectral reflectance is apparent, given the types and properties of the source data and our objective to use the data to characterize sprawl and forest fragmentation. These include features from the spatial domain, such as image texture, object shape and size, and proximity to other known cover types, derived both internally from the remote sensing image data and from other sources, such as the DLGs, and other spatial descriptors.

Two distinct, yet parallel, approaches are being investigated: knowledge-based expert systems (KBES) and artificial neural networks (ANN). In order to assess the relative performance of each method, the data and information used and the classes obtained will be kept as consistent as possible.

Knowledge-based expert systems development is being performed using the Knowledge Engineer engine available in ERDAS Imagine® 8.4, and will build upon previous research (Civco, 1989). Artificial neural network classification is being performed with NeuralSIM®, from Aspen Technology. NeuralSIM is a general-purpose neural network development shell, the interface for which is provided through Microsoft Excel®, and provides a wide range of tools for creating, testing, refining, and deploying trained networks. The adaptive gradient, back-propagation paradigm in NeuralSIM is being used to classify the same land-use types as are being defined with the KBES classifier. Trained networks will be deployed as stand-alone code (C++ or Visual Basic), as well as incorporated into commercial image processing products, likely ER Mapper, ERDAS Imagine, or ArcView Image Analysis Extension. Although ANNs have been widely used by these investigators previously (Civco, 1993; Wang and Civco, 1996; Zhou and Civco, 1997), a controlled, systematic comparison with the results of both a knowledge-based approach and the maximum-likelihood approach using multisource data has not previously been conducted.

ANN is also being used to investigate impervious surface mapping at a finer level of biophysical discrimination, such as described by Ridd (1995). Research underway addresses the development of a method for the generation of percentage impervious surface data from Landsat Thematic Mapper (TM) imagery, at the sub-pixel level, using an ANN as the modeling tool and high-resolution digital aerial and satellite imagery for sub-pixel calibration (Civco and Hurd, 1997). Further research will endeavor to sensitize the neural network to the less prominent impervious features, such as suburban housing and primary and secondary roads. A final version will be made to the user-community either as a stand-alone program or as a plug-in for a commercial off-the-shelf GIS software package.

In a parallel research track to the ANN impervious cover work, the project is using accurate planimetric data to generate imperviousness coefficients that can be correlated with RS-derived land-cover categories. In the first year of this research track, data from four towns were digitized from 1:2400 scale aerial photographs by independent firms contracted by each of the towns. The data were converted, as part of this study, to an ArcInfo 7.x format where editing and spatial analyses were performed. Conversion of the planimetric data resulted in

ArcInfo GIS impervious surface data sets for each town that included building footprints, sidewalks, driveways, parking lots, and recreational features such as pools, tennis courts, and patios. Average percent imperviousness was determined for each of the 28 1997 land-cover categories by overlaying the impervious surface planimetric data on the LULC data and calculating the percent of impervious surface found within each LULC class (Sleavin *et al.*, 2000).

At this stage of the project, NAUTILUS work on sprawl and forest fragmentation is concentrating on large-scale temporal trends in land-cover types and statistics. Remote sensing data from the Landsat family of satellites were chosen as the basis for determining temporal land-use change for the first pilot project study area, the Salmon River Watershed in Connecticut. Data include MSS, TM, and ETM+ from 1973 to 1999. At present, land-cover classification has concentrated on springtime, leaf-off imagery, although the value of multiseasonal data is well-known and they will be incorporated into future analysis. NAUTILUS will continue to add to this archive of Landsat data for this watershed as well as the others.

To date, nine Landsat MSS and TM images of the Salmon River Watershed have been analyzed, using an unsupervised, post-classification labeling approach: 1973 MSS, 1976 MSS, 1978 MSS, 1981 MSS, 1983 MSS, 1985 TM, 1988 TM, 1993 TM, and 1995 TM. Following the creation of 200 clusters, land-cover classifications were labeled into general categories of urban, agriculture, deciduous forest, coniferous forest, water, wetland, and barren. In addition, post-processing was conducted to minimize unlikely change categories (*i.e.*, urban land in 1983 changing to forest land in 1985). The land-cover changes were captured and identified in each of the classification images. Figure 3 charts the area for each land-cover grouping of interest for each of the nine dates for the Salmon River watershed. Although varying from year to year due to the phenological and atmospheric differences among the images classified, the classification totals identify a subtle trend towards an increase in urbanization and decrease in forest land cover over the 22-year period. A proof-of-concept study has also been performed in which forest to non-forest land-use change has been detected with a high degree of success using a backpropagation neural network (Civco *et al.*, 2000).

The Landsat data are also being investigated as a visualization tool. Toward this end, eight scenes of Landsat MSS and TM data from 1973 to 1995, acquired at near-anniversary dates (*i.e.*, April-May during the leaf-off season in the Northeast) have been radiometrically adjusted to one another and incorporated into an animated sequence.

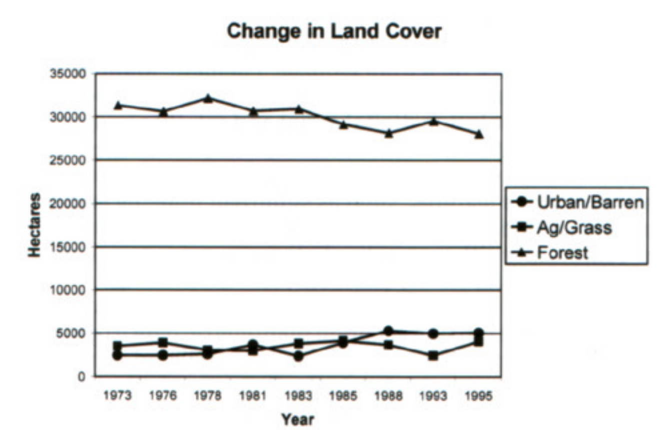

Figure 3. Salmon River Watershed land-cover areal extent: 1973–1995 (hectares).

Work has also begun on land-cover change statistics as they relate to urban sprawl and forest fragmentation. A hypothesis of the NAUTILUS project is that the temporal transition from forest and agricultural land to urban areas will be manifested as predictable changes in landscape patch characteristics: over time, forest and farm patches will grow more numerous but smaller in size, while the reverse will be true for urban patches. Research techniques being developed use readily available and widely used geospatial software, notably ArcView® GIS and its extensions, including Image Analysis®, Spatial Analyst®, and Patch Analyst, an extension incorporating many spatial statistical measures of FragStats (McGarigal and Marks 1995; McGarigal, 1998). The use of these software tools was based on the desire to make the methods developed easily transportable to other users and other locations.

To date, Landsat TM data from 1985 and 1995 for the Salmon River watershed have been classified using ArcView Image Analysis's clustering tool. Typically, as many as 100 spectral clusters were derived from the spring (leaf-off) TM data and reduced to six general classes (urban, grassland, forest, water, water, and barren). Because of spectral similarities between bare soil agriculture in the spring and barren lands, information from the summer TM was used to resolve some of the confusion. Pixels with uncertain classification, as well as cloud and cloud shadow, were classified as "other." These questionable pixels were eliminated from both images and omitted from further analysis. The land-cover data, in an ArcView Spatial Analyst Grid format, were processed with the public domain Patch Analyst Extension, extracting data on class area, number of patches, average patch size, total edge, and others.

Table 2 summarizes some of these statistics for 1985 and 1995 for three classes of interest: urban, agriculture, and forest. From Table 2 it can be seen that urban land area increased by nearly 60 percent over this decade, while both agricultural and forest land decreased by approximately 6 percent each. The number of patches of each land-cover type increased by 145 percent, 30 percent, and 10 percent, respectively, for urban, forest, and agriculture. Mean patch size decreased by 35 percent for urban, 27 percent for forest, and 14 percent for agriculture. While total class edge changed little for agricultural land, it increased by 48 percent for urban land and 17 percent for forest land. Collectively, these statistics demonstrate, at least for the decade studied, that the forested and agricultural landscape are becoming both smaller in area and more fragmented. They also show that urban patches increased in number and decreased in size during the decade, a finding in conflict with our preliminary hypothesis. This may be due to a proliferation of low-density urban sites before urbanization has proceeded to the point where patches have coalesced into larger urban centers — a phenomenon which may have implications for the development of suburban sprawl metrics.

Results and Discussion

Only one year into the NAUTILUS project, it is difficult to say if we understand all the parameters of our attempt to create the "next generation" decision support system. However, the convergence of two major trends leads us to believe that we are on the right track.

TABLE 2. SELECTED LANDSCAPE STATISTICS FOR URBAN, FOREST, AND AGRICULTURAL LAND IN THE SALMON RIVER WATERSHED: 1985 AND 1995

	Total Class Area (ha)		Number of Patches (n)		Mean Patch Size (ha)		Total Edge (km)	
CLASS	1985	1995	1985	1995	1985	1995	1985	1995
Urban	3005	4802	485	1192	6.20	4.03	1623	2400
Forest	29756	28045	1312	1697	22.68	16.53	2622	3061
Agriculture	3689	3485	2373	2608	1.55	1.34	1289	1296

One trend is the emergence of a wide variety of digital remotely sensed data, including moderate and high resolution satellite and airborne platforms. On the one hand, it is impossible to believe that this profusion of high quality data does not have incredible potential for being used as the basis for community-level decision support systems. On the other hand, our experience tells us that a plentitude of data is a double-edged sword, requiring additional time and energy to "translate" it for the audience. Even the most basic assumptions must be questioned. Is higher resolution always better? Probably not: if you want to say something meaningful about the forest, it can be counterproductive to see each individual tree. Another aspect of the new wave of RS sensors is availability. The number and frequency of satellite and other RS platforms gives rise not only to an increase in the types of information available, but to increased spatial and temporal coverage, and presumably (over time) decreased cost. Our emphasis in NAUTILUS on some of the more widely available RS sources and off-the-shelf processing software is predicated on the feeling that satellite-based RS data are now poised to be competitive with more intensive and expensive methods of obtaining land-use information, like low-altitude aerial photographs. The capability for satellite-based RS information to be accessed with sufficient frequency and economy to keep towns updated on land-use trends will be critical to its long term relevance to local decision makers.

The second important trend is the explosion of digital technology in everyday life. The number of citizens using the internet, CDs, and other digital methods of accessing information is expanding at an incredible rate. Digital media are fundamentally different types of educational delivery mechanisms: they are non-linear, and capable of being almost infinitely deep thematically. Both of these factors distinguish them from the "old guard," linear educational vehicles of presentations, publications, and videos. The true value in these new media is not in replacing the old standards, but in adding them to the educational arsenal to create an unprecedented array of choices from which the DSS target group can get their information. In this way, each type of media reinforces the others to provide a more complete educational experience. NAUTILUS and the next-generation of NEMO are being built upon this basic fact, shifting from a presentation-based DSS to a multi-media approach.

Conclusions: The Future of Geospatial Technology in Supporting Local Land-Use Decisions

Does the overall model of an RS-based, outreach-delivered DSS actually work? Almost eight years since the first NEMO town presentation, we can answer with a definitive "yes." Our results demonstrate that, for our target audience of local land-use decision makers, outreach education enhanced by geospatial technologies can be an extremely effective DSS.

To be successful, a decision support system should be designed to help a well-defined target group make better decisions *within the context of their typical operations.* Individual development scenarios centering on a specific issue may sometimes require technical specificity. In these cases, a data table or even a single number may suffice as decision support, and, most likely, detailed on-site research may be required. In most instances, however, land-use decisions are made in the multifaceted, political, and often emotional forum of the local land-use approval process. In these cases, more generalized DSS models founded on education, such as the ones we have developed and are developing at the University of Connecticut, will serve better.

The three case studies outlined in this paper demonstrate an evolution in our approach to a local land-use DSS, yet all three projects continue to operate and accrue impacts. In other words, we have not abandoned the reliable NEMO station wagon for the sleek NAUTILUS roadster. Rather, with each iteration of our DSS, previous methodologies have become nested within the configuration of the new model. NEMO is built into the Watersheds Project, and the Watersheds Project is built into NAUTILUS. Perhaps the most significant aspect of the evolution from NEMO to NAUTILUS is from an outreach project that makes use of RS data created for another purpose, to an integrated project where basic RS research is driven by the needs of the DSS — which, in turn, are driven by the needs of the target audience it serves.

The potential applications of RS data are endless, but with this potential comes the responsibility of "translating" these data into truly accessible and usable forms for a particular target audience. Technically excellent DSS models generating cutting-edge data may well fail because of lack of time, thought, and effort put into making those data relevant to the world of the end user. If more emphasis is placed on truly integrated research, applications, and outreach approaches, there are few limits to the important role that remote sensing and other geospatial technologies can play in local land-use decision support.

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