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North America Land Cover Summit

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NORTH AMERICAN LAND COVER SUMMIT: INTRODUCTION

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Land cover mapping, characterization, monitoring and forecasting are critical elements of many environmental monitoring and land management programs. Land cover data and information provide a direct, objective indication of the effects of land use impacts on natural resource conditions, environmental and human health, and the quality and quantity of water. While human modification of land cover is an inevitable aspect of modern society, human-induced changes in land cover have important implications for both society and the environment. Because the impacts of land cover change are not confined to national boundaries, there is an urgent need for accurate, consistent trans-boundary data on land cover condition and extent.

The North American Land Cover Summit (NALCS) was held from September 20-22, 2006 at the National Academy of Sciences, Washington, D.C., to assess national land cover monitoring efforts across the continent and identify areas of possible collaboration. Jointly sponsored by the U.S. Geological Survey (USGS), U.S. Environmental Protection Agency (USEPA), and the Association of American Geographers (AAG), the Summit was attended by scientists and administrators from Canada, Mexico, Australia, Germany, and the United States whose organizational affiliations included governmental agencies, universities, non-governmental organizations, and the United Nations. Summit participants assessed critical issues for improving land cover applications, identified institutional needs and gaps in technical capabilities, reviewed innovative uses of land cover information, and noted opportunities for interagency and international collaboration.

This AAG Special Issue volume consists of selected papers presented at the Summit - with a few relevant additions – and summaries of the conference breakout sessions. This peer-reviewed compilation provides an overview of the land cover monitoring efforts and environmental assessments being performed across the North American continent, as well as examples of continental-scale monitoring efforts in Europe and Australia.

Anthony de Souza of the host National Academy of Sciences (NAS) provided welcoming remarks on the morning of the first day. The conference charge was then delivered by David Lehman, senior advisor to the U.S. Secretary of the Interior, followed by overviews on how the Canadian, Mexican and United States governments derive and manage land cover information. The morning ended with a keynote presentation from Lee Schwartz, Chief Geographer of the U.S. Department of State, who explained the role of land cover information in economic development and humanitarian missions.

Two presentation sessions were held in the afternoon. The first focused on national land cover monitoring programs and produced the papers by Collin Homer *et al.* and Francisco Jimenez in this publication. Homer's paper (pp. 5-12) discussed the National Land Cover Database (NLCD) of the U.S., while Jimenez's paper (pp. 13-20) described Mexico's vegetation mapping program. The second session featured presentations on cooperative approaches in governmental land cover analyses. Stephan Kleeschulte and Gyorgy Büttner (pp. 31-44) provided the European experience in creating and managing the CORINE land cover database, while Michelle Barson (pp. 45-74) discussed the collaborative approaches used in creating land cover maps of Australia. The first day ended with a poster session focusing on regional land cover monitoring activities and environmental assessments.

Presentations on the second day started with non-governmental organizations explaining their needs for land cover information. John Weins *et al.* (pp. 153-168) discussed how The Nature Conservancy (TNC) includes areas around its protected areas in its assessments so as to include the impacts of nearby land cover changes. The second session of the day focused on global and regional land cover programs. Roger Sayre *et al.* (pp. 131-152) described the role of ecosystem mapping in assessing biodiversity and resource management, while John Latham (pp. 75-96) conveyed how the Food and Agricultural Organization (FAO) seeks to harmonize national land cover mapping efforts.

Afternoon sessions consisted of sessions examining land cover applications, such as community planning, biodiversity assessments, climate change impacts, wildfire management and resource management. Presentations published in this volume include K. Bruce Jones (pp. 215-250) on the importance of spatially explicit integration of data; Nathan Wood (pp. 169-180) on the use of land cover information for assessing the risk to coastal communities from tsunamis; and Yi Shi *et al.* (pp. 251-274) on the Midwest Spatial Decision Support System partnership that developed a web-based decision support tool for community planners. Also included is a paper by Mary White *et al.* (pp. 181-214) that describes a tool for evaluating an area's ecological condition for possible conservation efforts and a paper that assesses hydrologic responses to land cover change by William Kepner *et al* (pp. 275-292). The final two papers from the second day focused on the use of land cover information on assessing forest resources. Michael Wulder *et al* (pp. 21-30) discussed Canada's *Earth Observation for Sustainable Development of Forests* project, while Kurt Riitters and Gregory Reams (pp. 97-106) discussed the U.S. Forest Service's use of land cover information in formulating indicators of forest patterns.

Day Three continued the application sessions, focusing on land cover information in formulating alternative futures and assessing agro-ecosystems. This volume includes one paper from each session. Dreux Watermolen's paper (pp. 293-330) discussed how local governments in the state of Wisconsin can use land cover information in conducting community planning exercises. The paper by Rasim Latifovic and Darren Pouliot (pp. 107-130) assessed the need of inter-annual land cover maps for assessing agricultural production.

The remainder of the morning was devoted to breakout sessions that examined the potential for land cover monitoring and data sharing across the continent. Four thematic groups were formed, each focusing on a critical use of land cover information: indicators of environmental quality; ecosystem conditions; hazards identification and forecasting; and global change. Reports from all four groups are included in this volume as collections of the attendees' views on how collaborative, continental-scale land cover monitoring can promote national objectives for environmental quality and resource management. The Summit concluded with remarks from representatives from the three North American nations that recounted the lessons learned and outlined aspirations for the future.

The stated objective of the Summit was to pursue collaboration among institutions and government agencies across the continent in order to advance the development and application of comprehensive land cover information. A major outcome of the meeting was the establishment of the North American Land Change Monitoring System (NALCMS) which develops image mosaics and multi-scale land cover data products for the continent. The first products to be developed under this cooperative system are annual Moderate Resolution Imaging Spectroradiometer (MODIS) image mosaics and derived land cover classes that have been shared among the three countries. There are continuing discussions on conducting higher resolution land cover mapping activities in areas of interest to two, or all three countries, such as pathways for migrating birds and insects. It is hoped that this system is just the prelude to many other collaborations.

CHAPTER 1

THE UNITED STATES 2001 NATIONAL LAND COVER DATABASE

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Key words: *land cover, national database, remote sensing, imperviousness,* and *tree canopy*

INTRODUCTION

Land cover information is required by a broad spectrum of scientific, economic, and governmental applications, and provides essential input to analyze a variety of national issues. Thus, credible consistent national land cover information is increasingly more important. In 1999, new land cover research was implemented to expand and update the United States Geological Survey's National Land Cover Dataset (NLCD) 1992 into a full scale land cover database (with multiple instead of single products), and to produce it across all 50 States and Puerto Rico. This new database called the National Land Cover Database 2001 has been under production for six years. The 2001 refers to the nominal year from which most of the Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper-plus (ETM+) imagery was acquired. Three products from this database were completed in January 2007, for the conterminous United States, including 16 classes of land cover, percent tree canopy, and percent urban imperviousness.

NLCD 2001 production was funded through an organization called the Multi-Resolution Land Characteristics Consortium (MRLC). This consortium consists of 13 programs across 10 Federal agencies that require land cover data for addressing their agency needs (www.mrlc.gov). MRLC provided the umbrella to coordinate multi-agency NLCD mapping production and funding contributions. In addition to NLCD data, MRLC also offers approximately 8,300 terrain-corrected Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) scenes spanning growing season dates from 1982-2007, available for public Web-enabled download from www.mrlc.gov.

METHODS

NLCD 2001 production was accomplished according to protocols outlined in Homer et al. (2004) across 65 mapping zones for the conterminous United States. Production occurred with 12 mapping teams from both the government and private sector. To ensure consistency among teams, products were generated using standardized processes in data preparation, classification, and quality control. NLCD 2001 products were generated from a standardized set of input data layers mosaiced by mapping zone, including multi-season TM and ETM+ imagery centered on a nominal collection year of 2001, and Digital Elevation Model-based derivatives. This standard set of input data layers provided the best available data resources to derive the desired products. All data were geo-registered to the Albers equal-area conic projection grid, and resampled to 30m grid cells.

The land cover classification was accomplished using commercial decision tree (DT) software called See5* (Quinlan 1993). This was applied to standardized input data layers prepared for each mapping zone, and subsequently extrapolated through ERDAS IMAGINE* into classified pixels using customized software. DT is a supervised classification method that relies on large amounts of training data, which were collected from a variety of sources including existing Landsat-based classifications and training data pools, field sampling, and limited on-screen sampling. Training data were used to map all land cover classes except for the four urban classes, which were derived from thresholding of the imperviousness data product. When land cover modeling was completed, the final product was aggregated to a one acre minimum mapping unit (0.4 hectare or five TM pixels) to reduce single pixel scattering using a "smart eliminate" aggregation algorithm. This algorithm uses eight-corner connectivity from a central pixel to allow non-linear features like roads and streams to remain intact, and accesses a weighting table to allow "smart" decisions on a dissolve protocol. Although every effort was made to maintain consistency in classification between mapping zones during production, some edge matching was required to merge the 65 completed zones. A three kilometer buffer around each zone, (six kilometer overlap was available between mapping zones) served as the interface area for defining the most successful edge-matching boundary.

Imperviousness and tree canopy were classified using commercial regression tree (RT) software called Cubist* (Yang et al. 2002). Training data were generally derived from 1-m resolution Digital Orthoimagery Quarter Quadrangles (DOQQs) that were classified categorically into canopy/non-canopy, or impervious/non-impervious for each 1-m pixel. This training information was then used to derive the RT model, which was subsequently extrapolated across the mapping zone to derive continuous canopy and imperviousness predictions. A masking strategy was then used to further reduce errors of commission over areas with spectrally similar features that proved difficult to discriminate accurately (e.g. shrub and grass areas for canopy and bare agriculture fields for imperviousness). This masking method depended upon other ancillary GIS data layers to help define or eliminate problem areas. Final canopy and imperviousness products were not aggregated with smart eliminate like land cover, but were left in the single pixel format. A three kilometer boundary buffer was also used with these products, (six kilometer overlap was available between mapping zones) to serve as the interface area for defining the most successful edge-matching boundary.

RESULTS AND DISCUSSION

Sixteen classes of land cover were modeled for the conterminous United States. (Table 1 and Figure 1). Initial land cover product accuracy from cross-validation estimates was generated during classification, with an overall national accuracy of 83.9%. Continuous predictions from 1-100% for both tree canopy and urban imperviousness were also modeled over the conterminous United States, with accuracy estimates derived from cross-validation and reported as an average error estimate. The tree canopy mapping zone average error estimates ranged within a given zone from to 6% to 17% deviation from prediction, and urban imperviousness average error estimates ranged within a given zone from 4% to 17% deviation from prediction.

NLCD Land Cover Class Digital Code	**NLCD Class Name**
11	Open Water
12	Perennial Ice/Snow
21	Developed, Open Space
22	Developed, Low Intensity
23	Developed, Medium Intensity
24	Developed, High Intensity
31	Barren Land
41	Deciduous Forest
42	Evergreen Forest
43	Mixed Forest
52	Shrub/Scrub
71	Grassland/Herbaceous
81	Pasture/Hay
82	Cultivated Crops
90	Woody Wetlands
95	Emergent Herbaceous Wetlands

Table 1. Conterminous United States NLCD 2001 land cover legend by digital code

The major value of NLCD 2001 products lie in their ability to provide a complete, consistent coverage of the nation's land cover, and to serve as a resource for regional-to-national scale applications. These types of products are designed to meet land cover requirements over larger areas, and are not designed for local application (e.g., county-level use). However, the ability to modify and customize NLCD 2001 data products for more specific application was accommodated in the original database design. Users not only have three products to synergistically combine, but can also download the original imagery for additional modification or correction if desired.

Now that two eras of national land cover data are available, many users will be tempted to directly compare the two land cover layers as a way to measure land cover change. Users are cautioned that new improvements in mapping methodology, input data, and minor mapping legend modification will confound comparison between NLCD 1992 and NLCD 2001. Direct comparison of these two independently created land cover products is not recommended, because differences in the methodology

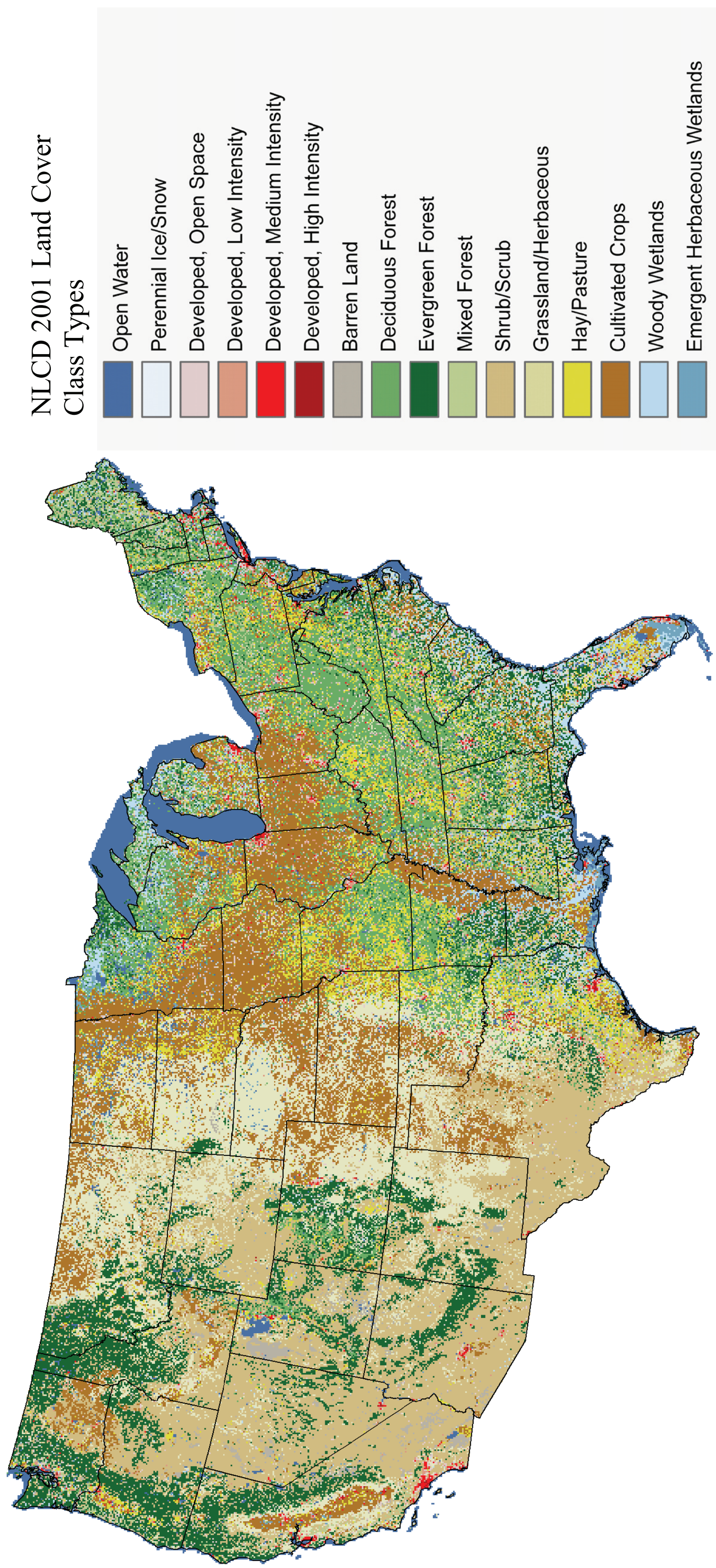

Figure 1. NLCD 2001 conterminous United States land cover product.

used to produce the two products will overwhelm true differences due to land cover change. However, an NLCD "bridge product" to aid land cover change analysis between the two eras will soon be available at the Anderson Level I thematic scale (Fry et al. in prep), and is scheduled for release for the conterminous United States by the end of 2007.

All NLCD 2001 products and mapping tools are available via Web-enabled file download from the MRLC Consortium website (www.mrlc.gov) with options for both dynamic download (user-defined download areas) and FTP download by zonal groupings. In most cases, files are available in several formats, and mapping zone metadata are supplied with all downloads. All NLCD 2001 product sets are distributed at 30m resolution in the NLCD standard NAD 83, Albers equal-area conic projection.

NLCD 2001 data for Alaska, Hawaii, and Puerto Rico will be completed by August 2008, which will then represent the first compilation of nationwide land cover ever produced at 30m resolution. NLCD 2001 will then provide a comprehensive land cover resource for the entire United States, and support hundreds of applications that require this scale of information. Future updates of NLCD 2001 are now being prototyped to ensure that land cover information stays current, and that land cover change is quantified and analyzed to broaden the utility of this information.

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This research reflects an enormous team effort across many organizations and individuals. Special acknowledgment is made for the support of the individuals and agencies of the MRLC Consortium, the many NLCD 2001 Federal mapping teams from the USGS, the National Oceanic and Atmospheric Administration (NOAA), the U.S. Department of Agriculture, Forest Service, and the private-sector mapping teams of SAIC, MDA Federal, and Sanborn who performed work under several USGS and NOAA contracts.

Endnote

* The use of any trade, product, or firm name is for descriptive purposes only and does not imply endorsement by the U.S. Government.

CHAPTER 2

LAND COVER IN MEXICO

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ABSTRACT

This document presented information and statistics related to the current land cover situation in Mexico, based on the analysis of the Series III land use and vegetation information (2002-2005) created by the Instituto Nacional de Estadística, Geografía, e Informatics (INEGI). Based on the objective to facilitate interpretation, the information has been divided into nine classes: Grassland, Forest, Tropical Rainforest, Xeric Shrubland, Other vegetation types, Agriculture, Areas without apparent vegetation, Water Bodies, and Human Settlements.

INTRODUCTION

Due to its geologic evolution and geographic location, Mexico's territory is characterized by contrasting topographic landscapes, variety of climatic regimes, soils and vegetation: ranking it in the top 10 countries with the greatest biological diversity on the planet.

In this context, the geographic information is an essential key for natural resources management of the country, and it should be part of the valuable process that transforms data into knowledge for intelligent decision making.

This document shows a national panorama of the actual state of the land cover of the country that permits the visualization of the current natural resources of Mexico, their distribution and surface extent.

INFORMATION ON LAND COVER

Preceding

During more than 30 years, The National Institute of Statistics, Geography and Informatics (INEGI) has produced and revised three compatible and comparable versions of the cartographic series of major natural resources features and their national distribution and the principal land uses that are found in Mexico. These cartographic series are:

- Series I (80's decade)
- Series II (90's decade)
- Series III (2002-2005)

The information presented in this document is based on the land use and vegetation information, series III, scale 1:250,000 that correspond to the 2002-2005 period.

Classification system

From this information source, a conceptual and special generalization was developed that should provide a national vision of the land cover. With this purpose 9 major classes were defined:

- Grassland
- Forest
- Tropical Forest
- Xeric Shrubland
- Other vegetation types
- Agriculture
- Areas without apparent vegetation
- Water Bodies
- Human Settlements

Once this information was generalized, it was reprojected from Lambert Conformal conic projection to Albers Equal Area conic projection to assure the most accurate surface measurements of the Mexican land cover.

Below are the definitions, the number of hectares, and the cartographical representation of each of the 9 classes.

Grassland

This class is characterized by the predominance of grasses and graminoids. They are present throughout the entire country, with the majority extensions located on semiarid zones (natural grasslands), or warm climate (cultivated grasslands). Grasslands are most common in level plains or where the topography is slightly undulating, and with less frequency in steep slopes. The main variants of this kind of vegetation are: Natural Grassland, Induced Grassland, and Cultivated Grassland.

Area

31,179,402 ha

Forest

This class is characterized by the presence of northern arboreal vegetation, principally from temperate and semi-cold weather regions. It is typical of mountain regions of the country. Based on their physiological and ecological characteristics, this forest class has diversified into a great number of vegetation types. These include: Coniferous Forest, Fir Forest, Pine forest), Oak Forest and Mountain Cloud Forest. Also included are areas that have been modified by diverse activities, where the forest has been altered or degraded (Secondary Forest Vegetation), and the cultivated forest.

Area

33,920,909 ha1

Tropical Forest

This class is characterized by southern arboreal vegetation, generally found on warm, humid, subhumid, and sub-dry climates. Commonly present are woody vines, climber wines and epiphytic plants. Besides the primary tropical forest, this class includes areas modified by different activities where the tropical forest is found altered or degraded (Secondary tropical forest vegetation).

Area

32,832,640 ha2

Xeric Shrubland

Xeric vegetation (from the Greek word: dry), is vegetation adapted to live under dry environmental conditions. This class is mainly constituted by shrub and sub-arboreal vegetation that usually present ramifications from the base of the stem and have variable heights, almost always less than 4 meters. It has a broad range, but is mainly distributed in arid and semi arid zones of the country. These types of vegetation include deciduous and evergreen vegetation, inert, semi inert and thorny vegetation forms.

Area

57,452,179 ha

Other types of vegetation

In this class are included vegetation types that do not correspond to the above mentioned groups, due to specific edaphic, and geographic location features. The following are types of vegetation including on this category:

- Hydrophilic vegetation: Vegetation developed in lowland and swampy regions of the lake bodies, lagoons and coastal zones. Include mangroves, popal, tulares and petenes.
- Riparian vegetation: This includes vegetation that occurs along the margins of rivers and creeks.
- Palm Communities: Associations of unbreached trunk plants that belong to the Palmae family.
- Coastal Dunes Vegetation: Vegetation communities that are established along the coast, and are characterized by the presence of small succulent plants. They are important in preventing erosion by holding the sand in place.
- Mesquite Communities: Vegetation communities dominated mainly by mesquite.

Area

5,657,280 ha

Agriculture

Mexico is not only characterized by its high biologic diversity. The same ecologic factors that promote this diversity also favor a great mosaic of diverse agro-ecosystems.

This class considers the concepts related to the agricultural land use by humans. The classification considers first the availability of water for crops and perennial crops.

The reported types of agriculture are the following:

- Irrigated Agriculture: In this type of agriculture supplementary water is delivered (by pumping or gravity force) to the crops throughout the agricultural cycle. Based on the types of crops the most representative are: Irrigation crops of the El Bajo region, the Sonora agricultural valleys, Sinaloa, Tamaulipas, and the Mexicali valley.
- Rainfed Agriculture: In this type of agriculture the development of the crops depends on rain.

Area

30,715,897 ha

Areas without apparent vegetation

This class includes barren lands, littoral deposits, dunes and riverbanks with or without vegetation that cannot be considered on any other vegetation class.

Area

954,149 ha

Water Bodies

This class includes all the natural water bodies (rivers, lakes, lagoons), and artificial water bodies (damns, dirt canals, canals) based on the Topographic Map scale 1:250,000, series II.

Area

2,475,285 ha

Human Settlements

This class includes urban polygons based on the Topographic Maps of 1:250,000-scale. In addition the human settlements, which are areas with urban growth, and suburbs that were adjacent to urban polygons as revised by the land use and vegetation map series III. (2002-2005).

In both cases satellite imagery interpretation was used to update the information.

Area

1,249,763 ha

NATIONAL PANORAMA

From this generalization of the land cover classes, we can obtain the results of the current national panorama of land cover in Mexico for the 2002-2005 time period: showing their spatial locations and coverage of the major group components.

CONCLUSIONS

The management of the data by known information sources and methodologies provides the highest level of confidence for its use.

This information is an important indicator of the land cover condition in our country, and allows the users to acquire trustable data of spatial location and area of each of these land cover types.

The information generalized by only one entity avoids duplicate efforts and erroneous figures that only create confusion and ambiguity when making decisions for the sustainable management of the national territory.

Group	Subgroup	Total by group (ha)
Grassland	Natural Grassland Induced Grassland Cultivated Grassland	31,179,402
Forest	Natural Forest Cultivated Forest	33,920,909
Tropical Forest	Evergreen Rainforest Sub deciduous Rainforest Deciduous Rainforest Thorny Rainforest	32,832,640
Xeric Shrubland	Xeric Shrubland	57,452,176
Other Vegetation Types	Hydrophilic vegetation Gallery vegetation Palm Communities Coastal dunes vegetations Mesquite Communities	5,657,280
Area without apparent vegetation	Areas without apparent vegetation Areas without vegetation	954,149
Human settlements	Human settlements	1,249,763
Water Bodies	Internal Water Bodies	2,475,285
Agriculture	Temporal Agriculture Irrigated Agriculture	30,715,897
TOTAL		196,437,500

Table 1. Land Cover Statistics. Land Use and Vegetation series III, Scale 1:250 000 National Statistics. Primary, Secondary and Induced vegetation conditions are included.

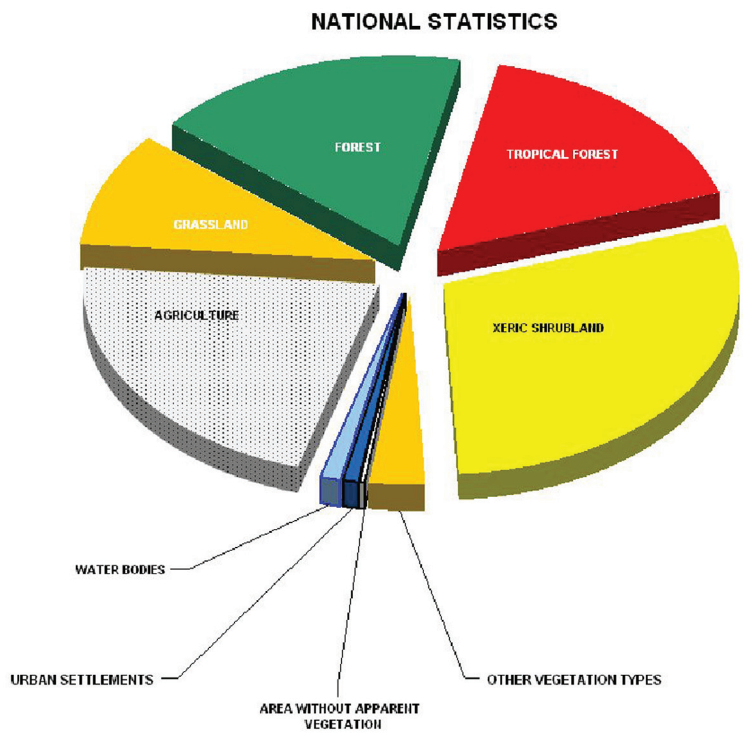

Figure 1. National Distribution of Vegetation Land Cover in Mexico

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Notes

[1] Includes primary forest and areas with secondary forest vegetation, and cultivated forest.

[2] Includes primary rainforest and areas with secondary rainforest vegetation.

CHAPTER 3

SATELLITE LAND COVER MAPPING OF CANADA'S FORESTS: THE EOSD LAND COVER PROJECT

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ABSTRACT

Capture of land cover information is a key requirement for supporting forest monitoring and management. In Canada, provincial and territorial forest stewards use land cover information to aid in management and planning activities. At the federal level, land cover information is required to aid in meeting national and international reporting obligations. To enable improved monitoring of Canada's forests, the Earth Observation for Sustainable Developments of Forests (EOSD) project was initiated. EOSD is a partnership project between the Canadian Forest Service (CFS) and the Canadian Space Agency (CSA), with provincial and territorial participation and support. An element of EOSD is the development of a land cover map of the forested area of Canada reflective of circa 2000 conditions. Including image overlap outside of the forested area of Canada, over 475 Landsat-7 ETM+ images were classified, over 80% of Canada was mapped, and over 600 1:250,000 map sheet products were developed for unfettered sharing. The objective of this communication is to provide a brief project background, a summary of activities to enable product development, and an indication of the nature of the products and access.

Key words: *Large area land cover, Landsat, classification, EOSD, forest, Canada*

INTRODUCTION

Canada is a large country, approaching a billion hectares in size. With over 400 million hectares (Mha) of forested land contributing $37 billion dollars to the balance of trade, Canada is determined to be a responsible steward of this renewable resource. Ensuring effective resource management requires current and reliable forest information. In support of national and international reporting requirements, the Canadian Forest Service (http://www.cfs.nrcan.gc.ca/) (CFS), in partnership with the Canadian Space Agency (http://www.space.gc.ca/asc/index.html), with the support and participation of provincial and territorial agencies, is using space-based, earth observation (EO) technologies to monitor the sustainable development of Canada's forests through an initiative called Earth Observation for Sustainable Development of Forests (EOSD) (http://eosd.cfs.nrcan.gc.ca/). EOSD will contribute to meeting Canada's national and international reporting requirements related to climate change and sustainable forest management by mapping the forested areas of Canada. For example, the EOSD project is designed to provide land cover maps, methods for estimating biomass using satellite and inventory data (Luther et al. 2006; Hall et al. 2006), and techniques to identify and map disturbed areas (Wood et al. 2002). Implementation of the EOSD program for the purpose of monitoring forested land began in early 2002. Production of a land cover map of the forested area of Canada was the initial focus of the EOSD program.

The EOSD land cover map of the forested ecozones of Canada was produced using Landsat satellite data. A consortium of Canadian federal and provincial government agencies, led by the Center for Topographic Information (CTI) of Natural Resources Canada (NRCan), produced a Landsat ortho-image coverage for Canada (http://www.ctis.nrcan.gc.ca/). Through application of standardized methods and use of best available elevation data, this ortho-image coverage of Canada provided a consistent data source (temporally, spatially, and geometrically) for development of easy to integrate information products for Canada (Wulder et al. 2002). The short-term goal of EOSD was to complete a land cover map representing circa year 2000 forested area conditions by 2006 (Wulder et al. 2003), and this has been accomplished. Inputs from EOSD are an important data source in the National Forest Carbon Accounting Framework (http://carbon.cfs.nrcan.gc.ca/) and Canada's new plot-based National Forest

Inventory (http://nfi.cfs.nrcan.gc.ca/) (Wulder et al. 2004a). The National Forest Information System (http://nfis.org/) will be used to integrate and synthesize applicable data and products. In this communication we summarize the EOSD Land Cover program and indicate resources to provide additional detail for interested readers.

SUMMARY

Using single scenes of Landsat data to produce land cover information is not uncommon. However, combining several or even hundreds of Landsat scenes for the development of a large area land cover map remains relatively uncommon (Franklin and Wulder 2002). To cover the forested ecozones of Canada, approximately 800 Mha must be mapped requiring over 475 images (Figure 1). All of Canada's forests are mapped with EOSD; the only areas of Canada not mapped by EOSD are non-forested northern regions and agriculturally dominated areas in the south. The classification approach for EOSD is based upon a hyperclustering, cluster merging, and labeling approach (Wulder et al.

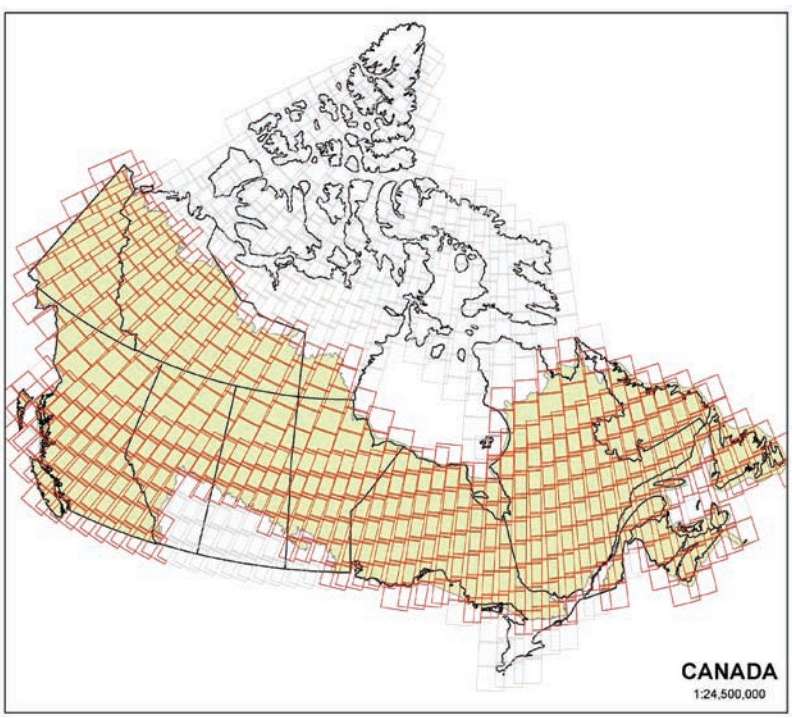

Figure 1. WRS-2 frames (red) corresponding to the forested land area of Canada. More than 475 Landsat scenes were used in the production of the EOSD land cover product.

2004b). Many more spectral groupings are created through the k-means clustering approach than can be expected to be unique classes, requiring a merging of similar groups, and then labeling of the spectral groupings into meaningful classes conforming to the closed 21 class legend. The legend used for EOSD was developed to fit with the hierarchical classification of the NFI (Wulder and Nelson 2003). Additional information on the methods and legend are available on-line: (http://eosd.cfs.nrcan.gc.ca/cover/legend_e.html).

EOSD land cover products are based upon the national topographic database's (NTDB) national topographic system (NTS) map sheet framework (there are 986 1:250,000 map sheets covering Canada's landmass), with 630 maps sheets required to cover Canada's forested ecozones. The EOSD land cover products are available for download on a NTS map sheet basis (Figure 2). Each map sheet represents an area of approximately 14,850 km^2. The products are available in a paletted GeoTIFF format, with a disabled TIFF world file, and United States Federal Geographic Data Committee (FGDC)

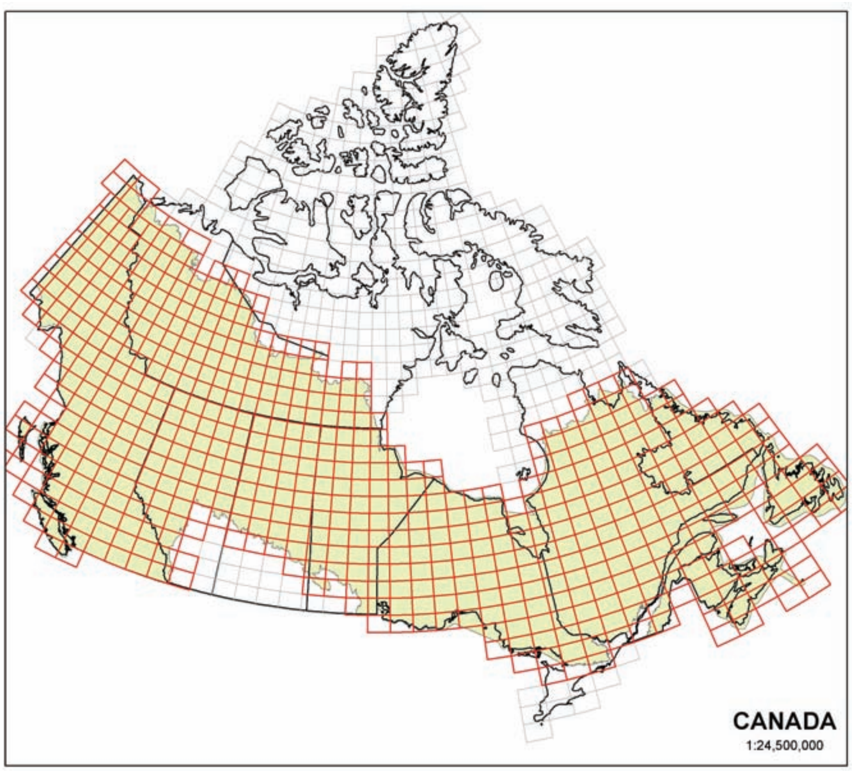

Figure 2. The EOSD land cover product is delivered by 1:250,000 NTS map sheet (red); there are more than 630 NTS map sheets (red) covering the forested area of Canada.

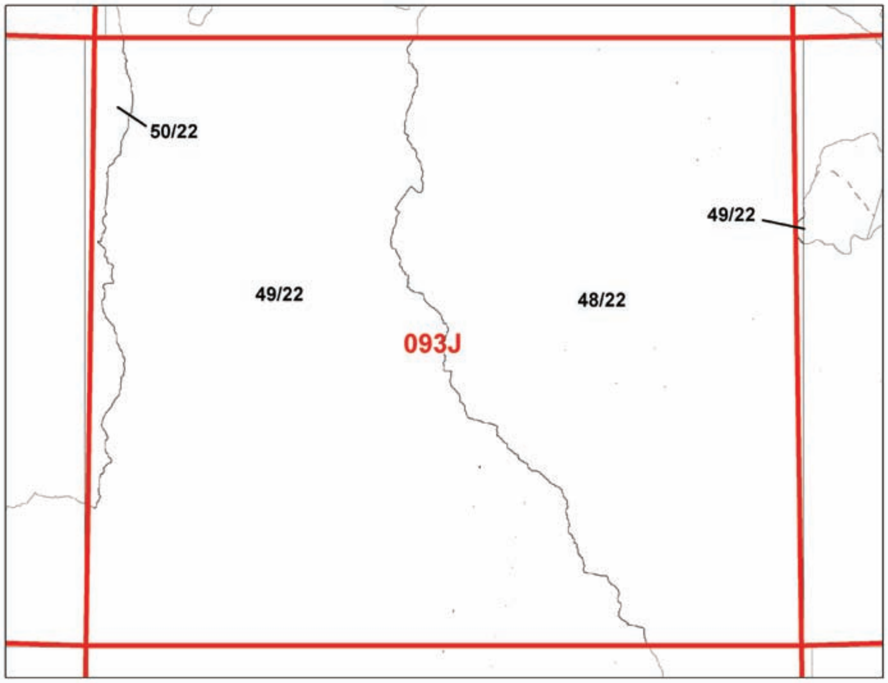

Figure 3. A sample of a 1:250,000 NTS map sheet (093J). Mosaic lines are shown, along with the source path and row of the corresponding Landsat image used to fill each portion of the NTS map sheet. This information is delivered with the product as an ESRI shape file, enabling the user to know the source image (the image date is also provided).

compliant metadata (http://www.fgdc.gov/). Final products are resampled to a 25m spatial resolution. As a single EOSD product tile may have been generated from a number of images, ESRI shape files are provided to spatially communicate source image information and actual mosaic lines (Figure 3).

To date, all of the 630 NTS map sheets required to cover the forested ecozones of Canada are complete and available for download through the National Forest Information System (NFIS) and the System of Agents for Forest Observation Research with Automation Hierarchies (SAFORAH).

SAFORAH is a networking data grid that enables distributed data storage and access (http://www.saforah.org). FTP download of bundled and compressed collections of entire provincial or territorial coverages is also accommodated by SAFORAH (http://www4.saforah.org/eosdlcp/nts_prov.html).
Identifying appropriate validation sources for large area land cover products is complicated by logistical constraints that frequently necessitate the use of pre-existing data sources. Many concerns emerge when comparing polygon (vector-based) data sets to raster imagery, including: geo-locational

mismatches; differences in features or classes mapped; disparity between the scale of polygon delineation and the spatial resolution of the image; and temporal discrepancies. As a result, when and where feasible the use of purpose collected validation data is recommended for the accuracy assessment of maps derived from remotely sensed data. If pre-existing vector-based data is judged as the only option for map validation, approaches accounting for the heterogeneity of land cover classes within a given polygon (in the pre-existing data to be used for validation) are recommended (Wulder et al. 2006a). Goodchild et al. (1994) outlined three possible approaches for evaluating map accuracy against a pre-defined target accuracy. The approach most suitable for large area land cover products involves identification of the minimum map accuracy that would cause the null hypothesis (associated with a specified target accuracy) to be rejected (Aronoff 1985). This approach supports the use of smaller sample sizes and allows a one-sided z-test statistic to identify the range of minimum map accuracies that would not cause rejection of the null hypothesis (Wulder et al. 2007).

A protocol for addressing the accuracy of the national EOSD product, based upon a stratified random sample, has been proposed (Wulder et al. 2006b). An operational trial of the suggested methodology has been undertaken over the contiguous landmass of Vancouver Island (Wulder et al. 2007). In this trial, agreement between the EOSD product and the airborne video data was defined as a match between the mode (most frequent) land cover class of a 3 by 3 pixel neighborhood surrounding the sample pixel and the primary or secondary choice of land cover for the interpreted video. The overall accuracy for the EOSD product covering Vancouver Island met the target accuracy of 80%, with a result of at 77% (with 90% confidence intervals: 74 – 80%) for level 4 (excludes vegetation density) of the classification hierarchy (13 classes). The coniferous land cover classes, which represented 71% of Vancouver Island, had a user's accuracy of 86%. Rather than using possibly ill-suited pre-existing information, purpose acquired video was found to be a useful and cost-effective data source for validation of the EOSD land cover product. The impact of using multiple interpreters was also tested and documented. Over 60% of the disagreement between interpreters resulted from differences in estimation of the vegetation density classes, suggesting greater effort must be made to calibrate interpreters and improve consistency in estimation of density classes. Improvements to the sampling and response designs that emerged from this trial will benefit a full-scale accuracy assessment of the EOSD product. A sample of a completed EOSD map sheet is provided in Figure 4. As the EOSD class legend (closed) is based upon the hierarchical NFI classification scheme (Wulder and Nelson 2003), knowledge of the EOSD class enables generalizations to more broad depictions, such as forest / non-forest (Figure 5).

CONCLUSIONS

The goal of EOSD land cover project was to produce a land cover map of the forested area of Canada with Landsat-7 ETM+ data, using proven methods, to provide timely and useful information for use within, and external, to Canada. EOSD products are being used by the Canadian NFI, with update of the EOSD land cover product envisioned to produce information on forest cover change over time. The potential for biases in the NFI photo plots can also be tested with EOSD land cover data and can also be used to determine if the NFI sampling adequately captures forest characteristics. Other applications, not yet envisioned for the EOSD land cover data, continue to emerge as awareness of the product increases.

The completion of the EOSD product has required the support and concerted effort of many partners. Cooperation and communication both within and between various levels of government provide an opportunity to share resources and work towards common objectives. Products generated from this project will be an integral component of Canada's new forest measuring and monitoring system and will assist the public and interested organizations in understanding the composition, distribution, and dynamics of Canada's forests.

ACKNOWLEDGEMENTS

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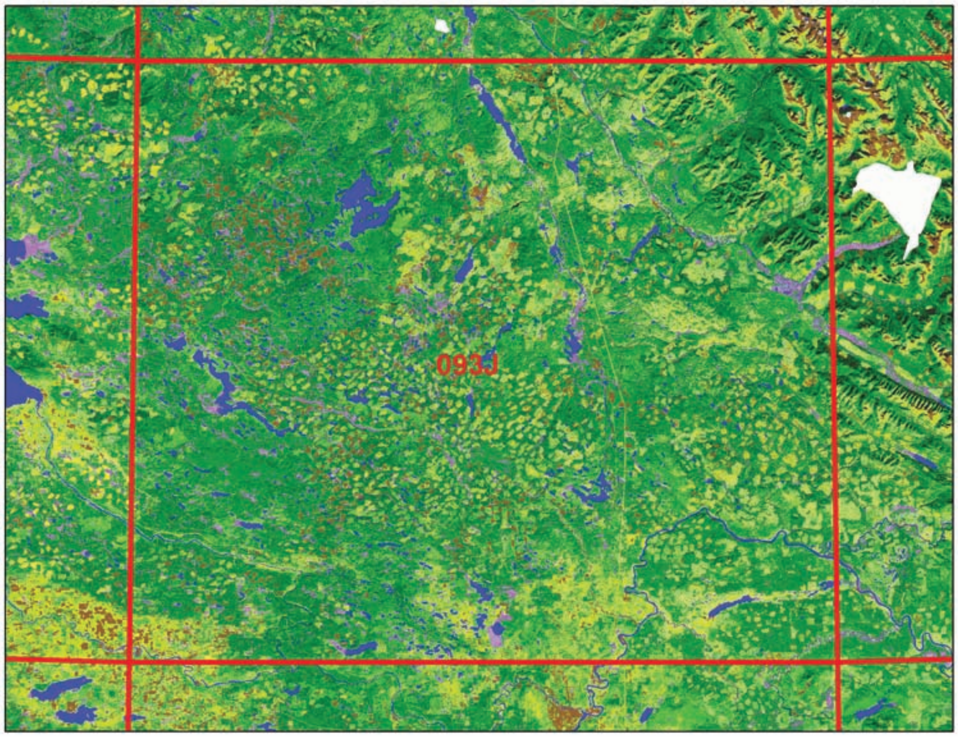

Figure 4. The classified EOSD product for NTS map sheet for 093J (and adjacent maps).

Figure 5. The classified EOSD product from Figure 4 shown generalized to forest (green) and non-forest (no colour). Such generalizations may prove useful for applications such as stratification for statistical sampling.

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CHAPTER 4

EUROPEAN LAND COVER MAPPING – THE CORINE EXPERIENCE

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ABSTRACT

The objective of this article was to provide the participants of the North American Land Cover Summit with information about continental wide land cover mapping projects from outside the United States, Canada and Mexico. The article presents the European CORINE Land Cover experience of the last 20 years. CORINE Land Cover (CLC) marks a milestone in European land cover mapping and monitoring at the scale of 1:100.000. Started as one part of a larger programme for the Co-ordination of Information on the Environment (CORINE) in 1985, the land cover project has extended from just a few countries to currently twenty-nine (finished, several other ones in progress) European countries, a time series on land cover changes from 1990 to 2000. A second update of the database for the reference year 2006 and with 38 participating countries is currently ongoing. The public availability of this unique land cover and land cover change database has triggered a wealth of downstream applications in the area of environment, agriculture and forestry as well as research and education, transport, and physical planning. The update of the database for the reference year 2006 is part of the programme on Global Monitoring for Environment and Security (GMES), the European contribution to the Global Earth Observation System of Systems (GEOSS).

Key words: *Land cover, land cover change, Europe, CORINE, CLC, GMES*

BACKGROUND

The objective of the European Environment Agency (EEA) is to provide policy makers and the interested public with targeted, timely and relevant environmental information in order to support sustainable development. Regarding land cover, EEA aims to provide those responsible for and interested in European policy on the environment with qualitative and quantitative land cover information, which is consistent and comparable across the continent. As part of the EEA mandate, the CORINE Land Cover (CLC) database initiated by the European Commission (EC) in 1985 should be further maintained and regularly updated. Consistent geo-referenced land cover information has been identified by different national and European policies as a key requirement for integrated environmental assessment.

SPECIFICATIONS AND METHODOLOGY

From 1985 to 1990, the European Commission implemented the CORINE Programme (Co-ordination of Information on the Environment) (Heymann et.al. 1994). During this period, an information system on the state of the European environment was created and nomenclatures and methodologies were developed and agreed at European Union (EU) level. The first European-wide land cover inventory (also referred to as CLC90) was realised successively in some 25 countries between 1986 and 1998.

In order to satisfy the growing demand for up-to-date land cover information, the EEA and the Joint Research Centre (JRC) of the European Commission in 1999 jointly launched the update of the CLC database. This project consisted of two components:

IMAGE2000: a snapshot of Landsat 7 Enhanced Thematic Mapper (ETM) satellite images of the European territory (+/- one year) as the basis of the land cover map, including all services related to satellite image acquisition, ortho-rectification and production of European and national image mosaic.

CLC2000: the production of a new land cover database, including the correction of the first inventory (CLC90), the detection of land cover changes (based on CLC90, IMAGE90 and IMAGE2000) and the creation of a seamless European database from the individual national data sets.

The CLC2000 project largely built on the experiences of the first inventory and tried to address and improve the main bottlenecks identified for the CLC90 database. Table 1 provides an overview of the main characteristics of the two inventories and the improvements made with CLC2000. Main

	CLC90	**CLC2000**
Organisation	Individual countries producing independently and being added successively	Coordinated production for 29 countries
Time consistency of country data sets	1986-1998	2000 +/- 1 year
Improved geometric accuracy: - satellite images: - CLC data:	 50 m 100 m	 25 m better than 100 m
Thematic accuracy	85% Not validated at European level	87% +/- 0.8%
Project duration	10 years	4 years
Data policy	No common data policy	Dissemination policy agreed from the start

Table 1: Comparison of main characteristics of CLC90 and CLC2000

achievements are the coordinated approach within twenty-nine European countries (European Union – EU25, Liechtenstein, Bulgaria, Croatia, and Romania – see Figure 1) a common reference date, a standard methodology and a common data policy, allowing full public access to the CLC2000 products (i.e. wall-to-wall land cover database, land cover changes, improved CLC90). Currently the database is being extended to Iceland, Norway, Switzerland, Turkey, Serbia, and Montenegro for the same reference year.

The standard approach to producing CLC is based on computer assisted visual interpretation of the ortho-rectified satellite images offered by IMAGE2000 according to the agreed CLC methodology (Perdigão, V., Annoni, A., 1997 and EEA-ETC/TE, 2002) providing a vector database at scale 1:100.000 with a minimum mapping unit of 25 ha. The standard CLC nomenclature includes forty-four classes in three hierarchical levels (see also Table 2). The project is implemented in a decentralised approach in the EEA member counties, i.e. each country produces the national database contributing specific regional knowledge and building a national land cover mapping capacity. The individual country data sets are later joined into one seamless geographic information system (GIS) layer, including the matching of land cover objects (polygons) across borders.

One of the most important innovations of CLC2000 is the provision of land cover change information. The mapped changes represent real land cover evolution, not seasonal differences or phenological

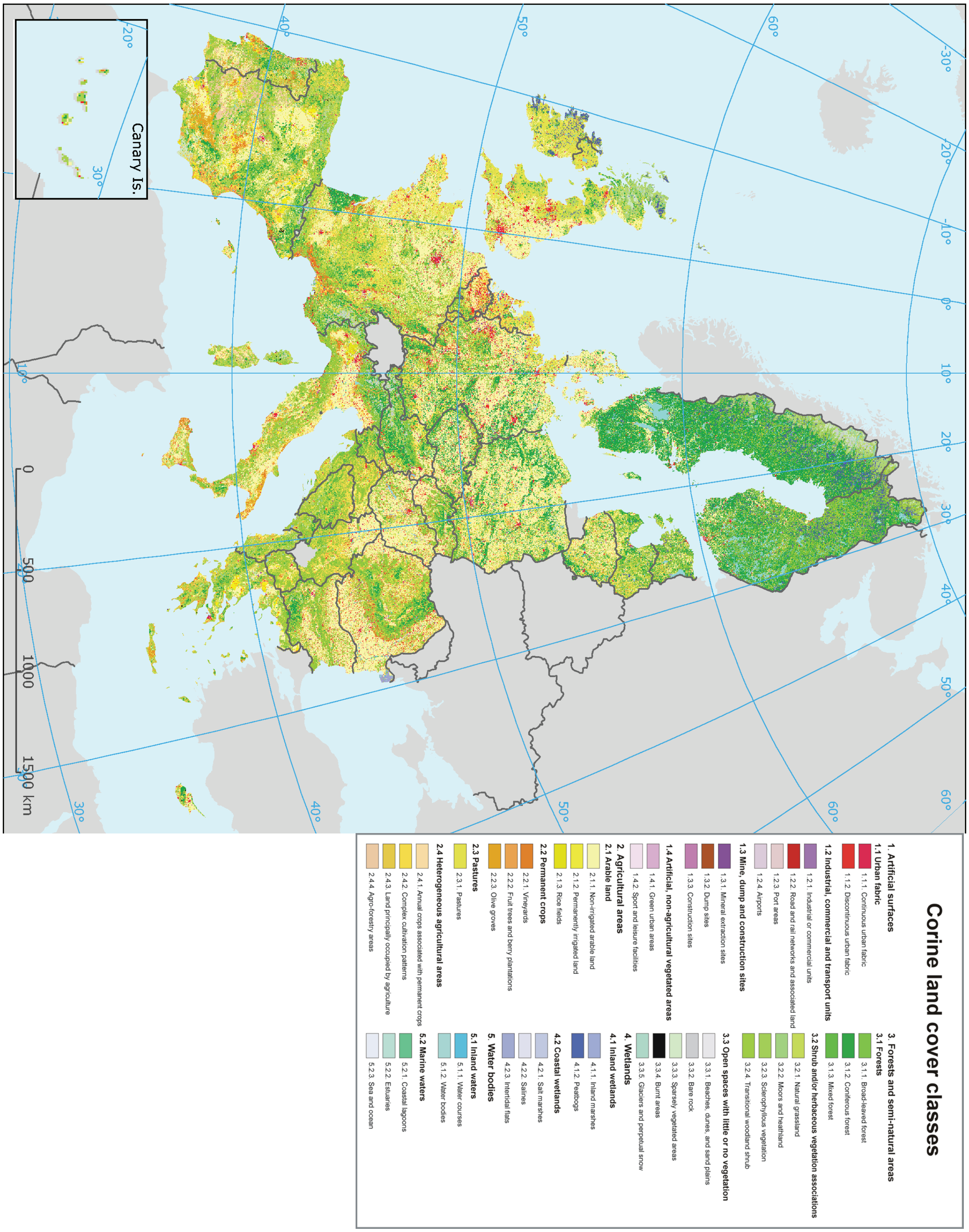

Figure 1: Coverage of CLC2000

LEVEL 1	LEVEL 2	LEVEL 3
1. ARTIFICIAL SURFACES	1.1. Urban fabric	1.1.1. Continuous urban fabric
		1.1.2. Discontinuous urban fabric
	1.2. Industrial, commercial and transport units	1.2.1. Industrial or commercial units
		1.2.2. Road and rail networks and associated land
		1.2.3. Port areas
		1.2.4. Airports
	1.3. Mine, dump and construction sites	1.3.1. Mineral extraction sites
		1.3.2. Dump sites
		1.3.3. Construction sites
		1.4.1. Green urban areas
	1.4. Artificial, non-agricultural vegetated areas	1.4.2. Sport and leisure facilities
2. AGRI-CULTURAL AREAS	2.1. Arable land	2.1.1. Non-irrigated arable land
		2.1.2. Permanently irrigated land
		2.1.3. Rice fields
	2.2. Permanent crops	2.2.1. Vineyards
		2.2.2. Fruit trees and berry plantations
		2.2.3. Olive groves
	2.3. Pastures	2.3.1. Pastures
	2.4. Heterogeneous agricultural areas	2.4.1. Annual crops associated with permanent crops
		2.4.2. Complex cultivation patterns
		2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation
		2.4.4. Agro-forestry areas
3. FOREST AND SEMI-NATURAL AREAS	3.1. Forests	3.1.1. Broad-leaved forest
		3.1.2. Coniferous forest
		3.1.3. Mixed forest
	3.2. Scrub and/or herbaceous associations	3.2.1. Natural grassland
		3.2.2. Moors and heathland
		3.2.3. Sclerophyllous vegetation
		3.2.4. Transitional woodland-scrub
		3.3.1. Beaches, dunes, sands
	3.3. Open spaces with little or no vegetation	3.3.2. Bare rocks
		3.3.3. Sparsely vegetated areas
		3.3.4. Burnt areas
		3.3.5. Glaciers and perpetual snow
4. WETLANDS	4.1. Inland wetlands	4.1.1. Inland marshes
		4.1.2. Peat bogs
	4.2. Marine wetlands	4.2.1. Salt marshes
		4.2.2. Salines
		4.2.3. Intertidal flats
5. WATER BODIES	5.1. Inland waters	5.1.1. Water courses
		5.1.2. Water bodies
	5.2. Marine waters	5.2.1. Coastal lagoons
		5.2.2. Estuaries
		5.2.3. Sea and ocean

Table 2: Standard CLC nomenclature

development stages of vegetation or different interpretations of the same object, but the process does not completely prevent these issues providing false positive and negative changes. The land cover change is interpreted as a categorical change, when one land cover class or its part(s) was a replaced by another land cover class(-es). The threshold for detection of changes is set to five hectares in order not to loose many significant, but small scale changes. Details of the CLC2000 project are available from Feranec et al, 2007. Looking to the main net changes urban areas have increased in Europe by 5 percent (870.000 ha) over the last decade (1990 to 2000), while agricultural areas have suffered a loss of a similar amount of total area. About two thirds of these agricultural areas were converted to artificial surfaces while almost one third was converted to forestland.

CLC VALIDATION

After its completion the seamless European CLC2000 database has been validated with the help of LUCAS data. The European Land Use/Cover Area frame statistical Survey (LUCAS) (European Commission – JRC, 2002) is a project managed by Eurostat, the statistical office of the European Commission. Its main purpose is to provide harmonised information on the agri-environment for Europe.

LUCAS data is the only information that is available for a European wide validation of CLC2000, which fulfils the criteria of validation data: being of high geometric accuracy, having a mostly coincident acquisition window and not having been used in the production process of the data to be validated. LUCAS data exist for approximately 10.000 locations in eighteen European countries and records independent land cover (fifty-seven classes) and land use (fourteen classes) information for each of the observations as well as landscape photographs in four compass directions (see Table 3and Table 4).

The validation of the CLC2000 database was based on the re-interpretation of the field photographs in combination with the LUCAS codes and the original satellite images. The consideration of the field photographs had the advantage of being able to consider the different minimum mapping units respectively observation units of CLC (25 ha) and LUCAS (circle of 3 m).

The result of the reinterpretation approach was that the total reliability of CLC2000 is 87.0 ± 0.8 percent, which leads to the conclusion that the 85 percent

A11 Buildings with one to three floors	B71 Apple fruit
A12 Buildings with more than three floors	B72 Pear fruit
A13 Greenhouses	B73 Cherry fruit
A21 Non built-up area features	B74 Nuts trees
A22 Non built-up linear features	B75 Other fruit trees and berries
B11 Common wheat	B76 Oranges
B12 Durum wheat	B77 Other citrus fruit
B13 Barley	B81 Olive groves
B14 Rye	B82 Vineyards
B15 Oats	B83 Nurseries
B16 Maize	B84 Permanent industrial crops
B17 Rice	C11 Broadleaved forest
B18 Other cereals	C12 Coniferous forest
B21 Potatoes	C13 Mixed forest
B22 Sugar beet	C21 Other broadleaved wooded area
B23 Other root crops	C22 Other coniferous wooded land
B31 Sunflower	C23 Other mixed wooded land
B32 Rape seeds	C30 Poplars, eucalyptus
B33 Soya	D01 Shrubland with sparse tree cover
B34 Cotton	D02 Shrubland without tree cover
B35 Other fibre and oleaginous crops	E01 Permanent grassland with sparse tree/shrub cover
B36 Tobacco	E02 Permanent grassland without tree/shrub cover
B37 Other non-permanent industrial crops	F00 Bare land
B41 Dry pulses	G01 Inland water bodies
B42 Tomatoes	G02 Inland running water
B43 Other fresh vegetables	G03 Coastal water bodies
B44 Floriculture and ornamental plants	G04 Wetland
B50 Temporary, artificial pastures	G05 Glaciers, permanent snow
B60 Fallow land	

Table 3: LUCAS land cover nomenclature

U11 Agriculture
U12 Forestry
U13 Fishing
U14 Mining and quarrying
U21 Energy production
U22 Industry and manufacturing
U31 Transport, communication, storage, protective works
U32 Water and waste treatment
U33 Construction
U34 Commerce, finance, business
U35 Community services
U36 Recreation, leisure, sport
U37 Residential
U40 Unused

Table 4: LUCAS land use nomenclature

accuracy requirement specified in the Technical Guidelines of CLC2000 has been correctly fulfilled. Details about LUCAS and the validation approach are described in EEA, 2006a.

APPLICATIONS

The availability of land cover change information has boosted the number of downloads of the CLC database from the EEA data service (http://dataservice.eea.europa.eu/ last accessed 19 October 2006). The database has been in the top three of the EEA data downloads from the first day of publication in November 2004. The popularity of the data and the first time availability of land cover change information have created a market for a wide range of applications. A survey among some 500 projects from about 6000 registered data users showed that the initial investment cost of roughly 13 Million Euro has generated revenues in the range of 250 Million Euro through underpinning downstream applications of the data and services. Application areas range from environment (34 percent), agriculture (14 percent) and forestry (9 percent) to research and education (22 percent), transport (3 percent), and physical planning (5 percent).

The EEA itself further developed the method on land accounting (EEA, 2006b; Weber, 2006), which analyses the stocks and flows (land cover changes) between two given dates (i.e. 1990 and 2000). The method includes an aggregation of individual land cover changes (by class) into groups of changes (land cover flows) with a similar effect on the territory (e.g. urbanisation, intensification or extensification of agriculture, deforestation). The method does not only allow looking at new land cover formations, but also to the sources, i.e. the land that was lost in the process. Figure 2 presents an illustration from the EEA report on the state and outlook of Europe's environment (EEA, 2005) on the increase of artificial lands (land occupied by new constructions) and the land cover classes that are lost (origin) due to this development.

FUTURE PLANS AND BOTTLENECKS

The availability of land cover change data has triggered a great interest in such information that the European Commission (EC) has requested the EEA to investigate the possibility for a more fre-

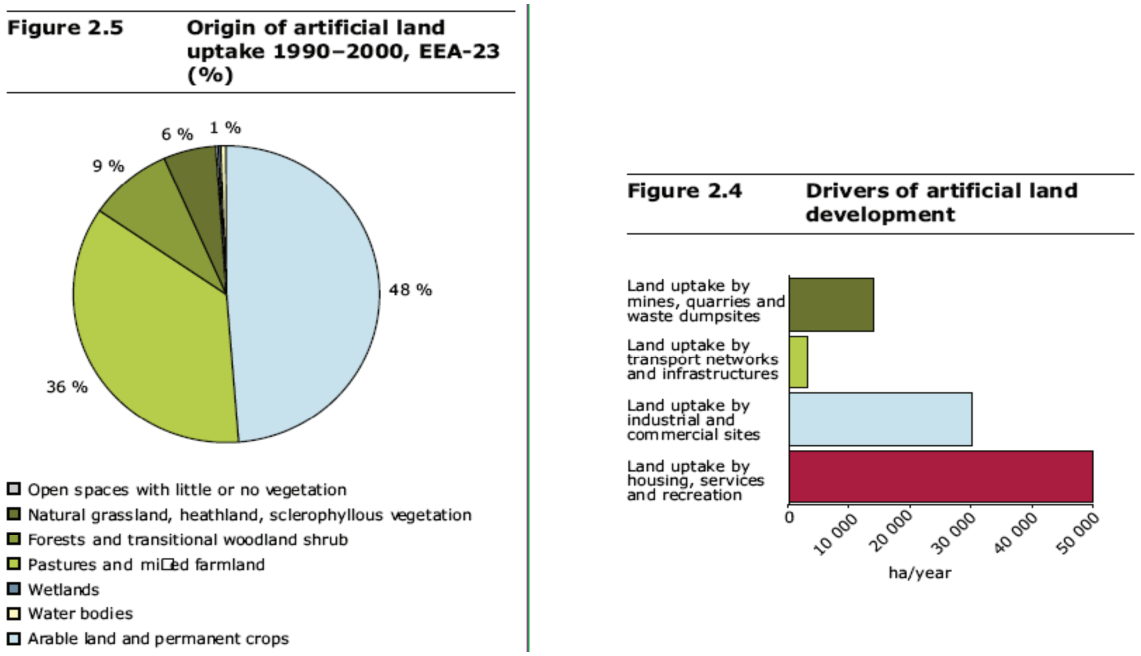

Figure 2: Land cover flows: Development of artificial land and its origin.

quent update of the CLC database. Recent strategic discussions among member countries, European Parliament and the main EU institutions responsible for environmental policy, reporting and assessment (DG Environment, EEA, Eurostat and JRC) have underlined an increasing need for factual and quantitative information on the state of the environment to be based on timely, quality assured data, in particular in land cover and land use related issues.

EEA and Directorate General (DG) Environment of the EC agreed to explore, within the frame of the GMES initiative, the best approach for an improved collection of relevant European land cover and land use data and information. The EEA Management Board endorsed a proposal in June 2005 to update the CLC data together with additional high spatial resolution land cover data as part of the implementation of the GMES fast track service on land monitoring. DG Agriculture has expressed its interest to support a CLC update which should be synchronised, as much as possible, with the LUCAS 2006 in-situ monitoring campaign, to provide complementary information on land cover and land use changes between 2000 and 2006.

Based on the EEA work programme for 2006-2008 to develop activities that integrate spatial analysis, ex-post policy effectiveness analysis and scenarios tools, to support the understanding of the environmental impacts of sectoral policies and the application of EU funding mechanisms in the 2007-2013 financial perspective, in March 2006 the EEA put forward a proposal for implementation of the CLC2006 update. This proposal is based on a collaboration between European Space Agency (ESA) and the European Commission on the implementation of a GMES Fast Track Service (FTS) on land monitoring, in line with and backed by the Communication from the Commission to the Council and the European Parliament "Global Monitoring for Environment and Security (GMES): From Concept to Reality" (COM(2005) 565 final). The three organisations (EC, EEA, ESA) have agreed to share the financial investment (approx. eighteen Million Euro) and organisation of this undertaking. While the EEA and its member countries will be mainly responsible for the national implementation of the CLC update, the provision of necessary in-situ data and validation of the results, the European Commission will also support the creation of the land cover change and high-resolution layers while ESA will be responsible of the provision of the required satellite data.

The proposal builds on the benefits of GMES by combining the planned CLC update with the production of additional high resolution data for a selected number of land cover classes such as those concerning built-up areas (degree of soil sealing) and forest. Some of the shortcomings of a standard CLC update, which is deemed insufficient to meet the wide range of user needs, can be solved by the creation of complementary high resolution land cover data for a selected number of classes.

The boundary conditions of the CLC update include the following points: The service should cover all EU member states and neighbouring countries providing a snapshot of a specific year for which the majority of the satellite data should be acquired;

- Continuity of CLC dataflow should be guaranteed;
- Core land cover data should be available preferably within one and a half years after the satellite data acquisition in order to ensure timely information;
- Updates with a continental coverage should be envisaged at least every five years; some environmental or other sensitive areas, i.e. urban areas, mining sites, protected areas, coastal zones or other regions with high rate of land use and land cover changes, might require more frequent updates;

- Coordination of European with national, regional, local monitoring activities should be fostered, in line with the principle of subsidiarity.
- The GMES service should build on existing land cover and land use experience and monitoring activities. Compatibility should be envisaged with CLC (for continental monitoring), Moland (for urban monitoring) as well as the FAO land cover classification system (for global monitoring);
- Co-ownership of the products should be guaranteed by all actors involved in the service implementation;
- Open access and free dissemination data policy as applied for IMAGE2000 and CLC2000 based services should be maintained.

Apart from these mainly procedural boundary conditions the implementation of the fast track service on land monitoring (and with it the update of CLC) is facing several operational hardships.

The failure of Landsat 7 has a significant impact on the availability of suitable satellite image data for land cover change mapping for the new reference year 2006. SPOT 4 and 5 data cover a much smaller area, thus requiring more effort on image pre-processing and image acquisition, while data from the Indian Remote Sensing (IRS) satellites have a good spatial coverage using the Advanced Wide Field Sensor (AWiFS), but at the expense of spatial resolution.

The cost related to the acquisition of the needed satellite will increase significantly.

Land cover change detection will have to consider multi-sensor approaches with different spectral and geometric characteristics.

Update on CLC2006 (July 2008)

The CLC2006 project on mapping land cover changes between 2000 and 2006 in 38 European countries was actually kicked off early 2007. By mid 2008 about 50% of the almost 6 million square kilometers have been mapped and verified by an independent team. The project will be completed by mid 2009.

CONCLUSIONS

Comparing the European and North American land cover initiatives, a number of similarities and differences can be noted. The similarities include the movement from technology driven Earth Observation solutions to user driven applications or hot topics on how to most effectively detect changes and the subsequent quality control of the change database. Differences are related to the fact that Europe is already in possession of a database on land cover changes for a large area (almost four Million square kilometres) for the year 2000 and that Europe is already affected strongly by the failure of Landsat 7 and the resulting lack of high-quality, low price satellite images.

Similar to North America, the European land cover programme needs to integrate several countries and languages, but instead of three countries (Mexico, the U.S. and Canada), Europe has (successfully) integrated over thirty different nations.

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CHAPTER 5

DEVELOPING LAND COVER AND LAND USE DATA SETS FOR THE AUSTRALIAN CONTINENT – A COLLABORATIVE APPROACH

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ABSTRACT

Nine Australian state/territory and federal government agencies have cooperated to complete mapping of land cover and land use for the Australian continent. The United States, Canada and Mexico are currently considering the joint development of a land cover data set for North America; this paper describes the issues encountered in establishing a similar collaborative mapping program for Australia. In Australia's mapping programs we have distinguished between land cover, the physical surface of the Earth, and land use, the purpose to which the land cover is committed. This collaboration has produced high quality data sets which are being used to establish where in the landscape government investments in land and water management will provide the best returns. The data are also being used to develop effective responses to major natural resources management problems, including water scarcity and water quality decline at national, regional and local levels. The development of the data sets is briefly described, their uses identified, the factors which have contributed to a successful model for collaboration discussed and future plans outlined. This collaborative model underpins the national coordination arrangements now being established in Australia to ensure development of nationally consistent data on natural resources.

Key words: *land cover mapping, land cover change, land use mapping, land management practices*

INTRODUCTION

Land cover, land use and land management practices play a significant role in mediating the movement of carbon, nutrient, sediment and water through the landscape, affecting both rates and size of fluxes (Meyer and Turner 1996; Foley et al 2005). Australia's need for spatially explicit data to describe the continent's land cover, land uses and management practices has been driven by recognition of the heterogeneity of our land, water and vegetation resources and the need to characterise this if we are to improve resource management. Capacity to quantify and predict these fluxes in relation to changes in climate, land cover, land use and land management practices is fundamental to improving natural resources management in Australia. Improvements in process modelling have increased our ability to quantify fluxes, but our ability to make practical use of these models in the 1990s was limited by the lack of spatially explicit land cover, land use and land management practice information at suitable scales.

Australia covers an area of 766 million hectares, approximately the area of the coterminous states of the United States, its latitudinal extent ranges from about 10 ^{o} to 43 ^{o} south. Australia experiences a wide range of climate zones, soil and vegetation types; recognition and accommodation of this diversity has been an important factor in developing and applying remote sensing methods for mapping land cover and land use. Within Australia land management is the responsibility of the six state and two territory governments (hereinafter "states"); mapping land cover and land use has been a collaborative effort between these state agencies responsible for natural resources management and or agriculture and the Australian Government Department of Agriculture, Fisheries and Forestry.

The initial focus of our collaborative mapping programs was land cover and land cover change in the intensively managed land use zone (Figure 1) which represents approximately thirty eight percent of the Australian continent. Outside this zone in the Australian outback, the land cover is disturbed but relatively intact (Graetz, Wilson, and Campbell, 1995). The land cover data sets were developed from Landsat Thematic Mapper (TM) data to provide the information on rates of clearing and replanting of woody vegetation and the implications for carbon fluxes needed for Australia's first national greenhouse gas inventory (Barson, Randall, and Bordas, 2000).

The changes in land cover brought about by clearing of native vegetation undertaken since European settlement, predominantly to establish much of Australia's agriculture, have led to an acceleration of sediment and water transport processes and significant changes in landscape function, particularly in relation to catchment (watershed) hydrology, hydrogeology and sediment movement (Graetz, Fisher, and Wilson, 1992). The 1:100,000 land cover data sets have been especially useful

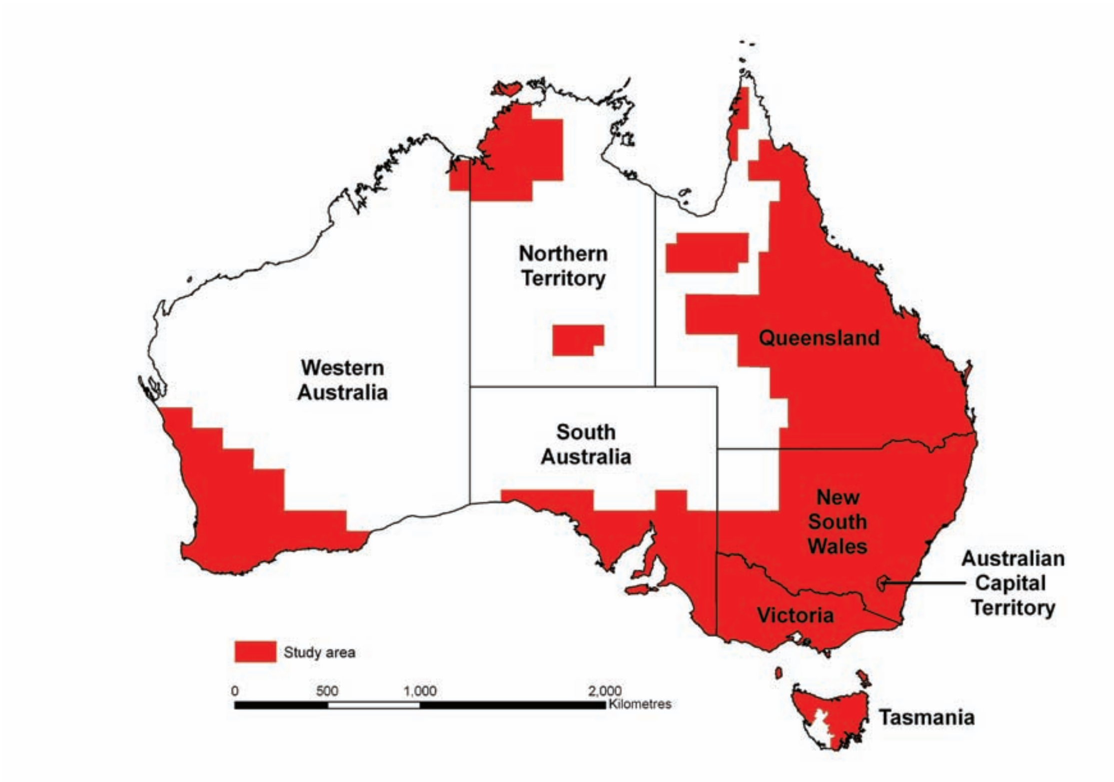


Figure 1. The extent of land cover mapping for the Australian continent

for quantifying the impacts of changes in the distribution of forest vegetation such as plantation development on water resource availability (e.g. Bressard and Vertessy, 1999). However, quantifying processes within landscapes that are no longer forested requires information on current land use. Two data sets at national (1:2,500,000) and catchment scales (1:25,000 – 1:250,000 depending on land use intensity) have been developed for this purpose through the Australian Collaborative Land Use Mapping Programme (ACLUMP).

Observation, experimental work and simulation modelling have demonstrated that the choice of land management practices (for example tillage and stubble management methods) can also have a significant impact on water quality, as well as on the status of the farm resource base and farm productivity (Barson and Lesslie, 2004). Governments and agricultural industries are funding programs to encourage farmers to adopt the most sustainable land management practices. The Land Use and Management Information System (LUMIS) is being developed collaboratively by Australian, state and territory government agencies to meet the need to capture and standardise information on a very

Land cover

Land cover refers to the physical surface of the earth, including various combinations of vegetation types, soils, exposed rocks and water bodies as well as anthropogenic elements, such as agriculture and built environments. Land cover classes can usually be discriminated by characteristic patterns using remote sensing.

Land use

Land use means the purpose to which the land cover is committed. Some land uses, such as agriculture, have a characteristic land cover pattern. These usually appear in land cover classifications. Other land uses, such as nature conservation, are not readily discriminated by a characteristic land cover pattern. For example, where the land cover is woodland, land use may be timber production or nature conservation.

Land management practice

Land management practice means the approach taken to achieve a land use outcome — the ‘how’ of land use (eg cultivation practices, such as minimum tillage and direct drilling). Some land management practices, such as stubble disposal practices and tillage rotation systems, may be discriminated by characteristic land cover patterns and linked to particular issues.

Land capability and land suitability

Land capability assesses the limitations to land use imposed by land characteristics and specifies management options. *Land suitability* (assessed as part of the process of land evaluation) is the fitness of a given type of land for a specified kind of use.

Commodity

A *commodity* is usually an agricultural or mining product that can be processed. Commodity information may relate to land use and land cover, particularly at finer divisions of classification. Agricultural commodity data are available through the ABS Agricultural Census.

Tenure

Tenure is the form of an interest in land. Some forms of tenure (such as pastoral leases or nature conservation reserves) relate directly to land use and land management practice.

Table 1. Definitions used in the Australian land cover, land use and land management practices collaborative mapping programs

wide range of management practices. LUMIS will provide the data needed to identify the agricultural industries and regions which would most benefit from investment in changed management practices, as well as information to evaluate the success of these investments.

Table 1 defines the terms land cover, land use and land management practice used in the Australian mapping programs.

MAPPING LAND COVER AND LAND COVER CHANGE

Australia's first national greenhouse gas inventory suggested that clearing for agricultural development could contribute as much as a quarter of Australia's total greenhouse gas emissions (Department of Environment, Sport and Territories 1994). These estimates were regarded as very uncertain, as little information was available on the rates of clearing or the type of vegetation cleared. It was agreed that a nationally consistent approach to monitoring rates of land clearing was needed. In 1994 the Australian and states' governments agreed to jointly fund and undertake land cover and land cover change mapping coordinated through the Bureau of Rural Sciences (BRS), the science agency within the Australian Government Department of Agriculture, Fisheries and Forestry.

The participating agencies reviewed the greenhouse gas inventory information requirements, the availability of existing data held by state agencies and the remote sensing data sources and methods for mapping land cover and detecting change. It was agreed that four digital data sets at a scale of 1:100,000 would be produced using Landsat Thematic Mapper (TM) data: Land cover 1990 and 1995, Structural Vegetation 1990 and Land Cover Change 1990 – 1995.

The Land cover data sets provided the information needed to establish the type of land cover present in 1990 prior to change, and to assign 1995 land cover categories to those areas of change. The major land cover category of interest for this project, woody vegetation, was defined as all vegetation, native or exotic, with a height of ≥ 2m and a crown cover density of ≥ 20 percent (McDonald et al 1990). This is the definition of forest agreed by state and Australian Government agencies for Australia's National Forest Inventory (National Forest Inventory 1998) and the definition used for Australia's first national greenhouse gas inventory (National Greenhouse Gas Inventory 1999). The definition includes vegetation usually referred to as forest (50 – 100 percent crown cover) as well as woodlands (20 – 50 percent crown cover) and plantations (silviculture operations), but not open woodlands where crown cover is ≤ 20 percent.

Land cover change was defined as increases (planting or regeneration) or decreases (clearing or burning) in woody vegetation. The reason for each change was also recorded. The Structural vegetation data were developed by combining existing digital vegetation data and the 1990 land cover data set; these data provided the basis for calculating biomass losses due to clearing.

Participating agencies jointly developed the specifications (Kitchin and Barson 1998) for these outputs. This work was Australia's first operational use of satellite remote sensing other than for meteorological purposes, and it was recognised that the remote sensing experience, computer processing capacity and ancillary data available and the skills of the nine contributing organisations varied greatly. The jointly developed project specifications included an agreed *a priori* land cover classification (Table 2); the cover types comprising features that could be reliably identified on Landsat TM images. Classification of these land cover types from TM imagery had been undertaken previously in south eastern Australia by four of the participating agencies (Ritman 1995). The project

Land Cover Classes	
0	Not classified
1	Pasture/Crop including herbfields, grasslands and open woodlands
2	Urban
3	Bare Ground
4	Water
5	Plantation
6	Orchard
7	Native or exotic woody vegetation (excluding plantations, orchards) where height ≥2m and crown cover ≥20 percent

Table 2. The land cover classes attributed from Landsat TM data for the Australian Land Cover Change project

specifications also set out the methods for data set development, data formats, attribute and positional accuracy standards, attributes for the information tables accompanying the raster data sets, methods for quality control and metadata requirements.

One hundred and fifty six pairs of TM scenes were chosen for 1990 and 1995. Criteria for scene selection included the driest time of the year (to maximise discrimination between the ground layer and tree canopies) and matching of scene dates to reduce differences in illumination and minimisation of cloud cover. Pre-processing of the Landsat TM data included geo-correction and co-registration of the 1990 and 1995 images, fixing of data dropouts, some radiometric calibration and the preparation of image masks for water, shadow, smoke and fire. State agencies tested their proposed image processing methods; the methods were chosen to give the best results for the vegetation, soils and wild fire patterns in their regions, as well as the resources they could contribute to the project. Details of the image processing methods are available in Barson, Randall, and Bordas (2000), and are summarised in Table 3.

State	Land cover themes	Land cover change
NSW	Unsupervised classification (100 classes) of 1991 images	Unsupervised classification of combined 1991 and 1995 images
NT	Unsupervised classification (100 classes) of 1990 images	Band 5 subtraction of 1990 and 1995 images
QLD	Classification of band 5 and NDVI using 1991 TM images	Thresholding of band 2, 5 and NDVI difference images
SA	Unsupervised classification (150 classes) of combined 1990 and 1995 images	Unsupervised classification (150 classes) of combined 1990 and 1995 images
TAS	Supervised classification of 1990 images	Thresholding of NDVI difference data
VIC	Unsupervised classification (150 classes) of 1990 images	Unsupervised classification of combined 1990 and 1995 images to create woody, non-woody, woody increase and woody decrease
WA	Combined 1990 and 1995 images and carried out canonical variant analysis based on biogeographic regions to identify indices and bands to classify land cover themes and land cover change	

Table 3. Image processing methods used by agencies participating in the Australian Land Cover Change project

Some field checking for the land cover data sets and comparison with existing vegetation and forestry data sets was undertaken to ensure that the image processing techniques used discriminated forest and woodland land cover (height of ≥ 2m and a crown cover of ≥ 20 percent) from open woodland (crown cover of ≤ 20 percent).

The land cover change data were filtered to remove individual pixels and clumps of two to three pixels that could have been erroneously identified as change. All areas identified as change on the imagery were checked against another data source such as aerial photography, other TM or Satellite Pour l'Observation de la Terre (SPOT) imagery, ancillary information such as forest management data sets or field verified where no independent sources of information were available. The data source used to check each change pixel was recorded.

State agencies supplied the Land cover, Land cover change and Structural vegetation data to BRS as 1:100,000 map sheets with a 1km overlap. The data sets were checked to ensure they complied with the output specifications. Positional and attribute accuracy were checked and the change tables were checked by assigning a logical code to the change data incorporating the four main attributes, type of change, land cover 1990, cause of change and replacement land cover 1995 to test whether the combination of change attributes was appropriate. As agreed with participating agencies at the beginning of the project, data which did not meet the agreed output specifications were returned for reprocessing.

A summary of the amount of change by type of change and cause of change per map sheet was supplied to state agencies for verification. The state data sets were produced by merging the map sheet tiles by Australian Map Grid zone, then projecting the zone into Albers Equal Area. The zones were merged to form the state data sets (25 metres, 1:100,000 scale) and clipped to the state boundaries. Subsequently these data were resampled to produce data sets at 100 metres (1:250,000) and 250 metres (1:500,000) cell sizes.

A method to assess the reliability of the change data for areas where no suitable reference data were available was developed by Lowell (2001) and applied to half of the images in the study area. Sample based estimates of change were prepared by independent consultants for comparison with the results produced by state agencies and the differences between states' and consultants' estimates of change evaluated. Of the sixty seven scenes evaluated, ninety seven percent met the acceptance criteria – the differences between the two estimates were not significant at the ninety five percent confidence interval. Overall the assessment demonstrated that the process of detecting land cover change from TM data provided repeatable and reliable results although the collaborating agencies used different change techniques and approaches to radiometric calibration (Barson et al 2004).

The land cover data have proved particularly useful for hydrological modelling and have been resampled to 1km and incorporated into the Australia's main hydrological modelling toolkit (Western 2005).

The total cost of the land cover and change mapping and collation of the Structural vegetation data set was $A 5.7 million. The four digital data sets produced, together with the project specifications and the final report are available on CD ROM at 25, 100 and 250m resolution from the authors, and can be downloaded from http://adl.brs.gov.au

Land cover change monitoring has continued in Queensland where land clearing contributes a significant proportion of Australia's greenhouse gas emissions (Department of Natural Resources and Mines 2006). The resulting data help quantify the state's emissions, assist in vegetation management and compliance checks for land clearing permits and provide information for regional ecosystem mapping. The Australian Greenhouse Office within the Australian Government Department of Environment and Water Resources is now responsible for monitoring land clearing at the continental scale.

MAPPING LAND USE

The availability of the seven class high resolution (1:100,000) land cover data set for 1995 improved our capacity to model the impacts of clearing and planting of forests and woodlands on water resource availability. However, additional information on the purposes to which the land cover is committed (the land use) and how the land use is undertaken (the land management practices) was required to improve our capacity to quantify and predict fluxes of carbon, nutrients sediments and to identify where changes in landscape management were needed to improve soil condition, water quality and habitat.

Land use mapping activities in Australia have focussed on developing nationally consistent coverage at catchment (watershed) (1:25,000 – 1:250,000) and continental scales (1:2,500,000), the establishment of technical standards including a national land use classification system and web based delivery to facilitate user and community access to land use information and national and regional reporting of conditions and trends. Different approaches have been adopted for the preparation of catchment and continental scale mapping, although they use the same classification (Lesslie, Barson, and Smith, 2006).

CATCHMENT SCALE LAND USE MAPPING

Building on the success of the Land Cover Change project, state agencies and BRS agreed in 1999 to collaborate on the mapping of land use at catchment scale. State agencies have operational responsibilities for the natural resource management issues affecting soils, water and vegetation. These agencies need information on the processes operating at the catchment scale to help evaluate natural resource condition and trends, and aid the development of cost effective on–ground solutions to water quality, soil erosion and acidification problems. At the national level these data are being used to help identify where the best returns on investments in natural resources management can be made.

The collaborating agencies recognised that many natural resources management issues are cross – jurisdictional, and that a nationally consistent although not necessarily uniform, approach to land use mapping was highly desirable. A model for the Australian Collaborative Land Use Mapping Program (ACLUMP), similar to that developed for the Australian Agricultural Land Cover Change project was adopted, with joint funding provided by Australian and state government agencies, and the land use classification and project specifications being developed jointly. The mapping has been done by state agencies, with BRS coordinating and collating the work and completing the quality assurance processes.

The agreed technical specifications have played an important role in developing consistent and reliable data sets. These output specifications cover the coding and attribution of land use and source information (including scale, date, source and reliability), data formatting, spatial referencing, data resolution, spatial precision, topological integrity and attribute accuracy (Bureau of Rural Sciences 2006a). The agreed procedure for coding and attribution, the Australian Land Use and Management (ALUM) Classification (Figure 2) is an *a priori* classification with a three – tiered hierarchical structure. The primary, secondary and tertiary classes broadly reflect the degree of modification and impact on native land cover, and provide a structure for attaching attributes describing the land use, commodities produced and land management practices used.

Six primary levels are distinguished in the ALUM classification in order of generally increasing levels of intervention in the landscape.

1. Conservation and natural environments: land used primarily for conservation purposes, based on the maintenance of essentially natural ecosystems present.
2. Production from relatively natural environments: land used primarily for primary production with limited change to the natural vegetation.
3. Production from dryland agriculture and plantations: land used mainly for primary production, based on dryland farming systems.
4. Production from irrigated agriculture and plantations: land mostly used for primary production based on irrigated farming.
5. Intensive uses: land subject to extensive modification, generally in association with closer residential settlement, commercial or industrial uses.
6. Water: water features – both natural and human made. Water is a land cover type, but is regarded as an essential part of the classification because of its importance to natural resource management.

Figure 3 outlines the catchment scale mapping process which has been developed to make the best use of existing spatial data resources, including Landsat Enhanced Thematic Mapper (ETM), SPOT satellite imagery, aerial photography and the digital cadastre which identifies land tenure boundaries. The mapping procedures are described in Bureau of Rural Sciences (2006a). Significant emphasis is given to verification of the draft maps in the field by personnel familiar with local land uses and to the

AUSTRALIAN LAND USE AND MANAGEMENT CLASSIFICATION version 6 (November 2005)

1 Conservation and Natural Environments

1.1.0 Nature conservation
1.1.1 Strict nature reserves
1.1.2 Wilderness area
1.1.3 National park
1.1.4 Natural feature protection
1.1.5 Habitat/species management area
1.1.6 Protected landscape
1.1.7 Other conserved area

1.2.0 Managed resource protection
1.2.1 Biodiversity
1.2.2 Surface water supply
1.2.3 Groundwater
1.2.4 Landscape
1.2.5 Traditional indigenous uses

1.3.0 Other minimal use
1.3.1 Defence
1.3.2 Stock route
1.3.3 Residual native cover
1.3.4 Rehabilitation

minimum level of attribution

2 Production from Relatively Natural Environments

2.1.0 Grazing natural vegetation

2.2.0 Production forestry
2.2.1 Wood production
2.2.2 Other forest production

3 Production from Dryland Agriculture and Plantations

3.1.0 Plantation forestry
3.1.1 Hardwood production
3.1.2 Softwood production
3.1.3 Other forest production
3.1.4 Environmental

3.2.0 Grazing modified pastures
3.2.1 Native/exotic pasture mosaic
3.2.2 Woody fodder plants
3.2.3 Pasture legumes
3.2.4 Pasture legume/grass mixtures
3.2.5 Sown grasses

3.3.0 Cropping
3.3.1 Cereals
3.3.2 Beverage & spice crops
3.3.3 Hay & silage
3.3.4 Oilseeds
3.3.5 Sugar
3.3.6 Cotton
3.3.7 Tobacco
3.3.8 Legumes

3.4.0 Perennial horticulture
3.4.1 Tree fruits
3.4.2 Oleaginous fruits
3.4.3 Tree nuts
3.4.4 Vine fruits
3.4.5 Shrub nuts fruits & berries
3.4.6 Flowers & bulbs
3.4.7 Vegetables & herbs

3.5.0 Seasonal horticulture
3.5.1 Fruits
3.5.2 Nuts
3.5.3 Flowers & bulbs
3.5.4 Vegetables & herbs

3.6.0 Land in transition
3.6.1 Degraded land
3.6.2 Abandoned land
3.6.3 Land under rehabilitation
3.6.4 No defined use

4 Production from Irrigated Agriculture and Plantations

4.1.0 Irrigated plantation forestry
4.1.1 Irrigated hardwood production
4.1.2 Irrigated softwood production
4.1.3 Irrigated other forest production
4.1.4 Irrigated environmental

4.2.0 Irrigated modified pastures
4.2.1 Irrigated woody fodder plants
4.2.2 Irrigated pasture legumes
4.2.3 Irrigated legume/grass mixtures
4.2.4 Irrigated sown grasses

4.3.0 Irrigated cropping
4.3.1 Irrigated cereals
4.3.2 Irrigated beverage & spice crops
4.3.3 Irrigated hay & silage
4.3.4 Irrigated oilseeds
4.3.5 Irrigated sugar
4.3.6 Irrigated cotton
4.3.7 Irrigated tobacco
4.3.8 Irrigated legumes

4.4.0 Irrigated perennial horticulture
4.4.1 Irrigated tree fruits
4.4.2 Irrigated oleaginous fruits
4.4.3 Irrigated tree nuts
4.4.4 Irrigated vine fruits
4.4.5 Irrigated shrub nuts fruits & berries
4.4.6 Irrigated flowers & bulbs
4.4.7 Irrigated vegetables & herbs

4.5.0 Irrigated seasonal horticulture
4.5.1 Irrigated fruits
4.5.2 Irrigated nuts
4.5.3 Irrigated flowers & bulbs
4.5.4 Irrigated vegetables & herbs

4.6.0 Irrigated land in transition
4.6.1 Degraded irrigated land
4.6.2 Abandoned irrigated land
4.6.3 Irrigated land under rehabilitation
4.6.4 No defined use (irrigation)

5 Intensive Uses

5.1.0 Intensive horticulture
5.1.1 Shadehouses
5.1.2 Glasshouses
5.1.3 Glasshouses (hydroponic)

5.2.0 Intensive animal production
5.2.1 Dairy
5.2.2 Cattle
5.2.3 Sheep
5.2.4 Poultry
5.2.5 Pigs
5.2.6 Aquaculture

5.3.0 Manufacturing and industrial

5.4.0 Residential
5.4.1 Urban residential
5.4.2 Rural residential
5.4.3 Rural living

5.5.0 Services
5.5.1 Commercial services
5.5.2 Public services
5.5.3 Recreation and culture
5.5.4 Defence facilities
5.5.5 Research facilities

5.6.0 Utilities
5.6.1 Electricity generation/transmission
5.6.2 Gas treatment, storage and transmission

5.7.0 Transport and communication
5.7.1 Airports/aerodromes
5.7.2 Roads
5.7.3 Railways
5.7.4 Ports and water transport
5.7.5 Navigation and communication

5.8.0 Mining
5.8.1 Mines
5.8.2 Quarries
5.8.3 Tailings

5.9.0 Waste treatment and disposal
5.9.1 Stormwater
5.9.2 Landfill
5.9.3 Solid garbage
5.9.4 Incinerators
5.9.5 Sewage

6 Water

6.1.0 Lake
6.1.1 Lake - conservation
6.1.2 Lake - production
6.1.3 Lake - intensive use

6.2.0 Reservoir/dam
6.2.1 Reservoir
6.2.2 Water storage - intensive use/farm dams
6.2.3 Evaporation basin
6.2.4 Effluent pond

6.3.0 River
6.3.1 River - conservation
6.3.2 River - production
6.3.3 River - intensive use

6.4.0 Channel/aqueduct
6.4.1 Supply channel/aqueduct
6.4.2 Drainage channel/aqueduct

6.5.0 Marsh/wetland
6.5.1 Marsh/wetland - conservation
6.5.2 Marsh/wetland - production
6.5.3 Marsh/wetland - intensive use

6.6.0 Estuary/coastal waters
6.6.1 Estuary/coastal waters - conservation
6.6.2 Estuary/coastal waters - production
6.6.3 Estuary/coastal waters - intensive use

Figure 2. The Australian Land Use and Management classification

independent validation and quality assurance processes.

Validation of the draft data is undertaken by independent assessors who assess attribute accuracy by locating a sample of land use features from high quality data (usually large – scale aerial photography) not used in the mapping process, classifying these features and comparing them with the classes depicted in the land use data set. The required attribute accuracy for catchment scale land use mapping is eighty percent. In the final quality assurance phase BRS checks that all the output specifications have been met, and produces a data quality statement which remains with the data set.

Cartographic scales vary according to the intensity of land use activities, ranging from 1:25,000 scale for irrigated and peri urban areas, to 1:100,000 for broadacre agriculture (cropping and grazing) regions and 1:250,000 for the semi arid and arid pastoral zone (Figure 4). The size of the Australian continent (766 million hectares) and the modest resources available to the mapping program resulted in mapping being conducted over the period 1997 – 2006. The digital data sets have been compiled to produce a mosaic for the continent which can be updated when new information becomes available. The use of pre –existing input data has been important in controlling the mapping costs; these are

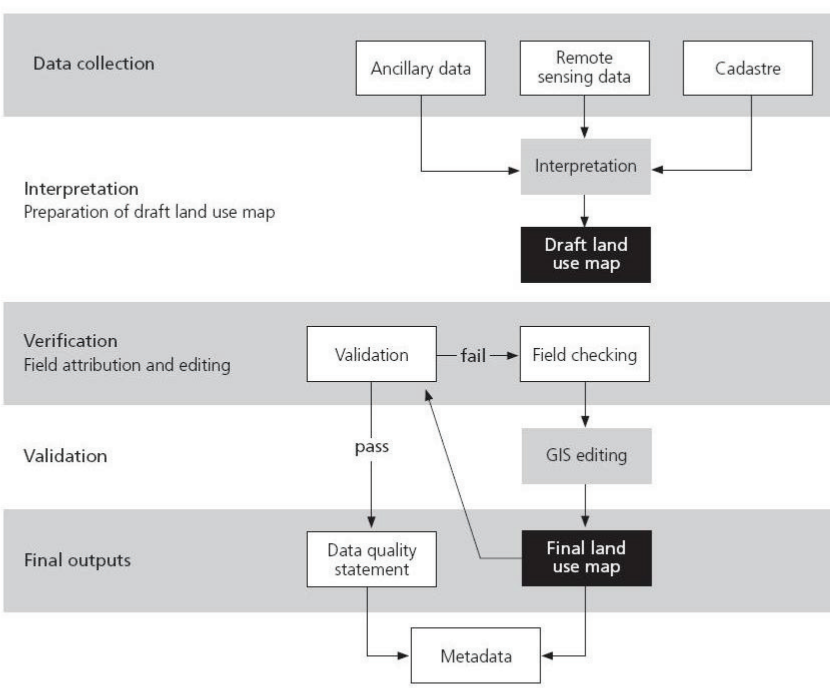


Figure 3. Generic catchment scale land use mapping procedure used by collaborating agencies

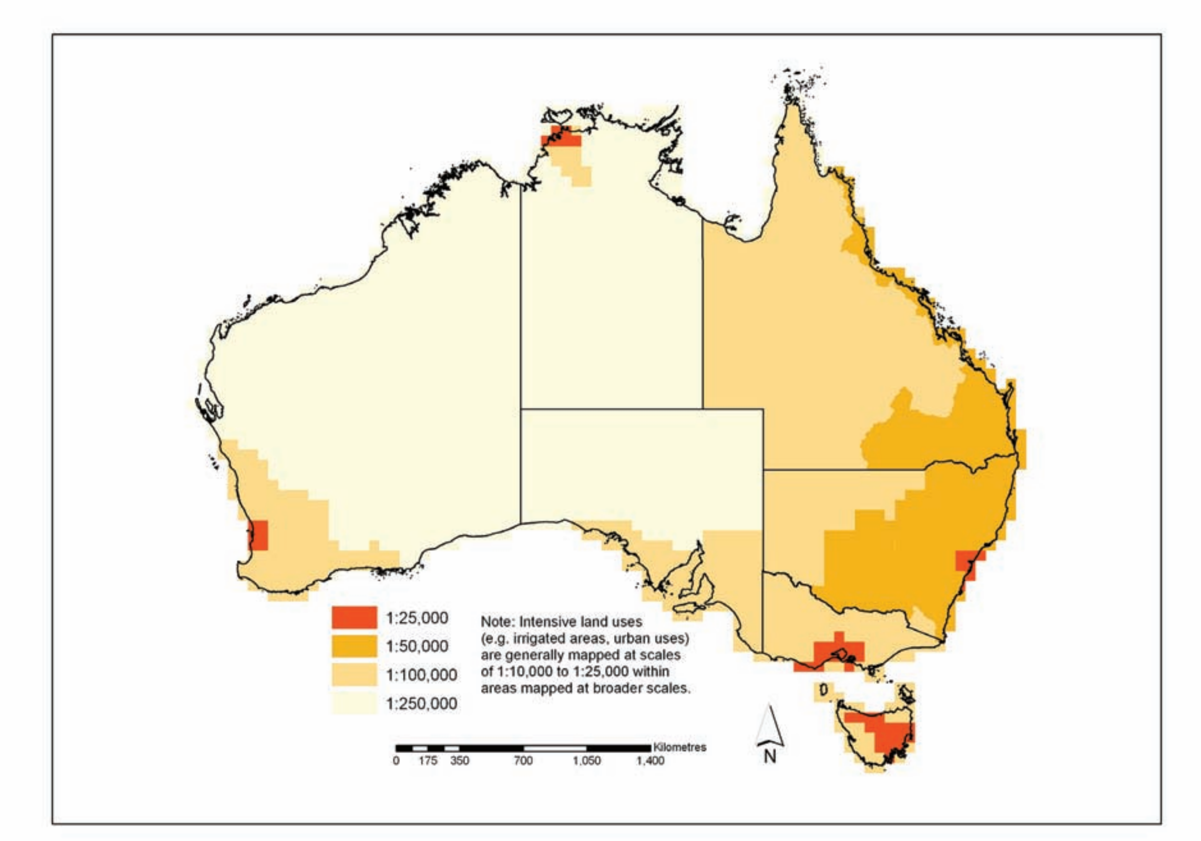


Figure 4. Cartographic scales for catchment scale land use

approximately $A3 - $A5.00 per square kilometre (depending on land use intensity) for 1:100,000 scale mapping.

NATIONAL SCALE LAND USE MAPPING

BRS undertakes national scale mapping to provide synoptic level land use assessments needed by Australian government agencies for strategic planning and evaluation and national scale modelling applications such as carbon accounting. Gridded data at 1.1km resolution are prepared by linking the phenological characteristics of crops and pastures (Figure 5), the Normalised Difference Vegetation Index (NDVI) annual time series from NOAA Advanced Very High Resolution Radiometer (AVHRR) data, ground control point data, the national agricultural statistics and spatial data on non agricultural land use (Walker and Mallawaarachi 1998; Bureau of Rural Sciences 2004). The resulting probability

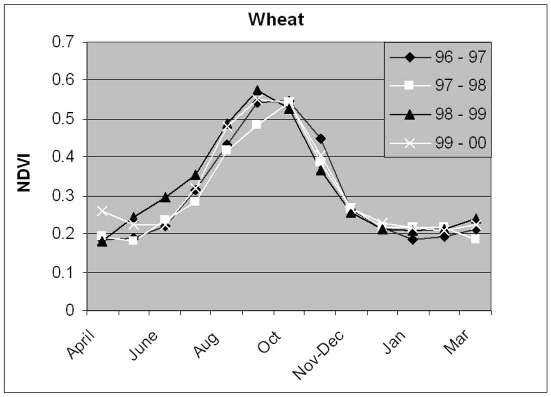


Figure 5. Normalised Difference Vegetation Index profiles for wheat for the years 1996 – 2000.

surfaces for each mapped agricultural commodity are combined to produce a map of most likely land uses.

The input data for national scale mapping relate to agricultural commodities, the tertiary level attributes for the Australian Land Use Management Classification (Figure 2). As this classification is hierarchical, the commodity attributes can be amalgamated to present land uses at the primary or secondary levels (Figure 6) of classification as required by the user. National scale mapping has been completed for 1992.–1993, 1993 –.1994, 1996 –.1997, 1998 – 1999, 2000 – 2001 and 2001 – 2002 using ground control data collected by state agencies. The catchment scale data are used to check the veracity of the national scale outputs. Figure 7 shows the differences in scale and information captured in the national (1:2,500,000) and catchment scale (1:100,000) mapping.

The national scale data have proved to be an inexpensive way of capturing changes in the agricultural landscape, with the time series costing approximately $A 300,000 to produce. Analysis of the time – series has identified regions where farmers practise crop/pasture rotations, and the expansion and contraction of irrigated agriculture.

MAPPING LAND MANAGEMENT PRACTICES

In Australia, land used for agriculture represents about sixty per cent of the total land area (Figure 6) making farmers the largest group managing Australia's natural resources. Management practices at farm scale impact on Australia's land, water and biodiversity resources as well as on the profitability and

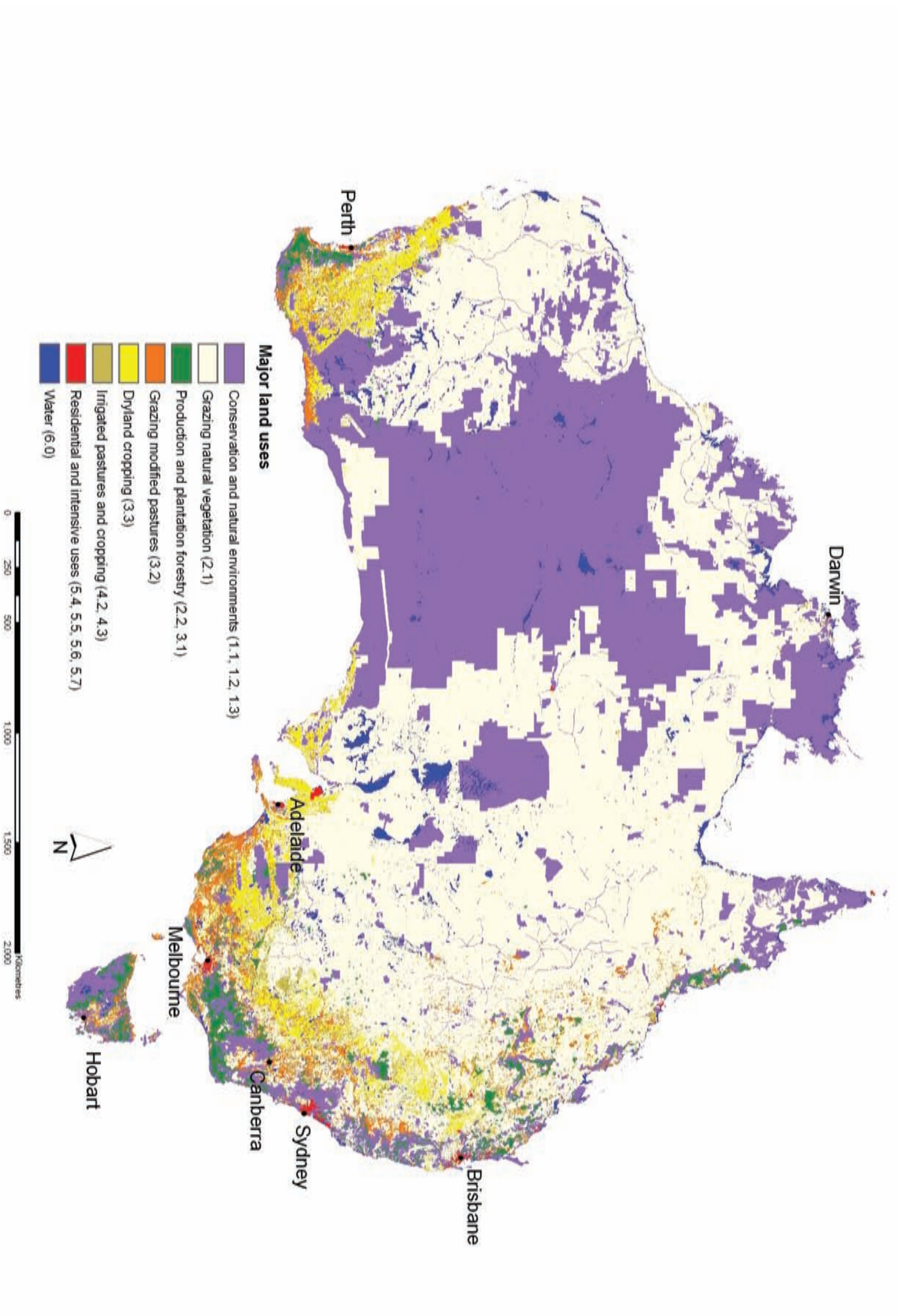


Figure 6. Land use mapping at the national scale

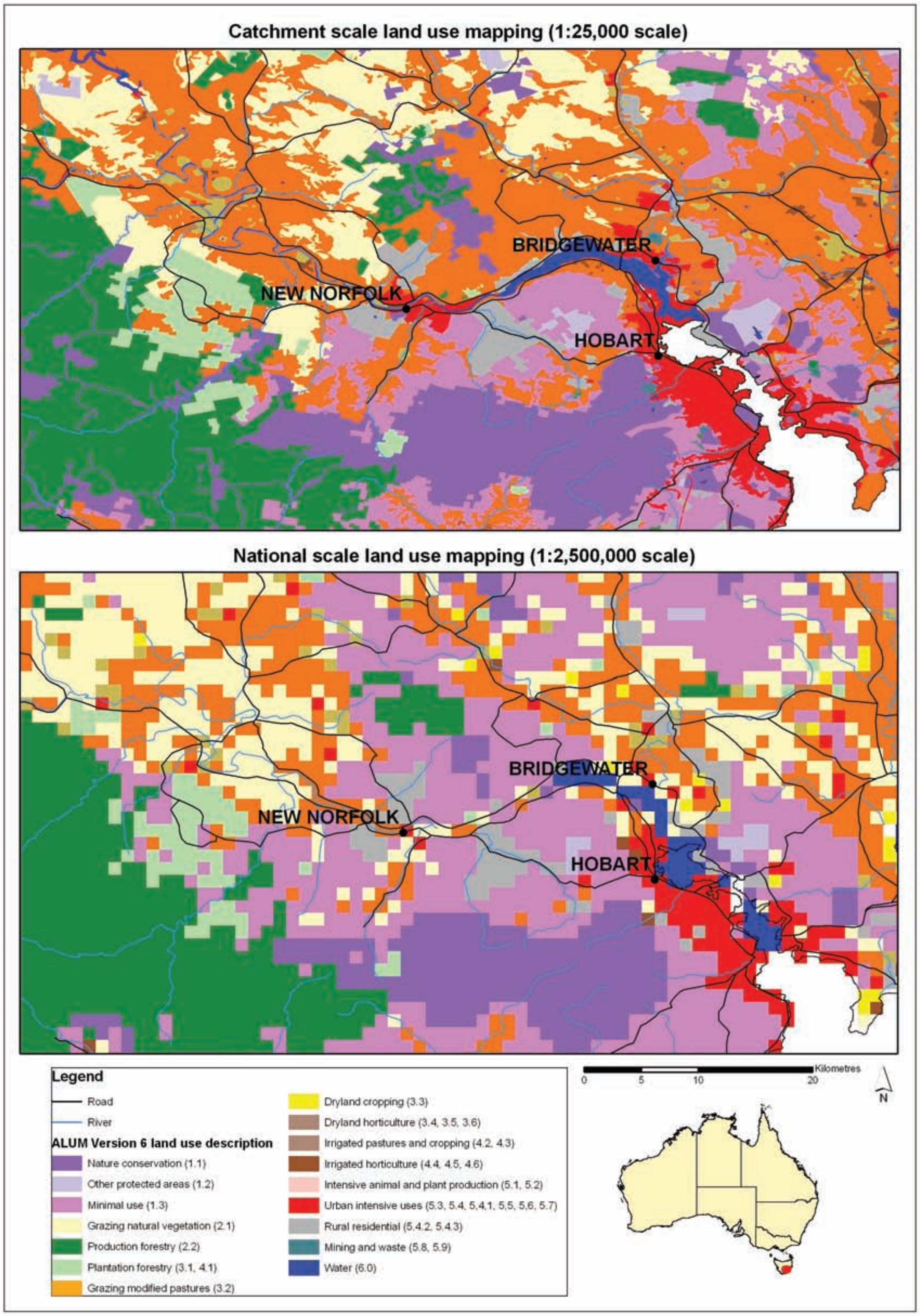


Figure 7. Differences in scale and information contained in the national (1:2,500,000) and catchment scale (1:100,000) land use maps of an area near Hobart, Tasmania.

sustainability of agriculture (Kokic, Davidson, and Boero Rodriguez, 2006). In 2004, state agencies, Australian government departments, industry groups and scientific organisations convened to discuss the need for a national approach to the collation and mapping of land management practices. It was agreed to develop a national categorisation and information system for land management practices, (Land Use Management Information System – LUMIS) for testing by state agency partners.

The LUMIS categorisation is a hierarchical system that moves from the object of management at the highest level through to generalised practices then specific actions. The primary components of the landscape (plants, animals, soil, water, and potentially air) and the managerial components (business and infrastructure) are the highest level of the categorisation. Figure 8 demonstrates how the management practice of liming would be categorised. Details relating to the action of liming such as the amount applied, characteristics of the liming material used and the application method can also be accommodated. LUMIS will also have a spatial locator to link the management practices information with land use and other data sets. Initially the categorisation focuses on agricultural practices, but it is structured to enable inclusion of practices associated with other land uses such as forestry, conservation and mining.

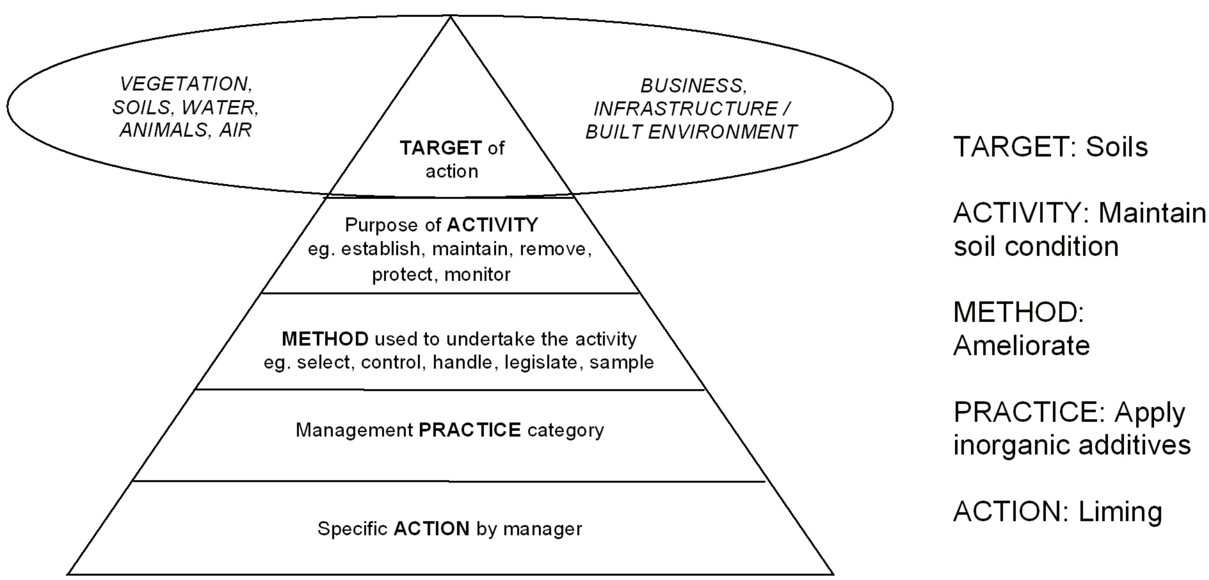


Figure 8. The Land Use Management Information System (LUMIS) is a hierarchical system that moves from the object of management at the highest level through to generalised practices and then specific actions. An example is given for the action of liming to maintain or improve soil condition.

An analysis of needs (Stewart, Yapp and Lesslie, forthcoming) was undertaken to prioritise the demand for land management practices information. Key management practices identified for initial data collection include protection of native vegetation, soil conservation methods, irrigation scheduling and application methods, controlling weeds and pest animals and crop rotation systems. State agency partners will undertake pilot studies in 2007 to develop methods for mapping these practices. These projects will collate and map land management practices from surveys of land managers, information from local experts, existing data from agencies, industry and local groups; field mapping and interpretation of aerial photography or satellite imagery.

One pilot study is exploring the potential high resolution imagery (e.g. SPOT 5) may offer for the use of object-classification algorithms to identify specific features such as contour banks in the landscape. Others will examine how remote sensing using standard pixel-based classifications and manual image interpretation can be used for sampling or mapping practices such as tree clearing or thinning, crop rotations, strip cropping, centre – pivot irrigation, fencing of riparian vegetation, and wildlife corridors or the impact of management (e.g. groundcover as an indicator of grazing management).

The results of these projects will contribute to a nationally agreed categorisation for land management practices and specifications for mapping these practices. Further work is planned to explore the appropriate scales and frequency for mapping land management practices.

A number of the state agency partners are investing in information systems which bring together spatial data on land management practices, land use, land cover and other data (such as social and economic information) to improve natural resource management decision making. Interagency collaboration is making the best use of the limited resources available for developing a land management practices categorisation and efficient data collection methods, as well as providing a nationally consistent approach to this issue.

SUCCESS FACTORS FOR COLLABORATIVE MAPPING PROGRAMS

The land cover and land use mapping programs have produced high resolution, high quality data sets that provide consistent information across jurisdictional boundaries. The data sets are used routinely by government agencies and researchers for modelling the impact of land cover changes on water availability (Brown et al forthcoming), water quality (Sherman et al 2007) and sediment budgets (Lu et al 2004; Wilkinson et al 2005). State agencies have used the catchment scale land use information to plan locust control programmes and for preparedness exercises for Foot and Mouth and Newcastle diseases (Western Australia); manage sediment and nutrient loads in the Gippsland Lakes and undertake surface water resources modelling in the Macalister Irrigation District (Victoria); support regional integrated natural resource planning and investment and develop regional strategies for industry development (South Australia); model sediment and nutrient transport across catchments associated with the Great Barrier Reef and define the extent and sizes of sub-divisions for residential expansion in south-east Queensland and to develop a horticulture database and plan pest and disease responses for the Northern Territory (Bureau of Rural Sciences 2006b).

A number of factors have contributed to the success of the programs. These include the partners in the mapping programs having a significant interest in using the resulting data for natural resource management in their own jurisdictions and their enthusiasm for sharing experience and expertise with other agencies. For example, the Queensland Department of Natural Resources and Water developed an improved validation technique for catchment scale land use datasets (Denham 2005) which is now part of the national standards (Bureau of Rural Sciences 2006a). Queensland have also developed a method for semi-automating the production of a draft land use map for field checking which is being trialled by other agencies. The state agencies are also custodians of or can readily access ancillary data sets such as aerial photography, which has helped to contain the costs of mapping.

Early in the development of the mapping programs agencies recognised the great diversity of environments being mapped and the varying levels of skills and resources available to the projects, and decided that these could best be used by agreeing on output specifications rather than standardising inputs and methods. The output specifications were formalised in manuals (Kitchin and Barson, 1998; Bureau of Rural Sciences, 2006a), with all collaborating agencies contributing to their development. Agencies were then free to develop mapping methods appropriate to their environments which they tested in pilot projects to ensure that the agreed output specifications could be met.

It was agreed that one agency, BRS, would take overall responsibility for quality assurance testing for the final products, and that data sets not meeting the agreed specifications would be returned for reprocessing. The arrangements were formalised through contracts with each partner agency which established the costings, the contributions to be made by the Australian Government and the state government agency, project milestones and payments and the agreed products to be delivered.

The Australian Government is currently promoting improvement in natural resource management in fifty six regions around the continent through the Natural Heritage Trust programme. Well informed investment decisions and the assessment of outcomes requires the collation of nationally consistent information on natural resource condition and trend, including land cover, land use and land management practices.

These needs and the success of the collaborative land cover, land use and other natural resources data coordination processes, have led to the formalising of national coordination arrangements for vegetation, water and salinity as well as for land use and soils. National coordination groups are now responsible for promoting the development of nationally consistent information, facilitating national assessment of natural resources condition and trend as well as meeting the needs of major information users in the natural resource sciences community, industry, state governments and regional groups. A key challenge for the national coordination groups is to provide data that can be integrated for analysis of landscape processes affecting water quantity and water quality, soil erosion and nutrient loss needed to examine the trade offs required to provide acceptable environmental, social and economic outcomes. Increasing demand for information to support integrated assessment has also led to recent plans for the establishment of an expanded nationally coordinated land cover mapping program.

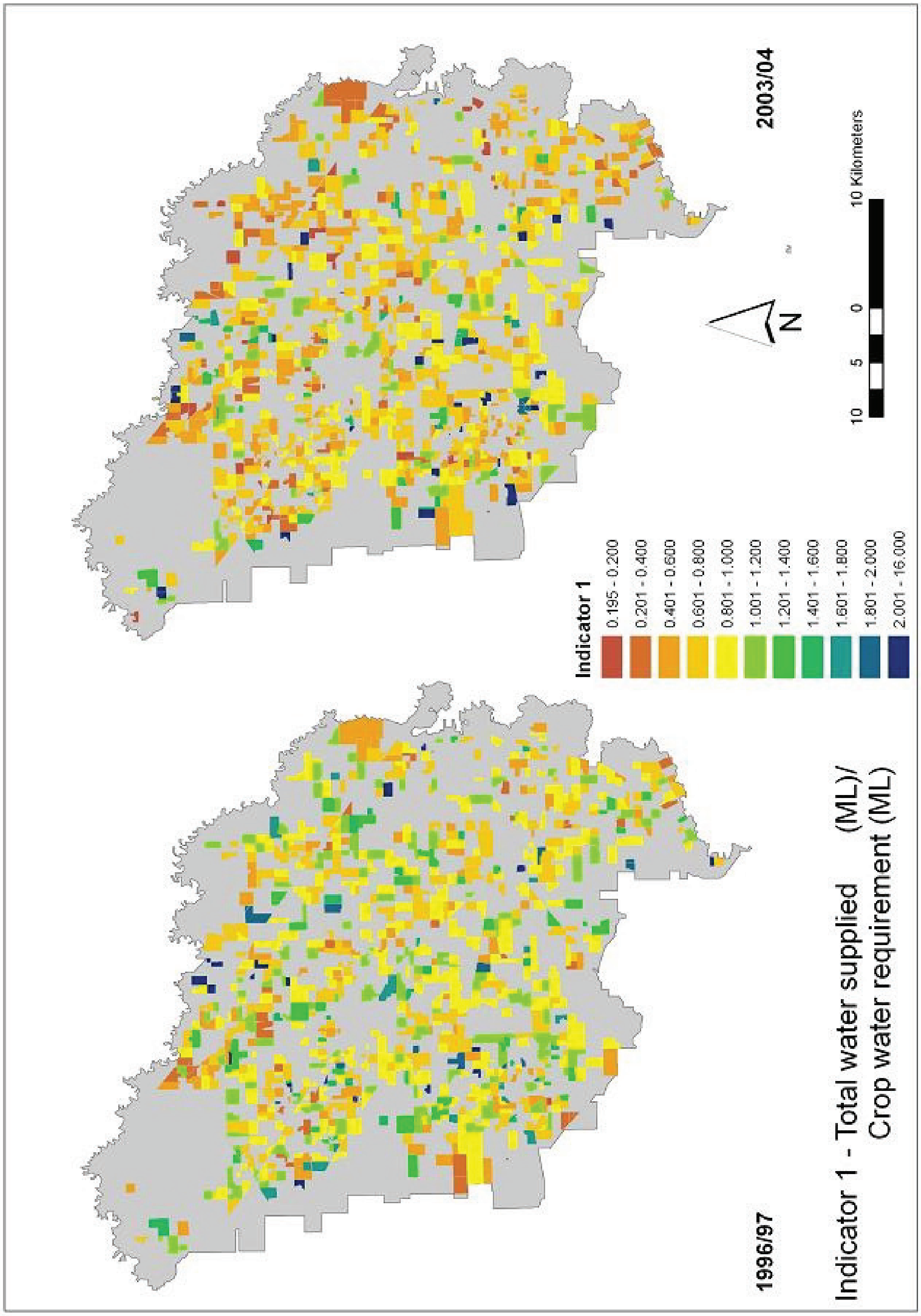
FUTURE DEVELOPMENTS

As land use mapping at the catchment scale nears completion, the focus of the program is shifting to the detection and reporting of change over time. An ability to measure, analyse and report on land use change is critical to effectively addressing key sustainability questions associated with processes such as salinity, habitat change, and water quality and soil loss. A capacity to measure and report change in land use over time is also critical to evaluating trends in agricultural productivity and natural resource condition, the effectiveness of public investment in natural resource management and reporting on industry performance initiatives such as environmental management systems and market-based instruments.

Several state agencies have assessed land use change by comparing catchment scale land use datasets from different years and creating a change data set (Jamieson et al 2006; van den Berg and Jamieson 2006). Pilot projects are now being undertaken to investigate the use of Moderate Resolution Imaging Spectroradiometer (MODIS) time series data to detect and report land use changes. Land cover changes detected from MODIS are being used to identify sites of likely land use change for further investigation. It is anticipated that the projects' results will provide the information needed to specify the outputs for mapping and reporting land use change consistently at the national level.

Land use information is also needed to implement water allocation and efficiency measures. For example, the National Water Initiative (Council of Australian Governments 2004) has recognised the potential for certain land use changes to have a significant impact on the interception of ground and surface waters and affect the subsequent availability of water for other purposes. Irrigated agriculture is a major user of water resources, and farm dam developments and large-scale plantation forestry intercept significant volumes of surface and ground water. Digital data sets are being developed to meet the technical requirements in this area, and substantial progress is being made in integrating land use and water management data to support water use analysis. For example, water use efficiency for cropping in the Central Goulburn Irrigation District in Victoria has been assessed in terms of total water supplied as a proportion of crop water requirements, indicating spatially where there are deficits and surpluses of supply (Figure 9).

Ensuring effective dissemination of land use, land management and land cover information to the users of information is also a priority. Land Use Mapping for Australia, a DVD and website (www.brs.gov.au/landuse) provide easy access to land use data, enabling users to view land use data online, download datasets and see the latest applications of the data to natural resource management issues. An online reporting system is currently being prepared to present synoptic change and trend


1996/97
2003/04
Indicator 1 - Total water supplied (ML)/
Crop water requirement (ML)
Indicator 1
0.195 - 0.200
0.201 - 0.400
0.401 - 0.600
0.601 - 0.800
0.801 - 1.000
1.001 - 1.200
1.201 - 1.400
1.401 - 1.600
1.601 - 1.800
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2.001 - 16.000
N
10 5 0 10 Kilometers

Figure 9.

information for land use and land management practices at a national level. Land use information will be presented with other environmental, social and economic data to give an integrated picture of a particular region.

CONCLUSIONS

Collaborative mapping programs which have brought together resources, skills and experience across jurisdictions are proving to be an effective and efficient way of developing high quality data sets fundamental to natural resources management in Australia. The availability of consistent data sets which have identical mapping categories irrespective of jurisdiction is of paramount importance in addressing water resources and other intra state issues. These data sets will also help identify where the Australian Government's funding for natural resource management should be provided to give the best returns on investment.

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The land cover and change mapping project could not have been completed without the substantial collaborative efforts of over sixty staff from the nine collaborating agencies and valuable ancillary data and support provided by other Australian, state and territory government agencies. The project team and team leaders included the Bureau of Rural Sciences (Michele Barson, Project Director); New South Wales Department of Information Technology and Management (Jeff Holmes, Project Manager); Northern Territory Department of Lands, Planning and Environment (Jane Hosking, Project Manager); Queensland Department of Natural Resources (Tim Danaher, Project Manager); South Australian Department of Primary Industries and Resources (Russell Flavel, Project Manager); Tasmanian Department of Primary Industry, Water and Environment (Mark Brown, Project Manager); Department of Natural Resources and Environment, Victoria (Adam Choma, Project Manager); and Agriculture Western Australia (Greg Beeston, Project Manager).

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CHAPTER 6

FAO LAND COVER MAPPING INITIATIVES

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ABSTRACT

The Food and Agriculture Organization of the United Nations (FAO), as part of its mandate, is conducting global assessment and monitoring of agricultural land, forest and fisheries resources, and assisting developing countries with their sustainable development and management. During the 1970s, FAO became one of the earliest operational users of satellite remote sensing data for land cover mapping and change monitoring in developing countries. Since the mid-1990s, the FAO land cover mapping activities have been expanded to include development of an advanced land cover mapping methodology appropriate for application at global and regional levels, and global harmonization of land cover classification. These tasks are now being completed and transformed into operational activities.

INTRODUCTION

The Food and Agriculture Organization of the United Nations (FAO), as part of its mandate, is conducting global assessment and monitoring of agricultural land, forest and fisheries resources, and assisting developing countries with their sustainable development and management. During the 1970s, FAO became one of the earliest operational users of satellite remote sensing data for land cover mapping and change monitoring in developing countries. Since the mid-1990s, the FAO land cover mapping activities have been expanded to include development of an advanced land cover mapping methodology appropriate for application at global and regional levels, and global harmonization of land cover classification. These tasks are now being completed and transformed into operational activities.

FAO needs timely and reliable information on land cover and its changes at global, regional and country levels to support implementation of the UN Millennium Development Goals, UNCED Agenda 21, WSSD Plan of Implementation, international environmental conventions on climate change, biodiversity, and desertification, and its programmes, projects and other activities. These include:

- FAO initiatives related to the Global Terrestrial Observing System (GTOS), which is managed by FAO, and its panel, the Global Observation of Forest and Land Cover Dynamics (GOFC/GOLD);
- FAO inputs to the GEOSS, IGOS, and, in particular, the Integrated Global Observations of the Land (IGOL), which is the IGOS new application theme;
- FAO Global Information and Early Warning System on Food Security, and the FAO ARTEMIS project's inputs to the sub-regional food security early warning systems in Africa;
- FAO Global Forest Resources Assessment project, which is implemented in 5-year intervals. The next assessment will be referenced to the year 2010 (FRA 2010);
- FAO LADA project for global assessment of land degradation in drylands;
- FAO projects for development of regional land cover databases to support environmental protection and rehabilitation (Africover and Asiacover projects);
- FAO projects for development of country-level land cover databases to support sustainable land use planning and agro-ecological zoning, including the assessment of aquaculture potential, in developing countries;
- FAO projects for natural disasters preparedness and mitigation, such as the monitoring of agricultural drought and desert locust recession areas in Africa, assessment of wildfires risk, and delineation of flood zones;
- FAO projects for detection of illicit drugs plantations and illegal logging;

- FAO projects aiming to enhance societal benefits of rural development, including improvement of fresh water supply, irrigation and road infrastructures, and delineation of habitats amenable to vector-borne diseases.

LAND COVER INFORMATION REQUIREMENTS AT GLOBAL AND REGIONAL LEVELS

FAO has been involved, in the framework of its participation in the implementation of the U.N. Millennium Development Goals, international environmental conventions, GTOS-GOFC/GOLD, IGOS/IGOL, FRA and LADA global programmes, and a variety of regional projects such as Africover, Asiacover and ARTEMIS, in a wide range of activities that require information on land cover and its dynamics at the global and regional levels. Considering its mandate, the main focus of these activities has been on the following applications:

Monitoring the impacts of climate change with particular attention on food security in developing countries

Climate change is considered one of the most serious threats to sustainable development and management of natural resources. It affects all climatic zones but has the most devastating effects in the arid and semi-arid zones, such as the Sahelian region of Africa. The increasing frequency, intensity and duration of droughts have disastrous effects on agriculture and pastoralism, on which the livelihood of majority of population in these zones depend. Although the consequences of climate change are the most serious in drylands, the tropical and sub-tropical humid zones experience higher frequency and intensity of tropical storms and floods, coastal zones are exposed to raising sea level, temperate zones to higher occurrence of wildfires, eutrophication of lakes and drying of wetlands, and northern zones to melting permafrost. As the communities in the worst affected regions in developing countries struggle to adapt to changed environmental conditions resulting from climate change, their traditional way of life becomes unsustainable and leads to worsening famine, impoverishment and migration of people from their traditional habitats.

Monitoring land cover dynamics is essential for the assessment of land degradation in drylands

(FAO-LADA global project) and timely development of adaptation strategies. Dryland areas have become more vulnerable to degradation because of the combination of climate warming and population increase. The expansion of agricultural cultivation in former grazing areas of drylands has exacerbated land degradation and led to food insecurity. In addition to LADA project, FAO implemented number of projects for identification of the areas with land degradation risk, and projects for agro-ecological zoning at the global, regional and country levels. (FAO, 2002; Fischer et al, 2002).

Climate change models for the reduction of impacts of the most important greenhouse gas, carbon dioxide (CO_2), need reliable information on land cover classes, which are its natural sinks and sources. Vegetation cover, in particular forests, is the carbon sink due to photosynthesis, as well as the source of atmospheric carbon due to respiration, forest fires and decay. FAO estimates that global forests store two-thirds of terrestrial carbon, nearly one trillion tons. Yet deforestation of tropical forest continues at an alarming rate, with South America having the largest net loss of forest, 4.3 million hectares annually between 2000 and 2005, followed by Africa with 4.0 millions hectares. (FAO, 2005).

The FAO Forestry Department has been conducting periodic assessments of global forest resources since its establishment in1946. Their objective is to provide reliable and globally consistent information on the state of tropical forest cover and the rates of its change. Since 2000, the global forest assessment has been carried out in 5-year intervals. It is based on a combination of country reports and analysis of high resolution remote sensing data in 117 sampling areas, each representing one Landsat TM/ETM+ scene, randomly distributed over the world tropical forest. (FAO, 2001 & 2005).

The need to improve the preparedness for, and adaptation to, the impacts of climate change has been receiving an increasing attention from national governments, inter-governmental bodies including the G8 countries, and United Nations. All recognized that it is an ecological, developmental and socio-economical challenge. The WMO and UNEP jointly established an Intergovernmental Panel on Climate Change (IPCC) for the collection and assessment of scientific, technical and socio-economic information relevant to the understanding of climate change, its potential impacts, and options for adaptation and mitigation. FAO provides information related to the impact of climate change on agricultural land and food production to IPCC.

Preparedness for natural disasters at global and regional levels

Climate change and frequency of natural disasters, such as tropical storms, agricultural drought, wildfires, floods, and large-scale pest infestations, are closely linked. Increasing frequency and intensity of disasters caused by natural and man-made hazards have prompted the introduction of a number of disaster risk reduction initiatives in recent years. These include the UN declaration of the 1990s as the International Decade for Natural Disaster Reduction, the 1994 World Conference on Natural Disaster Reduction in Yokohama, Japan, the 2000 UN International Strategy for Disaster Reduction (UN/ISDR), and the 2005 World Conference on Disaster Reduction in Kobe, Hyogo, Japan. Disasters represent a growing concern because of continuing population growth, widespread poverty and food insecurity in developing countries, and the onset of global environmental changes, such as land degradation/desertification and loss of biodiversity caused by a combination of climate change and land use pressures.

In order to increase the global preparedness for disasters, the United Nations organized an International Conference on Early Warning Systems in Potsdam, Germany, in 1998. It recommended the more effective use of information technologies by the national and regional early warning systems in the risk assessment strategies, planning of preparedness and mitigation of impacts. Land cover mapping is one of the key activities of natural disaster preparedness. It provides the reference data layer for disaster preparedness database and monitoring land cover changes facilitates up-dating of disaster preparedness plan.

Information on land cover and its dynamics is an important component in monitoring the environmental conditions in Africa and West Asia by the FAO ARTEMIS project, which started its operation in the mid-1980s. Its objectives are twofold: to provide an early warning on agriculture drought and monitor desert locust ecological conditions in its recession areas. The assessment and monitoring of land cover conditions are based on the decadal Normalized Difference Vegetation Index (NDVI) produced from the NOAA-AVHRR, SPOT-Vegetation, and Terra/Aqua MODIS multispectral image data that are recorded daily during the agricultural season. Monitoring of rainfall is based on the Meteosat thermal-IR data, recorded at hourly intervals and processed into 10-day and monthly products. The ARTEMIS products are integrated in dedicated GIS workstation with agro-meteorological and other relevant data, analyzed and used for: (a) location-specific assessment of food security risk by the FAO Global Information and Early Warning System on Food Security, and (b) identification of potential desert locust breeding sites by the FAO Desert Locust Plague Prevention Programme. (Hielkema, 2000).

Protection of environmental quality and biodiversity

Protection of natural ecosystems, their biodiversity and integrity, and the sustainable use of managed ecosystems, have become the top priority tasks of this century. Their fulfillment will not be easy, considering the increasing population pressures, growing demands for food and fibre, and impacts of climate change accompanied by increasing frequency and intensity of natural disasters. Reliable and timely information on land cover and its changes provides the essential inputs to effective ecosystems protection. Yet, the recent report "Filling the Gaps: Priority Data Needs and Key Management Challenges for National Reporting on Ecosystem Condition" (The Heinz Center, 2006), concluded that there is a lack of land cover data with parameters required for systematic assessment of ecosystems conditions at the global level, and included land cover on its list of ten highest priority data gaps.

There are number of initiatives for monitoring the environmental quality at a country and international levels. The UNEP is issuing periodic global assessments of the state of the environment and developed guidelines for harmonization of environmental assessment based on a set of indicators. There are many criteria for the selection of environmental indicators, but the following ones are the most important (Kalensky & Latham, 1998):

- Environmental indicators should be measurable at a reasonable cost and in required intervals;
- Their relationship to specific environmental conditions, which they are representing, should be easy to understand, measure, and interpret;
- A national set of environmental indicators should provide a comprehensive description of environmental conditions and their dynamics for the whole country;
- They should enable an international comparison of environmental conditions and their changes.

When selecting the environmental indicators, it should be remembered that the assessment of environmental quality is not just a technological task but it has a socio-economic dimension, closely related to rural poverty, food insecurity, and gender inequality. Land cover provides the location-specific baseline data to which other biophysical and socio-economic data are linked. Fragmentation of land cover is an important indicator of endangered biodiversity and often results in transformation of the whole ecosystem. Examples of extensive fragmentation of land cover caused by illegal logging and burning of primary rain forest are in the Amazon Basin, Myanmar, and Indonesia. The fragmentation of forest is usually followed by its conversion to agricultural use. Land cover monitoring by Earth resources satellites enables early detection of illegal forest clearing and provides time-specific documentation of its extent and location. (FAO, 2001).

Land cover is generally accepted as one of the most representative indicators of environmental quality. It can be interpreted from satellite remote sensing data and fulfills the above four criteria for the selection of environmental indicators. It reflects both, the natural and anthropogenic drivers of environmental change, such as the climate variability and change, natural and man-made disasters, and land use impacts. Systematic monitoring of land cover enables an assessment of the impact of climate change on land and fresh-water resources, including land degradation and desertification, changes in forest cover, wetlands, surface water bodies and coastal zones. Information on land cover changes has also become one of the most important inputs to greenhouse gas accounting and terrestrial carbon management, assessment of bio-diversity, and land degradation/desertification. The aim of the FAO/UNEP Global Land Cover Network, described earlier, is to accelerate harmonization among international land cover mapping projects in order to increase the global availability of land cover information.

THE CURRENT STATUS OF GLOBAL AND REGIONAL LAND COVER MAPPING.

There is an increasing number of land cover mapping projects being implemented at global and regional levels in recent years. However, there has been little or no compatibility among them in terms of land cover nomenclature, definitions of land cover classes, map legends, image interpretation methodologies, accuracy criteria and cartographic specifications. Although these land cover maps are a valuable source of information, most of them were designed for a specific application and are difficult to compare and use in other applications that may require different land cover definitions and map legends. (Kalensky et al., 2003).

Examples of recently completed or ongoing global land cover mapping projects.

- **GLOBCOVER**, a multi-agency global land cover mapping initiative led by the European Space Agency (ESA). Its objective is to develop a global land cover map for the year 2005. The input multispectral data were recorded with 300m ground resolution by the MERIS remote sensing system on-board of the ESA Earth observation satellite ENVISAT. Land cover classification is based on the FAO Land Cover Classification System (LCCS), which assures its worldwide applicability and compatibility with other land cover mapping projects. An important component of GLOBCOVER is global validation of its land cover products in sample sites.
- **Global Land Cover 2000 Project (GLC-2000)** was implemented by the Global Vegetation Monitoring Unit of the European Commission-Joint Research Center (EC-JRC). The VEGA 2000 dataset, consisting of image data recorded with 1km ground resolution by the SPOT 4 Vegetation remote sensing system during November 1999 – December 2000, provided the input multispectral data for the GLC-2000 mapping and vegetation index assessment. Land cover classification was based on LCCS. High resolution image data were used for validation of land cover in sample sites.
- **IGBP Global Land Cover Mapping Project** was implemented by the International Geosphere-Biosphere Programme (IGBP) in cooperation with NOAA, USGS, NASA, and EC-JRC in 1997. The NOAA AVHRR multispectral image data with 1km ground resolution recorded during mid-1990s provided the input data. The IGBP global land cover database consists of 17

land cover classes and vegetation index series.

- **GeoCover LC** moderate resolution global land cover datasets, based on Landsat TM and ETM+ image data of 1990 and 2000 (± 3 years) respectively, are being produced by the MDA-EarthSat company. Thirteen land cover classes are based on modified USGS-Anderson 1976 classification. Both datasets are co-registered and orthorectified to < 50m RMS error.

Examples of recently completed or ongoing regional (continental and sub-continental) land cover mapping projects

- **FAO Africover** land cover mapping project. (Kalensky, 1998). Its East African module, covering ten countries with a total area of 8.5 million km^2, was completed with the Italian government funding, in 2004. The Landsat TM/ETM+ multispectral image data, with 30m ground resolution recorded in the years 1996-2002, provided the inputs for land cover classification. The Africover project's implementation was based on innovative land cover classification and mapping methodology, which enables global harmonization of land cover classes while providing the flexibility for designing the project's outputs to suit the users' requirements. In particular, the Land Cover Classification System (LCCS) is becoming the land cover classification standard used by growing number of land cover mapping projects. The Africover land cover database is compatible with mapping scales 1:100 000 – 1:250 000. The Africover North African and Sahelian modules are in the preparatory phase. Operational mapping has begun for West Africa, beginning with Senegal and Burkina Faso. Land cover mapping of Libya based on Africover specifications has been recently completed, funded by the Libyan government.

- **FAO Asiacover** land cover mapping project. Its preparatory phase has been completed with FAO funding in 2005. Its land cover mapping methodology is based on the suite of software modules that were developed for the Africover project. The main differences will be the use of ALOS-AVNIR image data as the primary data inputs, the inclusion of socio-economic data layers in the Asiacover database, and development of integrated land cover & socio-economic products.

- **CORINE Land Cover (CLC)** project. The land cover mapping of the European Union countries by CLC project started in the mid-1980s. Its objective was to facilitate harmonization of the assessment of the state of the environment in all EU countries. In the beginning of 1990s, the CLC project was extended to include 13 Central and East European countries. The primary data inputs were the Landsat TM image data recorded in the years 1986-1995. The digital and hard-copy land cover maps at 1:100 000 scale, produced by the project in each participating country, have 44 land cover classes, with the threshold area of 25 hectares.
- **Image and CORINE Land Cover 2000 (I & CLC 2000)** project. The European Topic Centre on Land Cover of the European Environment Agency (EEA) coordinated its implementation, which started in 2000. The I&CLC 2000 project's objectives were to (a) provide a satellite image snapshot of Europe in 2000, (b) update the CORINE land cover map, and (c) produce land cover change map for the period 1990-2000. The primary inputs were the Landsat 7 ETM+ image data recorded in 2000 (± 1 year), with the SPOT image data used for land cover mapping of coastal zones. The outputs consist of land cover statistics, digital land cover vector or raster map at 1:200 000 mapping scale, digital change map 1990-2000, and a set of digital ortho-rectified color composite image mosaics. The last three products, distributed on CDs, were integrated in the EEA Terrestrial Environment Information System (TERRIS) database.

NEW PARADIGM FOR LAND COVER MAPPING

While the government policy-makers and rural land use planners require reliable information on land cover and its dynamics at the national and sub-national levels to support sustainable development and management of land and water resources, the international science community requires land cover information at the global and regional levels for implementation of the UN Millennium Development Goals, UNCED Agenda 21, WSSD Plan of Implementation and the following UN-coordinated environmental initiatives:

- The Framework Convention on Climate Change (FCCC);
- The Kyoto Protocol to FCC;
- The Convention on Biological Diversity (CBD);
- The Convention to Combat Desertification (CCD);
- The United Nations Forest Forum (UNFF).

A new paradigm for land cover mapping is clearly required that would provide information needed by these initiatives. In particular, it should facilitate the harmonization of land cover mapping procedures across sectoral barriers and national borders, increase flexibility of land cover classification to support diverse applications worldwide, enable effective integration of land cover data and other types of geospatial data (e.g. topographic, soils, land degradation) with socio-economic data, and provide links to attribute information. In order to address these challenges, the FAO and UNEP, with the support by the Italian Government, jointly established a Global Land Cover Network Topic Centre (GLCN-TC) in Florence, Italy. The GLCN-TC activities include the establishment of links with the existing land cover databases, promoting and assisting harmonization among land cover mapping projects and standardization of land cover classification based on the GLCN Land Cover Classification System (LCCS) and a software suite of innovative land cover mapping methodologies. (FAO & UNEP, 2002).

An Important component of GLCN-TC activities is the provision of training and advisory services on GLCN land cover mapping and monitoring methodology to developing countries and countries with economies in transition. An example is the Workshop on Harmonization of Forest and Land Cover Classifications for the Asia Pacific Region, which will take place in Dehra Dun, India, in December 2006. Its purpose is to promote and demonstrate harmonization of land cover and forest classification among Asian countries, based on LCCS.

The Global Land Cover Network (GLCN)

The Global Land Cover Network initiative is the result of a joint effort by the FAO and UNEP to respond to the need of international community for the availability of reliable and harmonized land cover information at a global level. This initiative is based on the recommendations of the Agenda 21 for coordinated, systematic, and harmonized collection and assessment of data on land cover and environmental conditions. The GLCN was developed in collaboration with the U.S.-led Geographic Information for Sustainable Development (GISD) global partnership, which aims to increase the use of Earth observation data and geographic information technologies in sustainable development projects focusing on food security, sustainable agriculture, natural resources management, disasters mitigation, and poverty alleviation. Its development benefited from the experience obtained during implementation of the Italian funded East African module of the FAO Africover project. The project produced and extensively tested the innovative methodologies for land cover classification and mapping, and led to development of the Land Cover Classification System, which is being used by growing number of national and international organizations. It.introduced a new, LCCS-based approach towards global harmonization of land cover nomenclature.

The GLCN overall objective is to provide direction, methodology and guidance for harmonization of land cover mapping and monitoring projects at national, regional and global levels in order to achieve compatibility among their products through the promotion of LCCS as the new standard classification system.

In order to fulfill the above objective, the GLCN Topic Centre was established to serve as an international clearinghouse for information on land cover mapping and monitoring projects (http://www.glcn.org/). Its configuration is in Fig. 1. The GLCN-TC conducts the following four types of activities:

- Methodology development -.includes certification of existing land cover databases for their compliance with GLCN technical specifications. It also includes a continuing development of GLCN methodology based on changing requirements on land cover products by their end users;
- Networking - establish effective linkages and cooperation with major land cover

databases and international, governmental and commercial organizations involved in land cover mapping and monitoring activities. The main aim is to increase the benefits from regional and global land cover mapping and monitoring initiatives to developing countries;

- Capacity building - includes provision of advisory services and organization of training courses on GLCN land cover mapping and monitoring methodology for technical staff and appraisal workshops for decision-makers. Its aim is to strengthen the national capacities for land cover mapping and monitoring in developing countries;

- Serving as an international clearinghouse - for information related to land cover mapping and monitoring activities. This task involves development and management of GLCN meta-database providing information on major land cover mapping and monitoring projects.

GLCN Land Cover Classification System (LCCS)

The LCCS innovative design is based on the following unique concept: rather than using pre-defined classes, the LCCS uses universally valid pre-defined set of independent diagnostic attributes, or classifiers. This presumes that any land cover class, regardless of its type and geographic location, can be identified by a pre-defined set of classifiers. The number of selected classifiers determines the level at which the land cover is classified. Thus, the larger number of classifiers is needed for a more detailed classification of land cover and *vice versa*. Furthermore, the classifiers provide a more comprehensive insight into the characteristics of land cover types than would be possible than through standard class names. The LCCS thus facilitates a multiple use of land cover database by allowing users to select the classification levels best suited to their respective applications.

The LCCS output is a comprehensive land cover characterization with a clear definition of class boundaries, without overlaps. The universality of LCCS is based on its following four characteristics:

- Independent of map scale;
- Independent of data source and data collection methodology;
- Independent of geographic location;

- Independent of application.

The above LCCS characteristics, combined with its capability to translate the existing land cover classifications into the LCCS-compatible land cover datasets, make the LCCS an optimal land cover classification standard for large-area projects. This is particularly important considering that an increasing number of regional and global land cover mapping and monitoring projects urgently need a universally applicable land cover classification system for objective international comparisons of land cover state and its changes. A growing number of international projects are already using the LCCS as their classification standard and a number of countries have translated their existing land cover legends to align with the LCCS system (e.g. South Africa and New Zealand). To illustrate the global usefulness of the databases generated by the Africover project, over 3000 request for data, representing over 800 different organisations have registered and downloaded data from the Africover website since January 2003.

Another unique approach to land cover classification adopted by LCCS was driven by pragmatic, operational considerations. Instead of attempting to use the same, large set of pre-selected classifiers compatible with land cover of large areas, such as the whole continents, it divided the classifiers into eight groups corresponding to eight major land cover classes representing the global land cover diversity. This has greatly reduced the number of classifiers needed for precise definition of any land cover class regardless of its location and thus significantly simplified the classification procedure. However, it required designing the LCCS implementation in two phases: the initial *Dichotomous Classification Phase* and the follow-up *Modular-Hierarchical Classification Phase*.

The *dichotomous phase* uses the following three classification criteria: presence of vegetation, edaphic condition and artificiality of land cover. It consists of three classification levels and results in eight major land cover classes in the third level (Table 1). These classes are then further classified during the *modular-hierarchical phase*, based on eight sets of pre-defined classifiers. Each of the eight major land cover classes defined during the dichotomous phase has its own distinct set of classifiers, tailored to the type of land cover class. An example of classifiers for land cover class “natural and

First level	Second level	Third level
PRIMARILY VEGETATED	TERRESTRIAL	MANAGED TERRESTRIAL AREAS
		NATURAL and SEMI-NATURAL TERRESTRIAL VEGETATION
	AQUATIC or REGULARLY FLOODED	CULTIVATED AQUATIC AREAS
		NATURAL and SEMI-NATURAL AQUATIC VEGETATION
PRIMARILY NON-VEGETATED	TERRESTRIAL	ARTIFICIAL SURFACES
		BARE LAND
	AQUATIC or REGULARLY FLOODED	ARTIFICIAL WATER BODIES
		NATURAL WATER BODIES, SNOW and ICE

Table 1. LCCS dichotomous classification phase.

	Classifiers			
4	Life form of main layer (e.g. woody, herbaceous)	Vegetation cover of main layer	Vegetation height	Spatial distribution (macropattern)
5	Leaf type (e.g. broadleved, needleleaved, aphyllous)		Leaf phenology (e.g. evergreen, deciduous, mixed)	
6	Vertical stratification second/third layer	Vegetation cover second/third layer	Vegetation height second/third layer	

Table 2. Set of classifiers and their hierarchical arrangement corresponding to the dichotomous class Natural and Semi-Natural Terrestrial Vegetation.

semi-natural terrestrial vegetation" is in Table 2. These *classifiers* are arranged in a fixed hierarchical structure, which has to be followed during classification procedure. Each set of *classifiers* also includes two types of additional, optional classification attributes, the *environmental attributes* and the *specific technical attributes*, which are used when further, more detailed description of characteristics of land cover classes is required.

The advantages of the Land Cover Classification System are manifold. It is a highly flexible system in which each land cover class is mutually exclusive and clearly defined, thus providing internal consistency. These characteristics are independent of the classification level. The classification can be stopped at any desired level and will result in clearly defined land cover class corresponding to that level. Any land cover type can be readily accommodated. The system is truly hierarchical and applicable at a variety of mapping scales and in any geographic location. It can be used as a reference standard system because it is based on diagnostic criteria that allow correlation with existing classifications and legends. The LCCS, which represents a paradigm shift in land cover classification, thus contributes towards harmonization and standardization of land cover classification and mapping. (Di Gregorio and Jansen, 2000; Di Gregorio, 2005).

International Standardization of the LCCS.

Through a cooperative agreement with the International Organization for Standardization Technical Committee 211 on Geographic Information, the UNFAO is developing a joint UN-FAO/ISO standard on classification systems in general and the LCCS in particular. The standardization effort is in four parts. The first is a general standard that addresses all classification systems. This general standard can be used for land cover classification or to address completely different fields (e.g. oceanography). The second standard is a description of the LCCS system of defining classifiers (classification rules). The third part is a register of classifiers and the fourth part deals with classification legends developed to address land cover in particular regions. For example, the CORINE classification legend developed for European countries, can be expressed in terms of the LCCS classifiers and thus becomes compatible with LCCS legends developed for other regions. Such compatibility, based on LCCS as the underlying structure, enables merging of land cover classes and generation of statistics over broad areas from land cover data generated by different mapping methodologies.

Development of UN-FAO classification standards is based on standardized Universal Modelling Language (UML) and compatibility with other ISO geographic standards to ensure that there is broad commonality with the entire geographic information community. . This approach assists industry in providing tools that support the LCCS classification, dissemination of land cover information and its inclusion in spatial data infrastructure. (ISO 19135:2005; ISO WD 19144-1; ISO WD 19144-2.)

CONCLUSION

The socio-economic, climatic and environmental challenges facing mankind at the dawn of the twenty-first century have been addressed by the United Nations Millennium Development Goals. Their aim is to increase food security, improve health and reduce poverty in developing countries. FAO estimates that the food security risks periodically threaten over 50% of developing countries. In spite of technological advances and improvements in food and feed production systems, there is a finite supply of land suitable for agricultural production. Yet, the population of developing countries is steadily increasing. The latest population growth projection by the United Nations estimates another 40% increase during the next 50 years. That would represent an increase by about 2.5 billion people, which equals the world's total population in 1950. In addition, the competition for land among different sectors is increasing and all too often, the best agricultural land is converted into different uses.

The degree to which the United Nations Millennium Development Goals are attained will determine mankind's future. Industrialized countries have developed their economies without paying much regard to preservation of natural resources and environmental protection. However, such a development model cannot be applied any longer because of the growing scarcity of natural resources and continuing environmental degradation in developing countries. Thus, the intensification of agricultural production has to be based on sustainable development and management of land and fresh-water resources to produce enough food for growing population.

Reliable information on current land cover, its past changes and future trends has become an essential prerequisite to sustainable development and management of land and water resources and environmental protection. However, it has to be understood that the land cover information by itself, although essential, is not a sufficient input to the above tasks. It has to be integrated with other relevant geo-information layers reflecting the environmental, economic, social and political factors affecting rural land management and environmental protection. These additional geo-information layers may include information on topography, soils, fresh-water resources, climate, land use, cost/benefits associated with land use types and agricultural production systems, land tenure, population density (including age distribution, health and rural poverty statistics), and agricultural policy (including forestry and fresh-water resources).

In most countries, the above inputs, except of information on current land cover and its dynamics, are usually available. They are collected and managed by government organizations with mandates for respective disciplines. Some of these inputs may also be available from non-governmental organizations. However, there are no organizations with the explicit mandate for systematic, country-wide mapping of land cover and monitoring its changes in developing countries. Ad hoc land cover mapping and monitoring activities are typically undertaken by a number of organizations, such as remote sensing centers, mapping organizations, agricultural and forestry institutes, with no harmonization of methodologies and little cooperation among them.

In the past, such sectoral *modus operandi* for implementation of land cover mapping projects served its purpose and provided required information to respective organizations. However, with the rapid advancement of geo-information technologies, in particular remote sensing and GIS, such an approach is not any longer effective and efficient. Rational land use planning requires a holistic approach, based on integration of land cover information with geospatial and socio-economic data, for their joint analysis and modeling. Furthermore, the United Nations Millennium Development Goals and international environmental conventions, have set new standards for the type, availability and quality of geospatial information required for their implementation. FAO and UNEP, with the support by the Italian Government, responded to this challenge through the establishment of GLCN-TC at the Istituto Agronomico per l'Oltremare in Florence, Italy. (FAO & UNEP, 2002). I should like to use this opportunity to invite your cooperation with its activities.

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ADDENDUM.

Participants of the North American Land Cover Summit (Washington, D.C., 20-22 September 2006) agreed that the GLCN-Land Cover Classification System (LCCS) should be considered as the classification standard for the future North American land cover mapping products.

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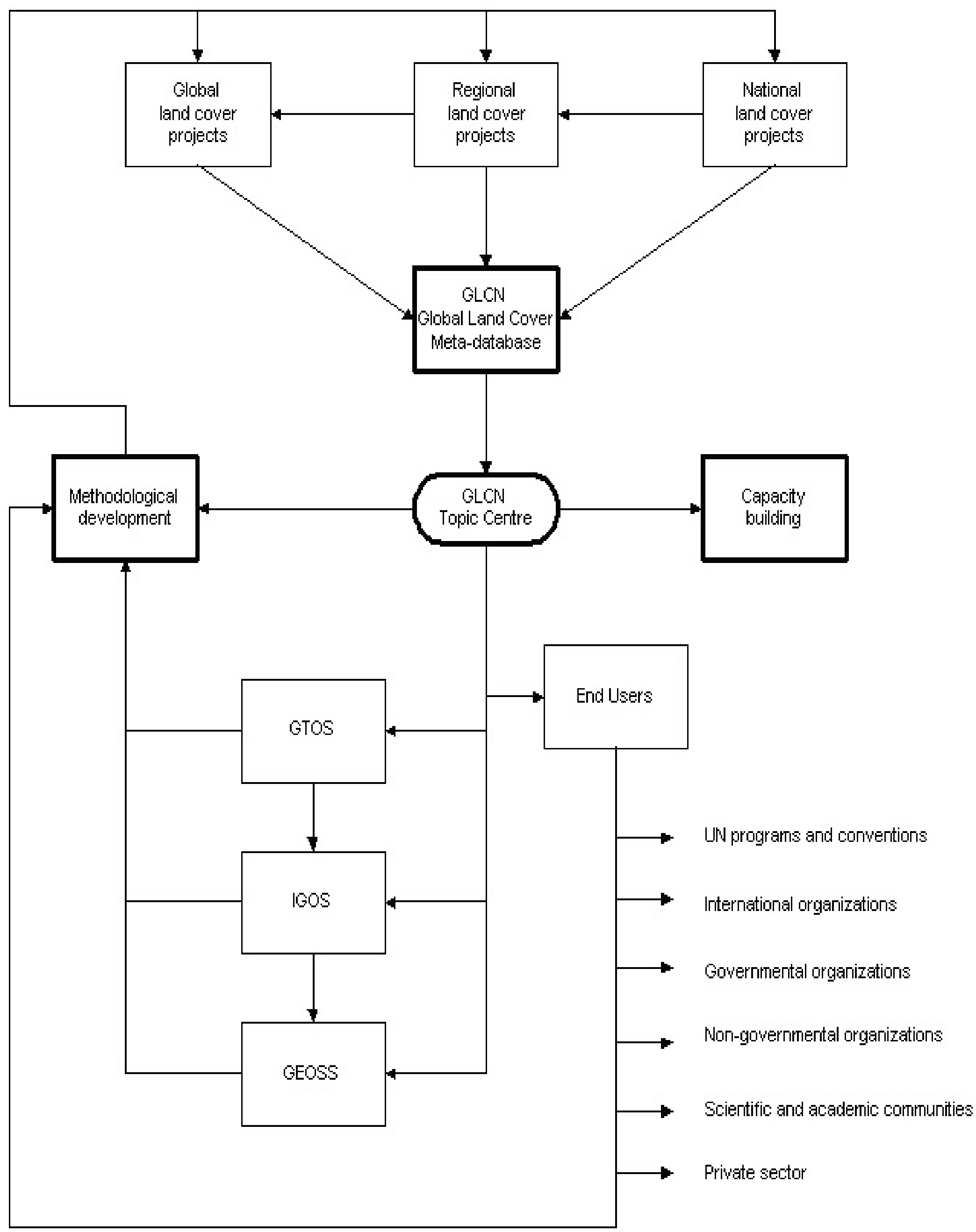

Figure 1. Configuration of GLCN-TC linkages and feedbacks

CHAPTER 7

APPLICATIONS OF NATIONAL LAND COVER MAPS IN UNITED STATES FORESTRY

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ABSTRACT

Land cover maps derived from satellite imagery have a long and varied history of uses in United States forestry science and management. This article reviews recent developments concerning the use of national- to continental-scale land cover maps for inventory, monitoring, and resource assessment in the U.S. Forest Service. The use of mid-scale digital resolution information (from 10 to 30 meters) is ideal for many forest applications from stand exams to watershed assessments of numerous forest related attributes. Forest and landscape patterns can be meaningfully assessed at those spatial scales as well, and consistent national land cover maps are required for conducting consistent national assessments of forest patterns. National and continental strategies for land cover mapping should recognize that almost all forest inventory, monitoring, and assessment applications require map comparisons over time, and an ideal temporal frequency for most applications is no more than five years.

Key words: *forest, inventory, monitoring, pattern*

INTRODUCTION

Land cover maps derived from satellite imagery have a long and varied history of uses in United States forestry science and management. Here we review some recent developments and applications in landscape pattern assessment, and forest inventory and monitoring. While land cover maps of various heritage and scale are used from local to regional to national scales, we focus on national applications because that scale is most relevant to the conference discussion of continental-scale issues and opportunities.

LAND COVER PATTERN

Land cover pattern refers broadly to the spatial arrangement of different types of land cover. While some spatial relationships may be visually apparent, human perception of land cover pattern is subjective. Pattern analysis is needed not only to quantify those perceptions unambiguously, but also to discover patterns that are not apparent to the human eye. This section discusses why land cover pattern is important and highlights some recent applications of national land cover maps.

People care about land cover pattern for a variety of reasons. Society is informed in the popular press about land cover patterns through headline issues such as urban sprawl and forest fragmentation. Spatial ecologists care about pattern because the spatial arrangement of the environment affects the flows of matter, energy, and information across the landscape, thus impacting ecological processes. Resource managers consider land cover pattern because it affects the production of ecological goods and services; the same amount of a land cover can be arranged in different ways with consequences for biodiversity, water quality, recreation experience, and other amenities. Land use planners describe landscape context partly in terms of the land cover patterns that contribute to a “sense of place” for human occupation. Assessment scientists consider land cover pattern as a leading indicator in risk assessment; when landscape patterns change, the ecological and social processes embedded within landscapes change, putting goods and services at risk. In summary, there is a widespread appreciation that land cover pattern is an important environmental attribute.

Consistent national-scale assessments of land cover patterns require consistent land cover maps as input data, and these have become available only recently with the advent of satellite-based imaging systems. An early application of global maps for assessing patterns (Riitters et al. 2000a) utilized the relatively coarse-scale Global Land Cover Characteristics (GLCC) database derived from the advanced very high resolution radiometer (AVHRR) platform (Loveland et al. 2000) and later applications (Heilman et al. 2002; Riitters et al. 2002) have taken advantage of higher-resolution maps produced by the Multi-Resolution Land Characteristics Consortium (MRLC) and National Land Cover Dataset

(NLCD) programs from Thematic Mapper (TM) imagery (Vogelmann et al. 2001; Homer et al. 2004). The underlying TM imagery has also fueled more detailed sub-national land cover mapping efforts, for example by the GAP Analysis Program (GAP; Scott et al. 1996) and those efforts, in turn, can potentially be used to improve the interpretation of national-scale analyses (Riitters et al. 2003).

Extensive analyses of spatial patterns on the 1990s MRLC/NLCD national land cover map were prompted to report forest fragmentation statistics in national assessments including the 2000 RPA Assessment and Interim Update (USDA Forest Service 2001, 2007), the 2002 State of the Nation's Ecosystems (Heinz Center 2002), and the 2003 National Report on Sustainable Forests (USDA Forest Service 2004). The supporting studies concluded that while forest was typically well-connected and the dominant land cover where it occurred, fragmentation, perforation, and roads were so pervasive that most forest land was at risk from potential 'edge effects' extending only a hundred meters from forest edge (Heilman et al. 2002; Riitters et al. 2002, 2004a, 2004b).

Figure 1 illustrates how a relatively simple 'pattern primitive' (a fundamental aspect of pattern) can be interpreted with respect to forest fragmentation at national scale. The pattern primitive is defined as the percentage of forest in a fixed-area neighborhood surrounding a pixel of forest on the land cover map. The measurement of the primitive was repeated for each forest pixel and for different neighborhood sizes surrounding each forest pixel. The results were summarized according to the percentage of all forest pixels that were surrounded by neighborhoods containing 100% forest (solid line in Figure 1) and >60% forest (dashed line). Note that if forests were not fragmented, then the solid and dashed lines would be superimposed horizontally at the 100% level in Figure 1. Fragmentation is represented by the departure from that condition, and the Figure shows that as expected, apparent fragmentation is both scale- and threshold-dependent. From the circled point on the dashed line, we can infer that forest is dominant where it occurs – 70% of all forest occurs in landscapes that are >60% forested within 50 km^2. From the circled point on the solid line, we can infer that fragmentation is pervasive – 50% of all forest is within 90 meters of forest edge (to see this, note there is a correspondence between the largest window that contains 100% forest and the minimum distance to forest edge).

A classical analysis of land cover pattern starts with the definition of analysis units such as counties

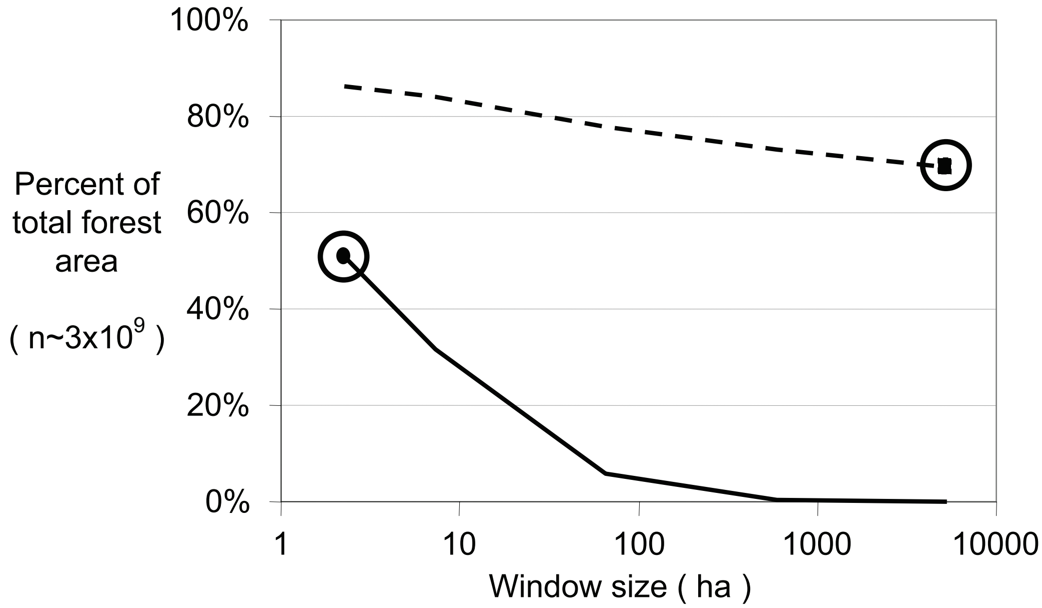

Figure 1. An example of interpreting the pattern primitive of percentage forest in moving windows of different sizes. See text for explanation. The sample size is approximately 3 x 10^9 pixels per plotted point.

or ecoregions, and patterns are then measured within each of those units. In that approach, a different analysis must be carried out for each different way of defining analysis units, for example as watersheds or as counties. In contrast, our applications have mapped pattern primitives at the pixel level, which preserves options for aggregating results to different analysis units such as watersheds or counties without having to repeat the analysis of pattern. In addition, it facilitates overlay with other maps to address more detailed questions. For example, the map of the pattern primitive described above can be aggregated over sub-national geographic extents to evaluate local forest spatial patterns (Riitters 2005), combined with forest type maps to evaluate the fragmentation context of different forest types (Riitters et al. 2003), or combined with road maps to evaluate the fragmenting effects of roads on forests (Riitters et al. 2004b). The use of pixel-level pattern primitives alleviates some of the problems associated with classical patch-based approaches to spatial pattern measurement on land cover maps (Riitters et al. 2004a, b).

Several pixel-level pattern primitives can be combined to better define land cover patterns and to address more complicated assessment questions. For example, if a second pattern primitive is defined as forest connectivity (roughly, the probability that a pixel next to a forest pixel is also forest), and evaluated in the same neighborhoods, the two primitives together differentiate among types of fragmentation (Riitters et al. 2000a) which exhibit substantial geographic variance and clustering (Riitters and Coulston 2005). Similarly-defined pattern primitives for other land cover types can be used to highlight the proximate causes (e.g., agriculture, urbanization) of forest fragmentation (Wade et al. 2003).

Riitters et al. (2000b) suggested that a database of land cover pattern primitives could facilitate integration of pattern information among ecological research and assessment projects. While common usage of a pattern database cannot guarantee integration among studies, the alternative of having each study conduct a separate pattern analysis is unlikely to achieve any meaningful integration because analyses rarely use identical protocols. The "National Land Cover Pattern Database" has been distributed on the internet since 2002 as a test of the concept.

One question posed by conference organizers was whether there are opportunities to leverage resources and avoid duplication. Experience shows that pattern analyses on land cover maps from remote sensing are usually duplicative and divergent – duplicative in the sense that analyses are repeated by different groups addressing a similar question, and divergent in the sense that such analyses are rarely similar enough to be strictly comparable across groups. Thus, there is an opportunity to leverage resources and avoid duplication by integrating some level of pattern analysis within the land cover database (Figure 2). Maps of land cover pattern primitives could be distributed with the land cover maps, obviating the need for duplicating some basic analyses and reducing divergence in some of the more advanced types of analyses.

INVENTORY AND MONITORING

There has always been a strong demand for timely, consistent, and reliable forest inventory and monitoring information of the type provided by the USDA Forest Service Forest Inventory and Analysis (FIA) and Forest Health Monitoring (FHM) programs. Recently the demand has been growing. Customers want more recent information, covering a broader scope of forest attributes, with more analysis and reporting and easier access to program databases. Many of these demands

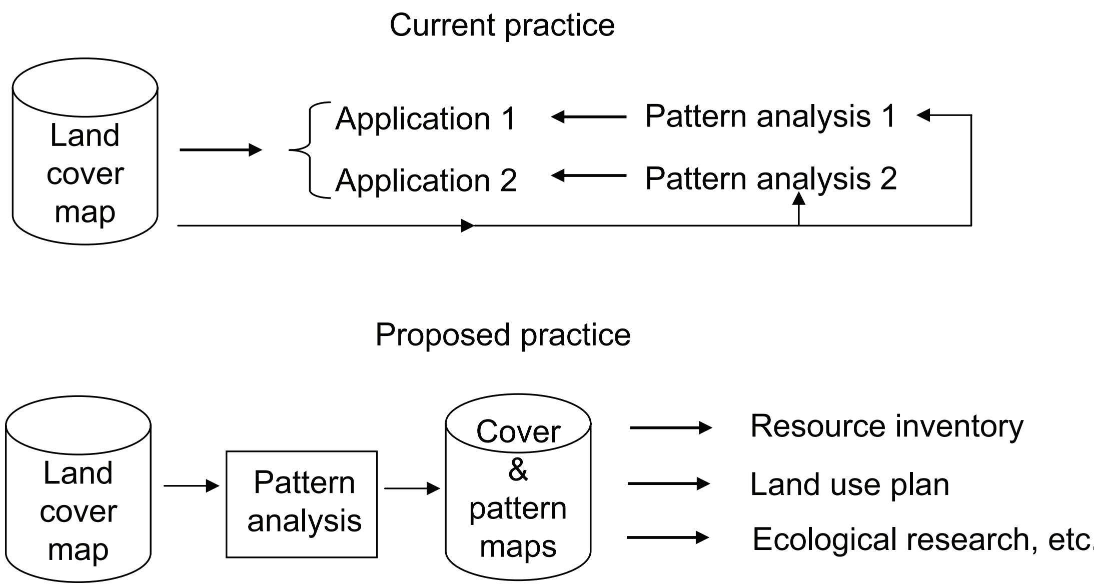

Figure 2. To avoid duplication or divergence of land cover pattern analysis (top: current practice), maps of land cover pattern could be integrated with the land cover map (bottom: proposed practice).

were expressed in the Agriculture Research, Extension, and Education Reform Act of 1998 (16 USC 1642(e)).

Collectively, the forest monitoring component of FIA provides a nationwide systematic sample of a wide array of measurements on forested ecosystems, which are used by a diverse set of customers for many purposes. For example, FIA data have been used to map habitat for endangered animal species, to identify areas of forest decline, and to track the effect of global change reflected in changing species distributions. In addition to producing a variety of reports and analyses at the state and regional level, information from the FIA forest monitoring program are publicly available through our online database (http://fia.fs.fed.us).

In response to needs for increased spatial and temporal resolution of forests, the USDA Forest Service has significantly enhanced the FIA program by changing from a periodic survey to an annual survey, by increasing the capacity to analyze and publish data, and by merging the FIA and FHM plots into a single three-tiered (or three-phase) FIA system. Phase 1 is the remote sensing activity used to characterize the spatial arrangement and ultimately the area of forest and non-forest land in the US. Phase 2 is the traditional FIA ground plots that focus on forest and tree information as it relates to timber and non-timber attributes. There is a Phase 2 field sample site for every 6,000 acres of forest, where field crews collect data on forest type, site attributes, tree species, tree size, and overall tree condition. FIA currently samples approximately 200 tree- and forest-related attributes at each Phase 2 sample point. Phase 3 consists of a subset of Phase 2 sample plots which are measured for a broader suite of forest health attributes including tree crown conditions, lichen community composition, understory vegetation, woody debris on the forest floor, and soil attributes including a laboratory chemical analysis. Finally, an associated sample scheme exists to detect cases of ozone damage.

In 1999, FIA integrated forest health monitoring (FHM) indicators into the Phase 3 (P3) subsample of the P2 plots. There are approximately 8,000 forested P3 sample plots in the United States where detailed health data are collected, roughly one for every 96,000 acres of forest. P3 plots are co-located with P2 (Phase 2) plots at approximately every 16th P2 plot. The spatial pattern of the FIA sampling hexagons is illustrated in Figure 3 (Brand et al. 2000).

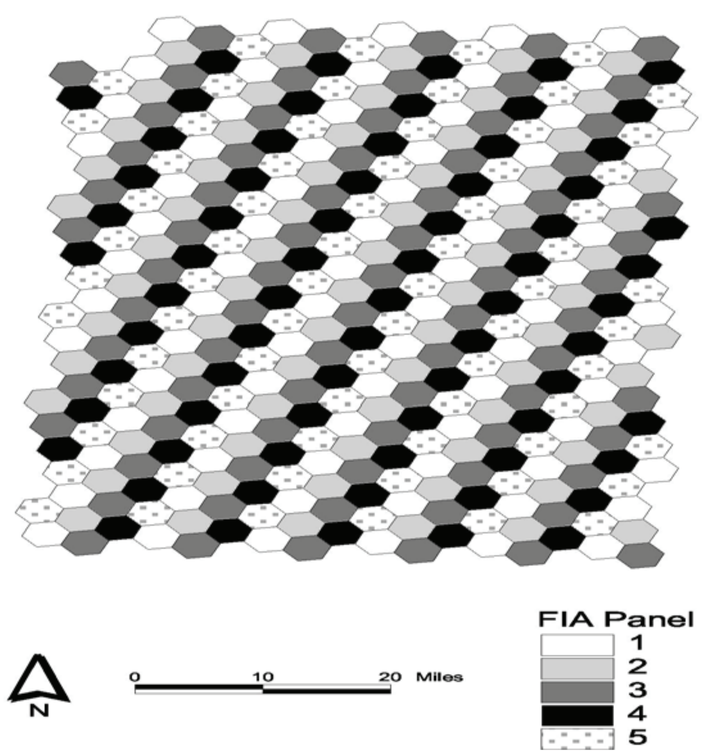

Figure 3. The assignment of FIA sampling hexagons to one of five annual panels.

Of special interest to this conference is that in 1999, FIA entered into a partnership with USGS and the EROS Data Center to provide the FIA ground plots as *in situ* ground samples for cover type model development, verification and accuracy assessment for NLCD 2001. The 1992 NLCD is a successful example of a national-scale digital land-cover database and map and is of value to FIA as an initial stratification layer of forest cover. The statistical efficiency gains from NLCD are profound. For example, using NLCD 1992 as an initial stratification of forest cover and subsequently using FIA databases on land use, FIA is able to show increases in relative efficiency of between 2 and 4 for the estimates of state forest inventories (Hansen 2001). This means that without the NLCD land cover information, that FIA would need to double or quadruple the number of FIA ground plots to meet the same precision standards.

The use of mid-scale digital resolution information of between 10 to 30 meters is ideal for many forest applications from stand exams to watershed assessments of numerous forest related attributes. For example, 30 meter resolution digital information like NLCD has been ideal for assessing the effects of urban sprawl, fire risk at the urban interface, watersheds and private forest lands at risk due to urbanization, pests such as southern pine beetle and emerald ash borer, habitat characterization for at-risk species, and the combined effects of all of these risks on timber and biomass supply. To assess the increasing fragmented landscape there is a need for frequently updated mid-scale resolution digital maps. Given the eventual research and development applications, it is not a stretch to say, that land cover map products are made most useful by integration of *in situ* sample data to increase both attribute and temporal resolution.

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CHAPTER 8

Approaches to IPCC Land-Use and Land-Use Change Reporting in Agriculture Areas with Remote Sensing

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ABSTRACT

Information on the spatial distribution of land use conversion to agriculture is required for UNFCCC and Kyoto reporting and for many other environmental studies. Such information is required over large geographical regions and multiple years. Remote sensing data and techniques combined with other data sources, such as census information can be used to provide spatially explicit information on crop type and extent. In this review, image classification techniques for extracting information from satellite data to support reporting for agriculture are discussed and evaluated. Three classification approaches are compared using LANDSAT images from south-eastern Ontario. Results do not strongly support a significant advantage of any one approach, but highlight the need for several dates of imagery over the growing season to effectively map crop type. Determining the area extent of agriculture is more straightforward and does not require multi-date imagery. However, it does need imagery from a specific temporal window where agricultural fields can be most effectively discriminated.

INTRODUCTION

Probabilistic forecasts of future climate outcomes based on historical observations and results of quantitative models suggest changes in climate processes due to human effects on the earth system's energy balance. It is predicted that changes will affect all major components: atmosphere, hydrosphere, cryosphere, lithoshpere, biosphere, and the interactions between them. Characterization of dynamic surface processes, resulting from a certain land surface composition is a source of information that improves our understanding of the causes of observed variability and change. Changes in land cover affect exchanges of energy and water, and the exchange of greenhouse gases between the biosphere, lithosphere, and atmosphere. Land cover changes contribute to climate change and variability, and when combined, may have profound effects on the Earth's habitability (U.S. Climate Change Science Program (CCSP), 2005).

Agriculture is one of the primary drivers of human-induced degradation of natural vegetation. Effects are twofold; 1) a reduction in potential carbon sinks through conversion of forested land into agriculture land, and 2) increases of greenhouse gas (GHGs - carbon dioxide, nitrous oxide, and methane) emissions due to cropping, improving pastures, and the application of fertilizers and animal wastes.

National reports to the United Nations Framework Convention on Climate Change (UNFCCC) are expected to contain data on carbon stocks, emissions, and removals of GHGs associated with land-use and land-use change. The UNFCCC and Kyoto protocol have initiated research on the carbon cycle, land-use, land-use change, and biological/ecological processes. The focus of this research is aimed at improving capacities for national carbon accounting for developing carbon sequestration strategies and alternative response options. Land cover information plays a major role in carbon balance modeling studies, which at a basic level includes the type and extent of vegetation (Houghton and Goodale, 2004). Knowledge of vegetation spatial distribution is also required for investigating and quantifying and scaling the local to regional ecosystem-atmosphere CO_2 fluxes. It has been recognized that remote sensing can contribute by providing systematic observations and temporal data archives that may reduce uncertainties in reporting on terrestrial carbon budgets. Thus, remote sensing combined with national and international in-situ measurement networks for monitoring aboveground biomass and land cover change can support the following five Kyoto requirements:

- Provision of systematic observations of land cover;
- Support the establishment of a 1990 carbon stock baseline;
- Detection and spatial quantification of land cover / land use change;
- Quantification of aboveground vegetation biomass stocks and associated changes;
- Mapping and monitoring sources of anthropogenic CH_4.

The Intergovernmental Panel on Climate Change (IPCC) has developed good practice guidelines for land-use, land-use change and forestry (LULUCF) estimates. The guidelines support the development of inventories that are transparent, documented, consistent, complete, comparable, assessed for uncertainties, and subject to quality control. The guidelines aim for efficient use of resources available to inventory agencies, and in which uncertainties can be reduced as better information becomes available (IPCC, 2003).

The IPCC guidelines contain little, if any, discussion on how to estimate land areas and changes in land area associated with LULUCF activities. In practice, countries use a variety of sources including agricultural census surveys, forest inventories, and remote sensing data, but methods and definitions used by different authorities in assembling the data are not always consistent (IPCC, 2003).

IPCC LULUCF provides suggestions for three approaches for representing areas of six broad land categories (forest land, cropland, grassland, wetland, settlement and other land) used for estimating and reporting greenhouse gas inventories. General characteristics of each approach are:

- *Basic land-use database* - This approach relies on existing national data including forest inventories, agriculture statistics, and census surveys. It does not require geographically explicit land area specification. The area of land use change is estimated at two points in time without determining inter-category relations. This approach does not necessitate explicit use of remote sensing data, but such data prepared for other purposes can be used.
- *Survey of land use and land-use change* – This approach includes more information on change between land categories. It specifies land-use transitions for the reporting period by providing information on the nature of change. The report generated from this approach can be presented as a non-spatially explicit land-use change matrix.
- *Geographically explicit land use* – This is the most comprehensive approach requiring spatially explicit land-use and land-use change data. Spatial units such as grid or vector coverages are used to represent reporting areas. The location of spatial units should be unchanged during the reporting time. Remote sensing combined with ground survey sampling is a suitable way for providing data for this approach. IPCC-LULUCF suggests that countries with more difficult access to some regions, but

with access to good remote sensing data should adopt this approach and develop an accounting system with an emphasis on remote sensing observations and techniques.

The use of remote sensing for collecting land-use information is identified in the IPCC guidelines. However, details on actual information extraction procedures and fusion of remote sensing data with other available sources of information are not explicitly outlined. Therefore, the purpose of this paper is to evaluate some capabilities of remote sensing for obtaining information about land area required for estimating carbon stocks, removals, and greenhouse gas emissions associated with agricultural land use. A short overview of remote sensing data, classification approaches and methodological issues specific to mapping land-use in agricultural areas are presented and illustrated in two case studies.

REMOTE SENSING DATA

Commonly used sensors for land cover mapping include: at medium spatial resolution MERIS (300 m and 1200 m), MODIS (250 m, 500 m, and 1000 m), SPOT/VEGETATION (1000 m) and NOAA/AVHRR (1000 m); at fine spatial resolution LANDSAT (30 m and 15 m), ASTER (15m) and SPOT (5 m, 10 m, and 20 m); and at very fine spatial resolution OrbView, Quick Bird and IKONOS (1 m to 5 m).

Finer resolution multi-spectral systems that include mid-infrared bands, such as LANDSAT TM, ETM+ and SPOT HRVIR, are well suited for land cover mapping. Their spatial resolution (10-30 m) allows delineation of fragmented agriculture and forestland as well as separation of smaller natural and anthropogenic disturbances such as forest fire, logging, and urban and industrial developments. Examples where complete LANDSAT data coverage of the country has been used as a primary source for deriving land cover information include: US National Land Cover Database produced by USGS, the Australian National Carbon Accounting System NCAS (Furby, 2002) and the New Zealand Land Cover Database (NZLCDB, 2005). In Canada, the National Carbon and Greenhouse Gas (GHG) Emission Accounting and Verification System (NCGAVS) for agricultural land and the National Forest Carbon Accounting System (NFCAS) are in development and both rely on LANDSAT coverage generated by the National Canadian Consortium led by the Centre for Topographic Information-Sherbrooke

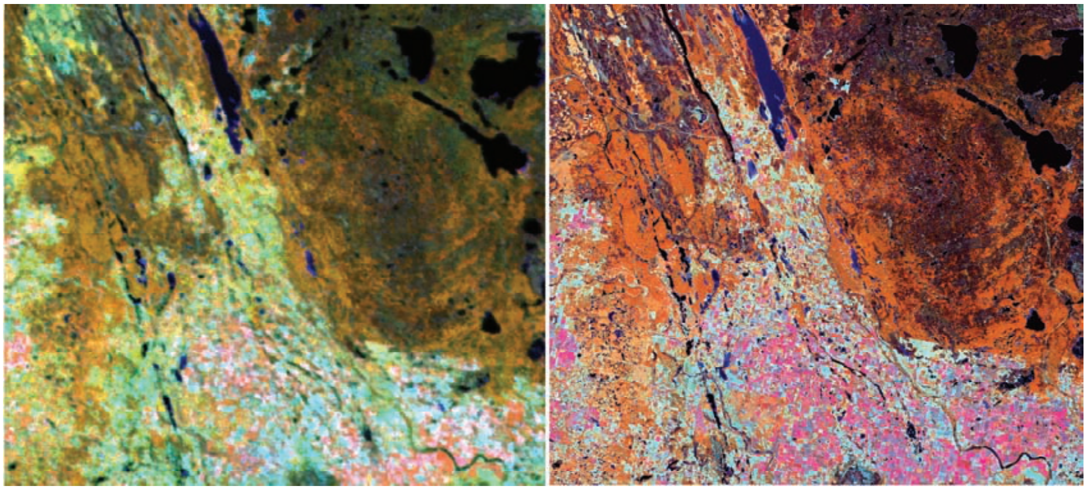

Figure 1. Example 250 m resolution MODIS image (left) and LANDSAT image (right) displayed as red = near-infrared, green = short-wave infrared, and blue = red.

(CTI-S).

Low and medium resolution sensors, allow cost effective monitoring of vegetation dynamics and land cover at a coarse scale (i.e. national coverage). Its role will likely be for monitoring and identifying areas of change where finer resolution data would have to be collected and processed for reporting (Fraser et al., 2005).

LAND COVER CLASSIFICATION

Digital classification of multispectral images is commonly used to obtain information on land cover. Despite long and extensive development the ultimate goal of a completely automated classification method has not yet been achieved due to the following constraints:

- Signal to noise ratio in satellite measurements can be high, as calibration, sensor response, geometric resampling, and geolocation are not perfect procedures;
- Difficulty in accurately characterizing atmospheric conditions during image acquisition hinders successful correction. Thus, apparent reflectance at the surface for the same target varies due to scattering from sub-pixel clouds, aerosol, haze and other atmospheric constituents;

- Viewing geometry and shadowing effects introduce significant variability in the satellite measurements that are difficult to precisely correct;
- Surface reflectance is influenced by soil moisture and vegetation water content, leading to considerable variability in surface spectral properties;
- Measurements are acquired over different vegetation conditions and phenological stages. Thus, spectral properties are time and space dependent, limiting spectral generalization\extension of known surface types.

To cope with this variability, supervised and unsupervised classification methods have evolved and remain as fundamental approaches. In general they fall into one of two groups: parametric and nonparametric classification algorithms. In the past, the most widely used supervised classifiers have been the parallelepiped, minimum distance and maximum likelihood. Recently, more sophisticated algorithms have emerged based on artificial neural networks (Benediktsson et al., 1990, Carpenter and Grossberg, 1988; Kohonen, 1989), decision trees, mixture modeling, and various combinations of neural-statistical approaches (Bruzzone et al., 1999; Benediktsson and Kanellopoulos, 1999; Wan and Fraser, 1999).

In unsupervised classification, no prior information about land cover types and their distribution is required in the clustering phase. A number of algorithms have been developed, as with supervised classification they can be either parametric or non-parametric, where the latter involve fuzzy and artificial neural network theory. The most widely used parametric methods include the Iterative Self Organized Data Analysis Technique referred to as ISODATA (Tou and Gonzales, 1977; Sabines, 1987; Jain, 1989) and K-means (Tou and Gonzales, 1977).

Conventional image classification techniques assume that all pixels within an image are pure, containing only one land cover type within the footprint of the pixel and assign the pixel to a single cluster know as “hard” classification. The alternative is “soft” classification, which assigns a membership or “agreement” value to each cluster. There are two paradigms in soft classification approaches: 1) fuzzy classification which defines membership based on spectral similarity; and 2) fractional, which is based on the mixed pixel effect and attempts to determine the fraction of each cover type within the pixel.

The following are a few examples of soft classification approaches:

- Fuzzy membership functions to estimate sub-pixel forest cover (Foody, 1994);
- Isolines in red and near infrared scatter plot to estimate sub-pixel fractional canopy density, using a geometric model of plant cover to infer the density associated with the isoline (Jensen, 1996);
- Empirical relationships between percent cover derived from high-resolution data and attributes of medium resolution data to extrapolate proportional forest cover over large areas (DeFries et al., 1997; Iverson et al., 1989, 1994; Zhu & Evans, 1994, Fernandes et al., 2001);
- Calibration of area estimates from spatial aggregation of land cover classifications derived from medium and fine resolution data (Mayaux and Lambian, 1997);
- Linear mixture modelling to deconvolve proportional land cover based on reflectance of end-members or pixels containing 100% of the vegetation types of interest (Adams et al., 1995);
- Relating the land cover composition of mixed pixels to artificial neural network classification output (Foody, 1996).

Object oriented classification is another recent approach that attempts to incorporate spectral, spatial, and contextual information into the classification decision. Objects are defined based on a segmentation procedure such as region growing or edge detection and edge following. The properties of these objects such as object spectral means, shape characteristics, within object spectral variance, object class membership at different scales, and object neighbour relations are used to improve classification (Baatz et al., 2003).

4. Case Studies

In two case studies remote sensing techniques for a) mapping land cover with predominantly agriculture land-use, b) mapping land-use change, and c) mapping crop type area distribution are presented. Examples of a) and b) are presented for the Chateauguay River region, while c), mapping crop type area distribution, is demonstrated for the Casselman Township area.

The study areas are located in the St. Lawrence Lowlands in an agriculture belt south of Ottawa and Montreal (Fig.2). In both areas, corn and soybeans are the two dominant crop types. Other crops include alfalfa and several varieties of cereal crops. Natural vegetation includes coniferous and mixed deciduous forest, wetland, and low ground cover vegetation such as grass.

Data

Image Data

Two LANDSAT scenes over Chateauguay River region were selected from the period after snow-melt and before crop emergence (May 1990 and June 2001). The images were selected from the beginning of the growing season where discrimination between agriculture land and natural vegetation was the highest.

The importance of selecting imagery from the appropriate time period is apparent from Figure (3). Two images acquired in July (3a) and November (3b) of the same area illustrate the difference in discriminating agriculture land from natural vegetation. The agriculture land mask given in (3c) has been generated from the November image shown in 3b. Confusion between natural vegetation and cropland in the July image (3a) was too high to permit generation of an accurate mask.

In case of the Casselman Township study, a multi year dataset was required to determine cropping pattern. Three LANDSAT and a SPOT image were selected from the July-August period. Two LANDSAT images for 2002 and 2003 were acquired in mid July. The only available clear sky image in 2000 was acquired in mid August with LANDSAT and in 2004 with SPOT 4 (Table 1). A November LANDSAT image was also acquired to aid in the separation of forest from non-forest.

Figure 2. Geographic location of the study area.

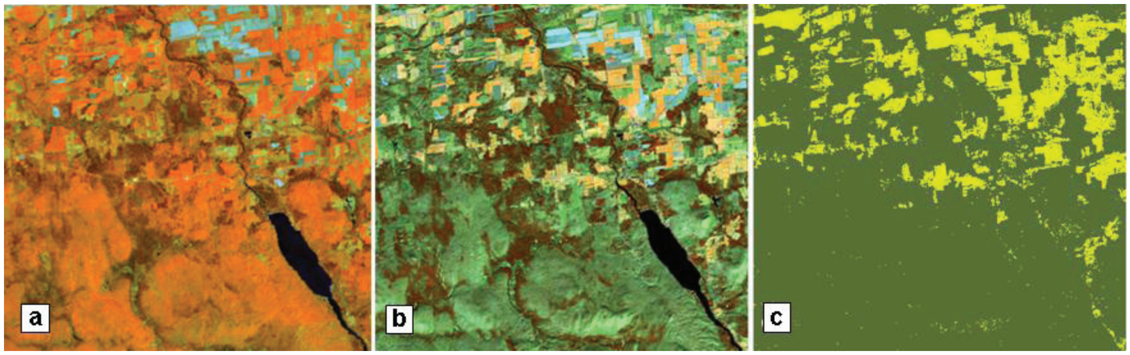

Figure 3. Example LANDSAT image used for mapping the agriculture area in the Chateauguay region. a) Image acquired in July; b) image acquired in November c) agriculture land mask developed from b.

Field Data

Ground truth data were collected on August 18, 2004 for the Chateauguay River region. Samples were acquired for natural vegetation including forest, wetland, shrub land, grassland, and some agricultural areas. The objective of the fieldwork was to collect data to produce a regional land cover map required for other land cover related studies. In addition to fieldwork, air photos of the whole region were assembled and used for assessing accuracy of agriculture areas while ground truth data were used mainly for assessing accuracy in mapping natural vegetation. Fig. 4 shows the location of the field samples collected in the Chateauguay region.

Field data for the Casselman region was acquired on August 21, 2004 and overlaid on the 2004 SPOT image to determine crop type spectral properties. These properties were then used to select training and validation samples for each classification through visual interpretation in combination with air photos. Only agriculture classes were included in the sampling, as these were the classes of interest. Fig. 5 shows sample locations of field data collected for Casselman.

Area	Sensor	Date
Chateauguay	ETM+	08/06/2001
Chateauguay	TM	29/05/1990
Casselman	ETM+	05/11/2000
Casselman	ETM+	15/08/2000
Casselman	ETM+	20/07/2002
Casselman	TM 5	15/07/2003
Casselman	SPOT 4	18/08/2004

Table 1. Image data used in case studies

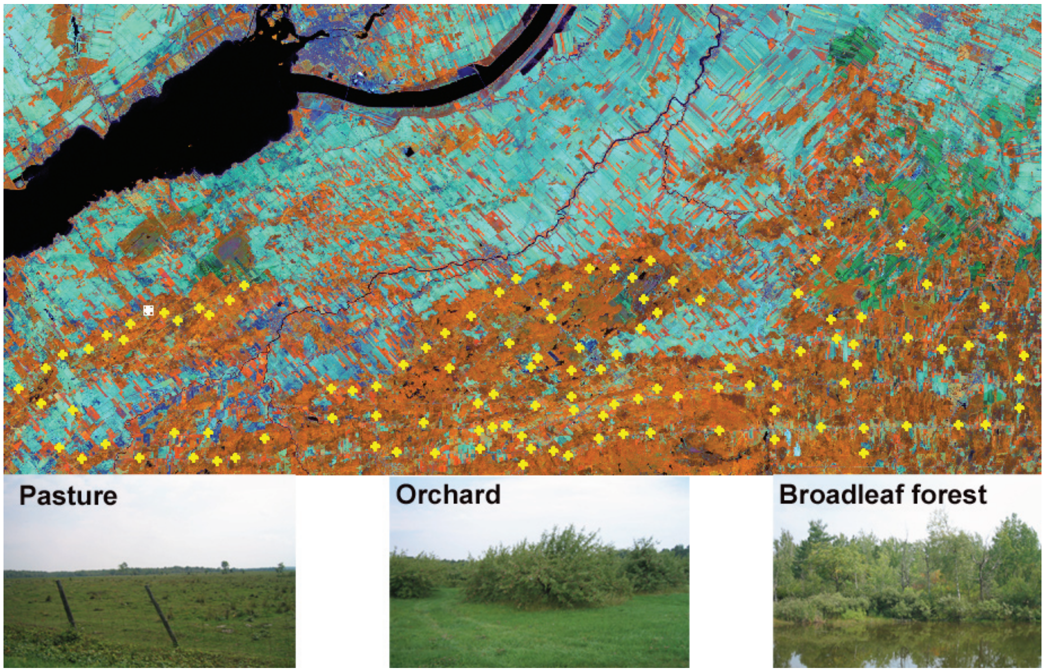

Figure 4. Chateauguay region sampling points depict location where ground truth was acquired. Sample mainly includes natural vegetation forest, wetland, shrub land, grassland and orchards.

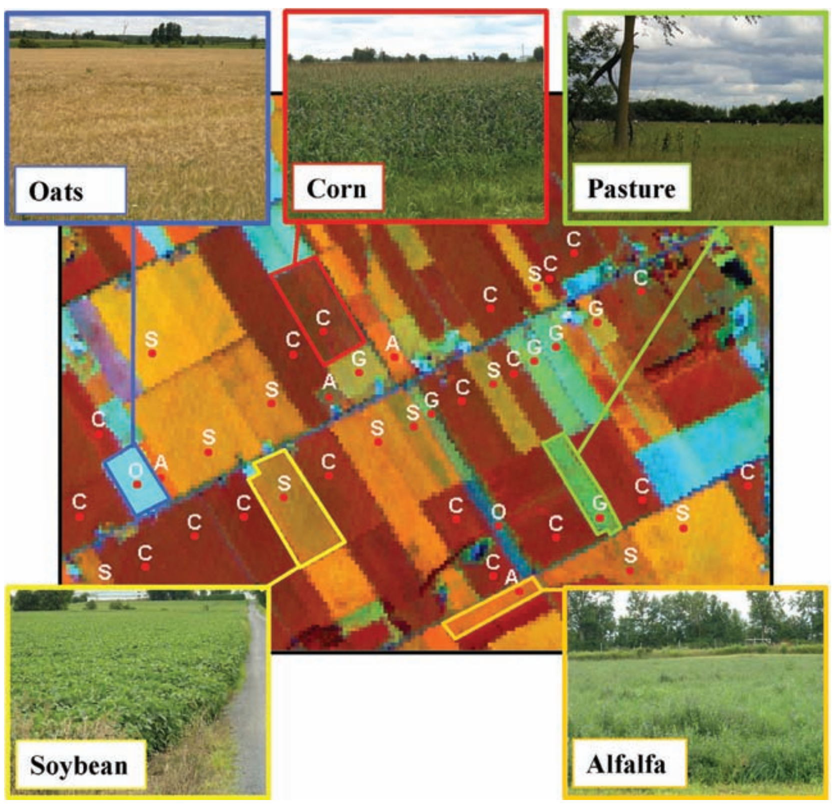

Figure 5. Casselman region sampling. Letters correspond to crop type: C = corn, S = soybean, A = alfalfa, G = grass\low-lying vegetation, O = oats. The oat field in the lower left of the image has the same spectral characteristics as other barren fields in the image. Image is displayed as: red = near infrared, green = shortwave infrared, blue = red.

Image Pre-Processing

An integral part of generating land cover information from satellite imagery is image data pre-processing. The purpose of pre-processing is to geolocate imagery and reduce sensor and scene noise. In both studies image geometric rectification was performed using ground control points (GCPs) acquired from the National Ground Control Database, GeoGratis (http://geogratis.cgdi.gc.ca/clf/en). Additional GCPs were collected along digital baseline features from the National Topographic Database. Pixels corresponding to selected GCPs locations were identified on the LANDSAT images. Linear polynomial control point rectification with nearest neighbour resampling was conducted on the reference LANDSAT scene, resulting in an average RMS error of 0.65 of a pixel (30 m pixel spacing). An average RMS error below 1.0 pixel was targeted as acceptable. Other scenes were co-registered to existing orthorectified reference images of the area.

Variation in solar illumination condition, phenology, and detector performance results in differences in radiance values unrelated to changes in the land cover type. Radiometric normalization represents the first order data transformation approach used to reduce the variability between multi-temporal data sets acquired over the same geographic area. The process substantially reduces or normalizes the inter-scene variability resulting from different phenological conditions, atmospheric conditions, radiation incidence angles, and detector disparities. Relative radiometric normalization uses one image as a reference and adjusts the radiometry of the subject image to match the reference. The radiometric normalization of the LANDSAT images used in this study was performed only for Chateauguay region using the approach given by Du et al. (2001).

Results and Discussion

Chateauguay Region

The Chateauguay example demonstrates approach 1 for IPCC reporting, where the area of agriculture land is derived from remote sensing data, while other parameters such as crop type required for estimating greenhouse gas emissions can be obtained from other data. In this approach, the area converted from natural vegetation to cropland or vice-versa can be derived over different time steps depending on needs. Annual change of the crop area between map dates can be interpolated following the procedure suggested in the IPCC good practice guidelines (IPCC, 2003). The need for area updates would be determined based on census data. If census data indicate a significant change in crop area, then spatial information can be updated more frequently using remote sensing. Integration of agriculture census and remote sensing data allow for 1) flexibility in selecting years of update when high quality remote sensing data are available and 2) increased report accuracy and consistency.

Classification by Progressive Generalization (CPG, Cihlar et al., 1998) was used to classify the 1990 and 2001 scenes into the following four categories: natural vegetation, cropland, urban land and water. The Fuzzy-K means clustering algorithm was used to generate 150 clusters and merged based on spectral and spatial similarity criteria (Latifovic et al., 1999). Final 52 spectral clusters were further agglomerated and labelled based on a subset of the field data.

Post classification change detection (Fig. 6) was employed to quantify the change in area under crops. The method assumes that reference and compared images are classified into a common legend and that the classification method utilized for mapping provides high accuracy (>95%) for both images. Such high accuracy with LANDSAT data is possible only for classifying a few classes e.g. natural vegetation, cropland or forest non-forest. Landscape changes are simply detected as differences between pixel labels. For a comprehensive review of change detection methods see (Choppin et al. 2004).

Visual evaluation of the maps was performed through comparison to a large number of air photos. The assessment showed very good delineation accuracy of agriculture fields. Results of post classification change detection revealed that 8 % of the area changed between 1990 and 2001 (Fig. 7). Some of this change is misclassification in the 2001 image, which was acquired when of few crops were starting to emerged. Thus, the actual change is smaller than the remote sensing estimate. In cases where more precise estimates are needed, a procedure that calibrates remote sennsing estimates based on field data such as that outlined by Ambrosio and Martinez (2000) can be used.

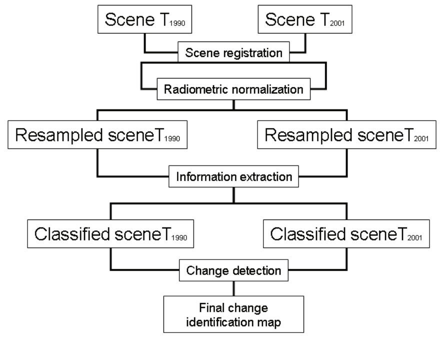

Figure 6. Post-classification change detection procedure. Years given do not corresponded to those used in this analysis.

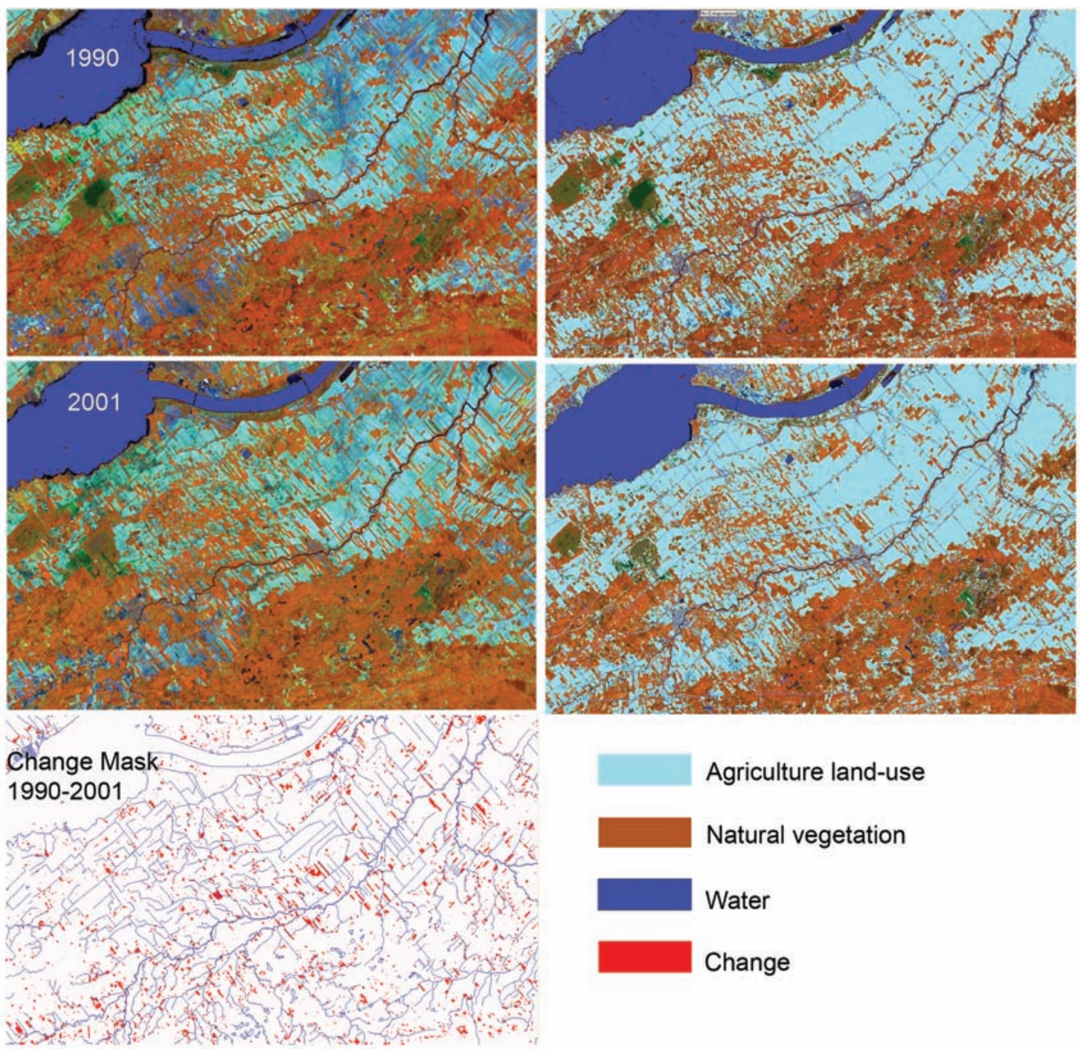

Figure 7. Example agriculture areas of the Chateauguay region for 1990 and 2001. Left side - shows the LANDSAT imagery red = near infrared, green = shortwave infrared, and blue = red band.Right - shows agriculture area mask. Figure at the bottom shows change mask

Casselman Region

Three methods for crop type classification (maximum likelihood, CPG, and object oriented classification (OOC)) were compared based on accuracy and temporal consistency. The intention of the comparison was to determine if one of the methods strongly outperformed the others for basic crop type mapping.

Initial classification attempts showed that the broadleaf forest class was frequently mixed with agriculture classes, mainly corn. The class location in feature space is presented in Fig. 8 consisting of red, near infrared and shortwave infrared spectral measurements. It is evident that corn and broadleaf forest values populate the same part of feature space.

To improve map accuracy of agriculture crop types, a mask of natural vegetation was created using a late November LANDSAT image (Fig.9a). At this time, the forest class is very distinct from other classes making the extraction straightforward. An urban mask was also created using an existing road coverage of the area, available from National Road Network, Canada, Level l, (www.geobase.ca/geobase/en/list.jsp). The road coverage was converted to a raster mask through a series of dilatation and erosion operations to fill in areas with high-density roads (Fig.9b). The remaining area that was not under natural vegetation and urban masks was classified using one of the three methods.

Maximum Likelihood

For maximum likelihood classification, training data were selected from the imagery and checked for normality. Class spectral distributions were almost all normal except for the soil and grass classes, which had bimodal histograms. These classes were split and re-merged post-classification. A sieve filter was applied post-classification to merge clusters smaller than 9 pixels to their largest neighbor.

Classification by Progressive Generalization

CPG classification was implemented with the K-means classifier to generate an initial 150 spectral clusters. Cluster agglomeration was performed based on cluster spectral similarity and spatial proxim-

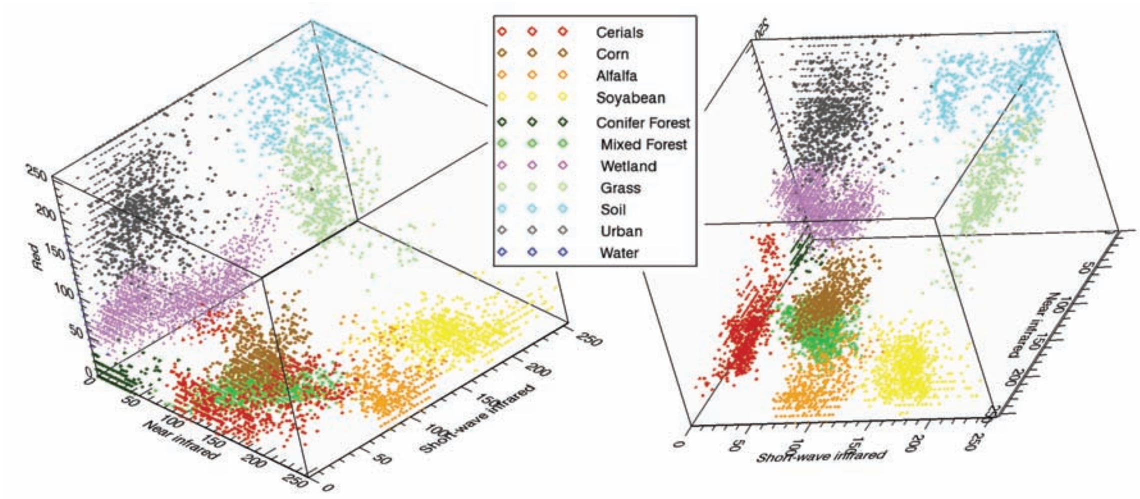

Figure 8. Feature space representing mid July class spectral properties.

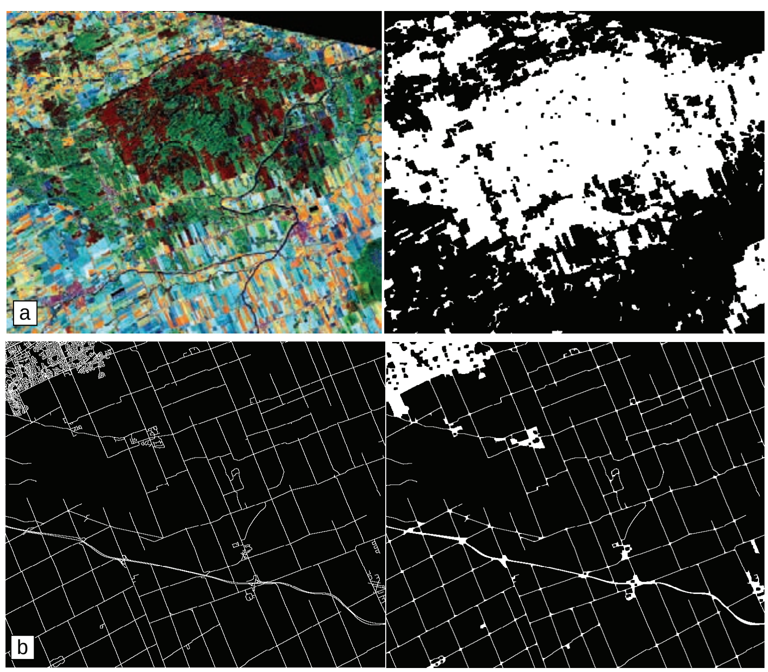

Figure 9. A) November LANDSAT image (left), natural vegetation mask (right). B) Road vector coverage (left), urban area mask (right).

ity following a procedure described in (Latifovic et al., 1999). The agglomeration yielded fifty-five different spectral clusters. In the labeling procedure, those fifty-five were grouped into 14 thematic classes according to the legend provided in Table 2. Post-classification refinement included a sieve filter applied to merge clusters smaller than 9 pixels to their largest neighbor. The same procedure was repeated for each year to produce a complete crop type time series.

Value	**Label**
1	Water
2	Cloud shadow
3	Cloud
4	Urban
5	Bare soil
6	Low Vegetation (open field, grass)
7	Shrubland
8	Wetland
9	Mixed coniferous-deciduous forest
10	Coniferous forest
11	Soybean
12	Alfalfa
13	Corn
14	Cereals

Table 2. Classification legend.

Object Oriented

OOC was carried out using the commercial software package eCognition. Numerous parameter combinations were evaluated to segment objects and the best set, determined visually, was used in the classification. For classifier training, objects were selected from the imagery and only the spectral data was used in the initial classification. Additional classifications included the standard deviation of each object for each band (Stdv) and the length to width ratio (Shp) of each object.

The results from each classification are shown in Fig. 10. Visual comparison of the classification results to the original imagery shows that the classified images preserved the spatial pattern of agriculture fields in the original 3 band images. Overall, the maps appear to contain similar information, but some differences are evident. OOC produced the most spatially generalized results due to the classification of image objects instead of pixels, whereas the MLC and CPG methods were much more spatially variable. The disadvantage of object-based classification is that it makes a much larger error for a given misclassification since the entire area of the object is incorrect. Using a per-pixel approach reduces this, as not all pixels within the object will be incorrectly classified, but individual pixels are typically more difficult to classify than objects. For example, the narrow cornfield in the upper right of Figure 10 was classified as shrub by OOC, but was predominantly classified as corn by CPG and partly corn by MLC.

Accuracy Assessment

Accuracy was assessed for each cover type separately using an accuracy index that incorporated both omission and commission error into a single summary value.

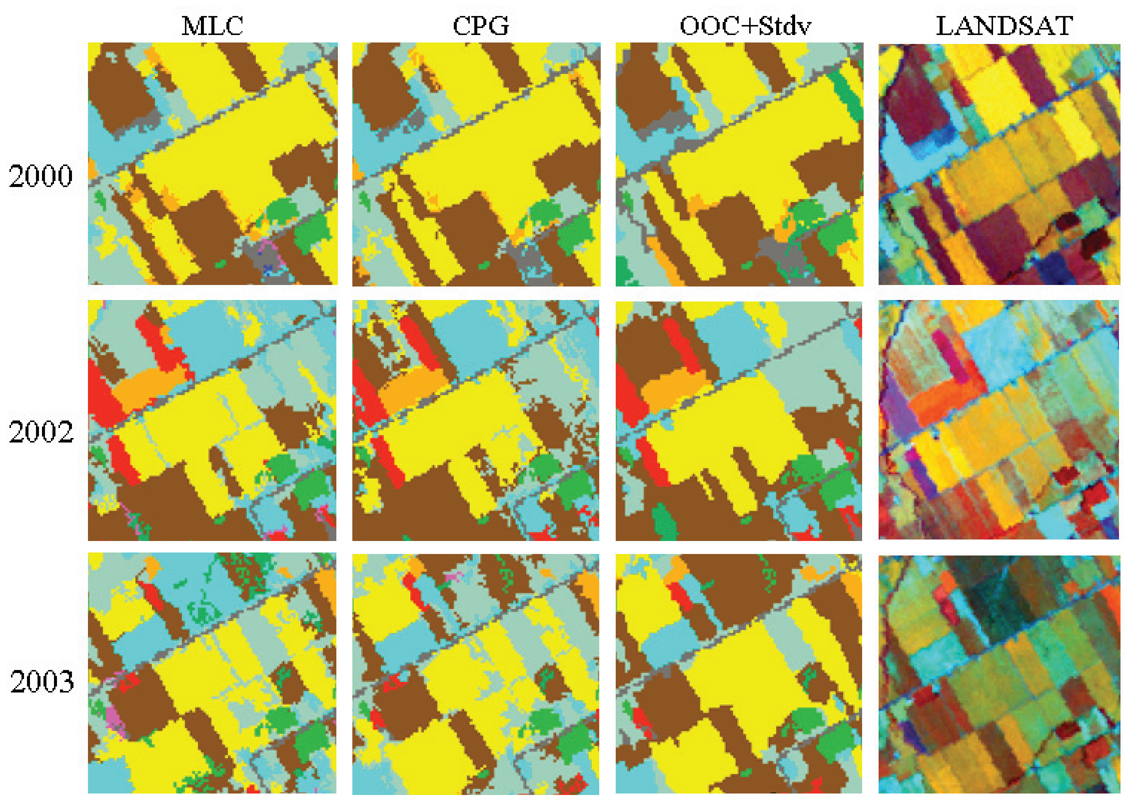

Figure 10. Example classification results. In the example yellow - soybean, brown - corn, orange - alfalfa, red - cereals, grey - low-lying vegetation, green - forest, light blue - soil, blue – built-up, pink - wetlands.

AI = ((n-o-c)/n)×100

Where n is the number of validation samples for the class, o is the number of omission errors (i.e. where validation samples for the given class and map did not agree), and c is the number of commission errors (i.e. where the given map class and validation samples overlapped).

Table 3 shows the classification results for 2000-2003. Data for 2004 were not available when these results were complied. All methods performed well and were close enough that subjectivity in each could account for the observed differences. However, some general trends are evident and confidence in the results is enhanced by the consistency of the results over multiple dates. The object oriented classification using only spectral information produced the lowest overall result, but including either

Year	**Method**	**Soil**	**Low Veg.**	**Soybean**	**Alfalfa**	**Corn**	**Cereals**	**Average**
2000	MLC	72.5	75.7	94.4	92.4	98.0		86.6
2002	MLC	61.2	63.1	77.2	77.1	76.3	69.0	70.7
2003	MLC	18.6	59.9	83.6	84.2	83.6	73.0	67.2
Average	**MLC**	**50.8**	**66.2**	**85.1**	**84.6**	**86.0**	**71.0**	**74.8**
2000	CPG	78.3	65.7	87.3	83.5	94.0		81.8
2002	CPG	82.3	74.9	65.5	56.8	85.6	70.2	72.6
2003	CPG	52.0	54.3	81.0	87.3	86.8	81.4	73.8
Average	**CPG**	**70.9**	**65.0**	**78.0**	**75.9**	**88.8**	**75.8**	**76.0**
2000	Object Oriented	52.7	19.8	81.7	76.9	93.1		
2002	Object Oriented	76.9	66.7	82.0	81.7	86.9	75.0	
2003	Object Oriented	18.3	57.3	87.4	90.4	72.6	72.7	
Average	**Object Oriented**	**49.3**	**47.9**	**83.7**	**83.0**	**84.2**	**73.8**	**69.8**
2000	Object Oriented+Shp	52.9	24.2	83.9	80.8	95.7		
2002	Object Oriented+Shp	81.5	73.2	90.5	90.5	92.5	76.4	
2003	Object Oriented+Shp	14.7	49.1	83.9	95.0	87.1	60.7	
Average	**Object Oriented+Shp**	**49.7**	**48.8**	**86.1**	**88.7**	**91.8**	**68.5**	**72.2**
2000	Object Oriented+Stdv	71.1	60.7	89.3	83.2	96.9		
2002	Object Oriented+Stdv	78.7	64.1	88.3	87.1	84.6	73.4	
2003	Object Oriented+Stdv	28.8	54.7	88.9	94.4	80.5	45.8	
Average	**Object Oriented+Stdv**	**59.5**	**59.9**	**88.8**	**88.2**	**87.3**	**59.6**	**75.0**

Table 3: AI values (%) for comparison with test data.

shape or within object variance improved results. CPG produced the best overall result and was the most consistent, suggesting that this was the optimal approach considering only crop type accuracy.

Crop Type Temporal Distributions

The temporal distribution of crop types derived using the CPG classification approach is presented in Fig 11. It shows the effect of image acquisition date on the crop area estimates. For July dates (2002 and 2003), the area of bare soil is higher than the August dates (2000 and 2004). Soybean is also the lowest for the July dates, indicating that it is the last crop to emerge and develop being misclassified as bare soil at this time. Considering only the August dates, it appears the crop distributions have not changed substantially, except for soybean in 2004. The July dates show more variability in area, likely due to the underdeveloped crop canopies. The area of cereal crops was similar in both 2002 and 2003. Cereal crops could not be mapped for the August dates as their spectral properties were not distinct from other cover types in August.

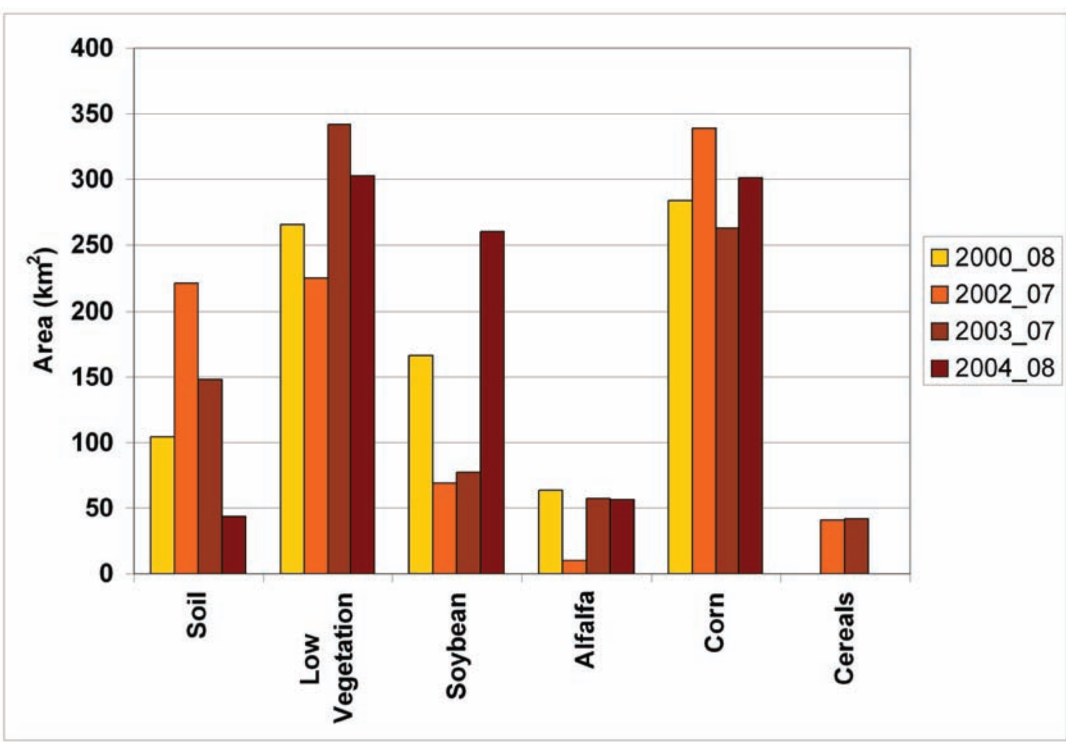

Figure 11. Crop type area estimates from the CPG classification results.

CONCLUSIONS

These case studies highlight the potential contribution of remote sensing for greenhouse gas reporting based on the IPCC land-use, land-use change framework. In both cases, selecting imagery from the appropriate time period is critical to success. This is especially true in the case of crop type mapping. Deriving the agriculture area from remote sensing is relatively straight forward and combined with census data should provide a reasonably precise means of reporting. Crop type mapping has the potential for improved accuracy, but also increased error and reduced precision, as crop spectral signatures can be confused amongst themselves and with other land cover classes. Successful mapping will likely require several images throughout the growing season in order to map all crop types and separate natural vegetation from crops.

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CHAPTER 9

Terrestrial Ecosystems of South America

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ABSTRACT

Standardized terrestrial ecosystems of South America were mapped using a biophysical stratification approach, and employing an ecological systems classification recently developed for Latin America and the Caribbean. The classification effort involved the development of diagnostic criteria and names for describing expert-derived ecological systems. The mapping/modeling effort stratified the continent into unique physical environments supporting a variety of land cover types. Ecosystem footprints were delineated by overlaying continental datalayers for elevation class, landform, lithology, bioclimate, and image-derived land cover. Polygonal occurrences of these ecosystem footprints were developed at a working pixel resolution of 450m (20 hectares). The ecosystem footprint polygons were subsequently labeled using the standardized ecosystems. 659 ecosystem types were identified and mapped across the South American continent; by comparison there are 110 World Wildlife Fund (Olson et al., 2001) terrestrial ecoregions. These standardized ecosystems, mapped for the entire continent at a relatively fine scale, are useful for a variety of biodiversity conservation and resource management applications. These data can be used to identify areas deserving of management attention due to their value for biodiversity conservation, as well as the production of ecosystem goods and services (e.g., food, water, fuel, fiber, forage, etc.).

Key words: *biodiversity conservation, biophysical stratification, ecosystems, ecosystem classification, ecosystem management, spatial analysis, spatial planning*

INTRODUCTION

In their seminal work on ecology, the Odum brothers (Odum, 1953) described ecosystems as systems of biotic communities interacting with their physical environment. Since the publication of that early textbook on ecosystem science, ecosystems have largely been recognized as scaleless, varying in size from a whole forest to a small pond, even from the entire biosphere to a small speck of dust. Bounding the area within which organisms interact with their physical environment has always been an interpretive exercise, and depends on the biotic and abiotic components of interest, and the application at hand. As such, various kinds and sizes of ecosystems have been recognized, classified, and mapped. These range from large, coarse scale ecosystems, or ecoregions (Omernik,1987; Bailey, 1996; Olson et al., 2001), to smaller, fine scale environments that support particular biotic assemblages (Franklin, et al., 2002).

Spatial delineation of ecosystems is a difficult undertaking because ecosystems are inherently complex, changing through both space and time. However, recent interest in conserving ecosystems for both biodiversity and ecosystem service values (Millennium Assessment, 2005; Heinz Center 2006) has led to a need for improved knowledge of ecosystem types and distributions on the landscape. Managing the variety of resources within ecosystems (e.g. water, forests, wildlife, etc.) may best be accomplished by an ecosystem-based management approach (Convention on Biological Diversity, 2000), which requires that ecosystems be delineated and their occurrences considered as management or conservation targets (Redford et al, 2003). Ecosystems of regional extent, or ecoregions (Bailey, 1996), are appropriate for use as large (1000s to 10,000s km^2), ecologically meaningful planning units, and have been globally delineated (Bailey, 1996; Olson et al., 2001), but are generally too coarse for on-the-ground management applications. Finer scale ecosystems are more appropriate for local management applications. A conceptual hierarchy relating ecological complexity and scale of management applications is presented in Figure 1, which distinguishes between ecoregions as coarser scale planning units and ecosystems as finer scale management or conservation targets.

There are several applications for which meso-scale ecosystems (10s to 1000s of hectares) are useful. Many conservation priority setting approaches are based on an analysis of the species and

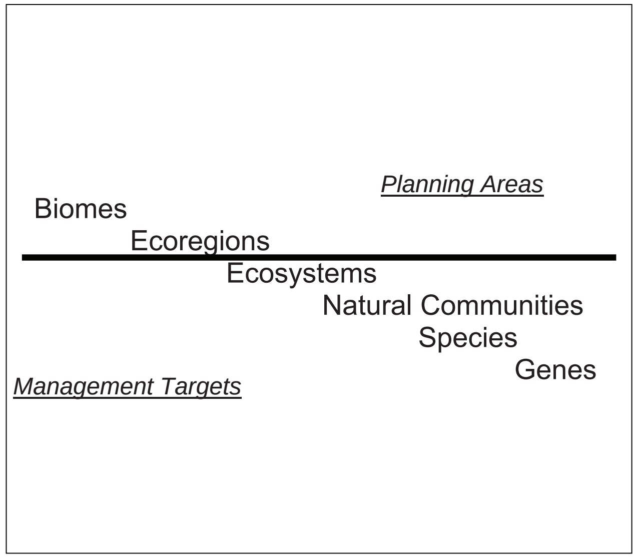

Figure 1 - Ecosystems as conservation targets.

ecosystems occurrences within a particular geography (often an ecoregion) to determine which of these conservation target occurrences merit inclusion in a portfolio of conservation areas or strategies (Groves, 2003). Biodiversity conservation gap analyses (Scott et al., 2001; Rodrigues et al., 2004; Dudley and Parrish, 2006) examine the extent to which species and ecosystems are represented in areas designated for conservation – these gap analyses require good maps and data on the distribution of ecosystems. The Convention on Biological Diversity (CBD) mandates signatory nations to design ecologically representative networks of protected areas, and encourages national and regional gap analyses of ecosystems to identify unrepresented and under-represented ecosystems (Convention on Biological Diversity, 2004). The emerging science of economic and societal valuation of ecosystem goods and services similarly requires a geospatial ecosystems framework to be able to attribute ecosystem service values in a spatially explicit manner to individual ecosystem occurrences on the landscape (Millennium Assessment, 2005).

Although ecosystem classifications and maps exist for several South American countries, there was no single, standardized classification or map of ecosystems for the continent at the start of the 21st century. This lack of critically important conservation and management information was addressed in a collaboration to classify and map standardized, meso-scale ecosystems for South America.

APPROACH

Ecological systems, defined as spatially co-occurring assemblages of vegetation types sharing a common underlying substrate, ecological process, or gradient, have been identified for all of Latin America and the Caribbean (LAC) in a recent classification effort by the conservation non-governmental organization NatureServe (Josse et al., 2003). That classification work, which enlisted the support of several LAC regional vegetation specialists, produced a list and description of 780 ecological system types for the region, but the on-the-ground occurrences of these ecosystems were not mapped as part of the classification effort. Diagnostic classifiers such as climate type, topographic position, and substrate type were developed to differentiate ecosystem types according to the physical environments in which the vegetation assemblages were located.

In addition to lists and descriptions, conservation planners and resource managers need maps of the types and locations of the ecosystems they seek to manage. To extend the utility of the ecosystems classification for South American managers and conservationists, we developed a standardized method to map the on-the-ground occurrences of these terrestrial ecosystems at a relatively fine spatial resolution (450m) for the whole continent.

The mapping method is derived from a fundamental consideration of ecosystem structure. Ecosystems are composed of both physical and biological structural elements. An ecosystem at any point is an integrated expression of these structural components, vertically organized (from top to bottom) as climate, landform, surface and sub-surface waters, soil, and bedrock, with biota occurring essentially throughout (Bailey, 1996). It follows that ecosystems can therefore be spatially delineated by mapping and integrating these structural components in geographic space, and that ecosystem boundaries will represent area-based changes in the structural components.

A continental biophysical stratification approach was adopted to delineate ecosystem footprints as unique physical environments that support a particular land cover type. The resulting ecosystem footprints were subsequently labeled (attributed) using the ecological systems classification described above. This two step process is diagrammed in Figure 2.

The biophysical stratification approach involved the development of continent-wide data surfaces for

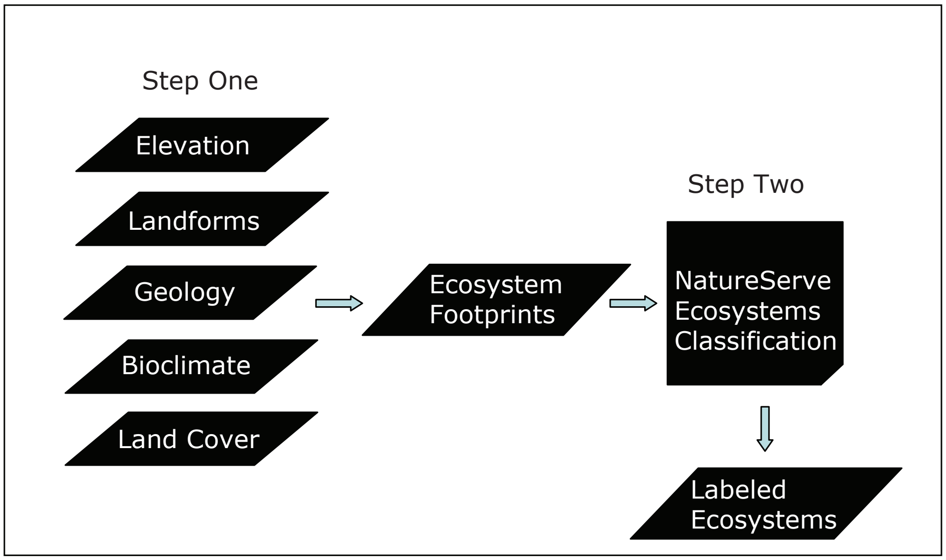

Figure 2 - Biophysical stratification approach to delineate ecosystem footprints as unique physical environment/land cover combinations. Ecosystem footprints were subsequently attributed with NatureServe ecological system labels.

each of four physical environment variables: 1) elevation class, 2) landform, 3) lithology, and 4) bioclimate region. These were combined in a continental, GIS-managed union of the four datalayers to produce a map of the unique physical environments of South America as defined by these four physical environment parameters. Land cover for the continent was also added into the overlay to identify the land cover types located within the abiotic ecosystem footprints. In addition to the general methodological descriptions that follow, detailed procedures for this approach are further characterized in Bow et al. (2005).

METHODS

Historically, terrestrial ecosystems have been defined from a wide variety of perspectives, with emphases on ecosystem function and processes (Bormann and Likens, 1979), physical factors that structure the system (Bailey 1996), and as fundamental elements of biodiversity (Groves, 2003). We incorporate all three of these perspectives in our consideration of terrestrial ecosystems as groups of plant community types that tend to co-occur within landscapes with similar ecological processes, substrates, and/or environmental gradients. Ecological processes include natural disturbances such as fire and flooding. Substrates may include a variety of soil surface and bedrock features, such as shallow soils, alkaline parent materials, sandy soils, or peatlands. Environmental gradients include local climates, hydrologically defined patterns in coastal zones, arid grassland or desert areas, or life zones in mountainous areas. A given terrestrial ecological system will typically manifest itself in a landscape at intermediate geographic scales of 10s to 1000s of hectares and persist for 50 or more years.

The ecological systems of Latin America and the Caribbean were developed by vegetation scientists and landscape ecologists in a series of four regional classification development workshops. In these expert workshops, diagnostic classifiers were developed to explain the spatial co-occurrence of natural communities; diagnostic classifiers included bioclimate, biogeographic history, physiography, landform, physical and chemical substrates, dynamic processes, landscape juxtaposition, and vegetative structure and composition. In these workshops, and with subsequent classification development by additional regional vegetation experts, a total of 780 ecological systems were listed and described for Latin America and the Caribbean. The classification, as with all classifications and maps, is still evolving, with the addition of new ecosystem types as they are described and reviewed. The classification is available at (http://www.natureserve.org/getData/LACecologyData.jsp).

Elevation Class – A 90 m digital elevation model (DEM) for the continent was created from Shuttle Radar Topography Mission (SRTM) data. A seamless, continent-wide dataset was produced and processed to remove no-data values and spurious sinks and spikes. To facilitate processing, the 90 m resolution dataset for the continent was resampled to a 450 m resolution. The following elevation classes were identified and mapped according to their floristic importance in determining South American vegetation distributions: 0-500 m, 500-1000 m, 1000-2000 m, 2000-3300 m, and > 3300 m (Eva et al., 2002; Navarro and Maldonado, 2002).

Landforms – The 450 m continental DEM was also used to produce a continent-wide landforms datalayer, with all pixels assigned into one of the following regional physiographies: plains, rolling plains, hills, mountains, plateaus, valleys, floodplains, and coastal plains. The methodology for the landform class derivation employed a 5 by 5 cell moving neighborhood analysis window to assess relative relief, and followed other regional scale approaches to model macro-landforms (Hammond, 1964; Dikau et al., 1991; True et al., 2000). Four landforms; plains, rolling plains, hills, and mountains were first modeled for the entire continent; coastal plains, floodplains, valleys, and plateaus were subsequently independently derived and overplotted on the underlying plains/hills/mountains matrix.

Geology – A continental geology dataset was acquired which had been derived from a recent digitization of the geological survey maps of each South American nation by Geologic Data Systems, Denver, Colorado, http://www.geologicdata.com/). This datalayer was developed from 1:500,000 scale sources for all countries except Brazil, which was developed from 1:1,000,000 scale maps. For our ecosystem mapping purposes, the South America geology data were reclassified into the following lithological classes: zonal, sedimentary, limestone/calcareous, alluvium, salt, glacial, and unique. This classification was developed to identify general lithological substrates which give rise to distinct vegetation distributions at regional or continental scales (Kruckeberg, 2002).

Bioclimates- Bioclimate regions were developed using the 1 km^2 resolution WorldClim (Hijmans, et al. 2005) global meteorological raster data and formulas developed by Rivas-Martinez (Rivas-Martinez and Rivas y Saenz, 2007) to delineate isobioclimate regions. The Rivas-Martinez approach quantitatively defines five macroclimate regions for the planet (polar, boreal, temperate, mediterranean, and tropical), and then subdivides these into finer bioclimate regions using meteorological data synthesized into indices of continentality, thermicity, and moisture.

Global Land Cover- The Global Land Cover 2000 (Eva at al., 2002; Mayaux et al., 2006) dataset was acquired for South America. This dataset has a spatial resolution of 1 km^2, and a classification resolution of 73 land cover classes for South America, which were subsequently reclassed into 26 land cover types.

Ecosystem Footprint Generation- Ecosystem footprints were generated by combining each of the raster input datalayers (elevation class, landform, lithology, bioclimate, and land cover) in a continent-wide, non-hierarchical, spatial union. These five input data grids were combined to produce a new continental ecosystems raster data surface where each cell was labeled with a unique grid code. The numeric value of each grid code was designed to be additive, in order to retain the values of the original input classes in the resulting label. For example, the unique grid code 1742020 represented: 1000000 (elevation = 0 to 500 m), + 700000 (landform = floodplain), + 40000 (lithology = alluvium),

+ 2000 (bioclimate = tropical pluvioseasonal), + 20 (land cover = broadleaf deciduous tree cover).

Unique gridcodes were modeled for all parts of South America, except the Galapagos and Falkland Islands, and then evaluated and attributed to one of NatureServe's ecological systems.

Labeling of Ecosystem Footprints – The ecosystem labeling step was an automated matching approach to associate the ecosystem polygons and their grid codes with an ecosystem type from the NatureServe LAC Ecological Systems classification. Independent of the mapping work, the NatureServe ecological systems were characterized and attributed for the elevation class, landform, lithology, and bioclimatic region within which they were expected to occur, and the land cover type they were expected to contain. This information was organized in a matrix of ecosystem types and their attribute classes, and was used as a labeling look-up table in the GIS.

Accuracy Assessment – Ideally, a verification of the mapped ecosystem occurrences would be conducted in an extensive field campaign with stratified random sample points generated and visited to collect information on the elevation, landform type, lithology, bioclimate region, and land cover. Such a field verification effort was not possible within the scope of this project, but a rigorous comparison analysis was conducted. Twenty one mapped representations of vegetation, land cover, habitats, and ecosystems at national and regional scales throughout the continent were acquired and evaluated for suitability in the comparison analysis. Of these, seven sources were judged acceptable for use in a comparison analysis and their classes were crosswalked into the NatureServe classification logic and used as "reference" data for the comparison. A stratified random sampling was conducted for each ecosystem type in nine biome-representative WWF ecoregions (Olson et al., 2001) across the continent. The ecoregions were used as a stratification unit for the assessment, and were not one of the seven comparison datasets. A traditional accuracy assessment analysis was implemented to produce Kappa statistics, user's accuracy, and producer's accuracy on every ecosystem type in each sampled ecoregion. 75-100 twenty hectare hexagon sample units were randomly generated following the sampling adequacy suggestions of Congalton and Green (1999), who suggested a target sample size of 75-100 samples for every class in any classification scheme where the number of classes exceeds twenty. If the number of ecosystem occurrences in the sampled ecoregion was insufficient to meet this target sample

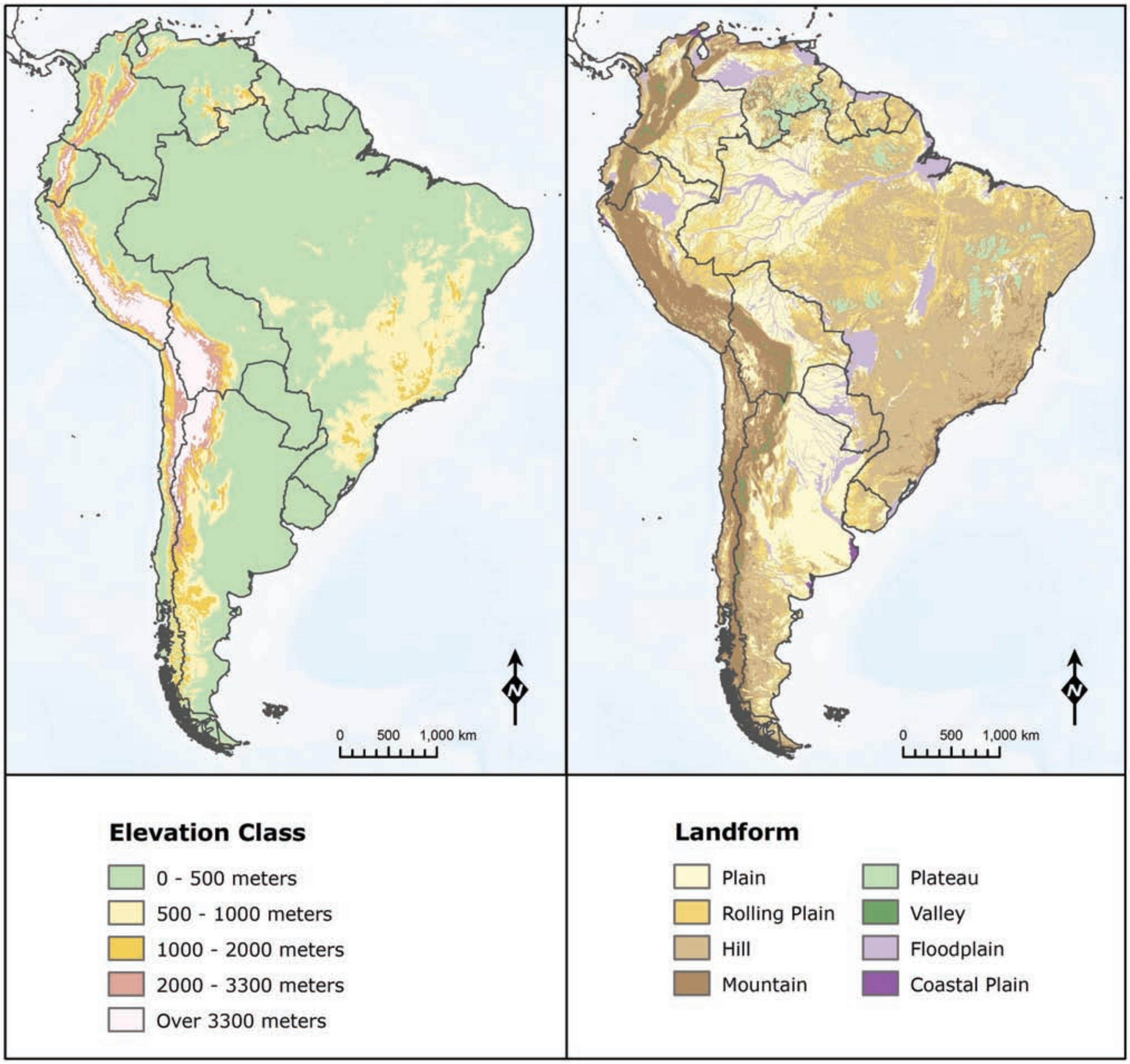

Figure 3 – Elevation classes and landforms of South America, derived from a continental 450 m digital elevation model.

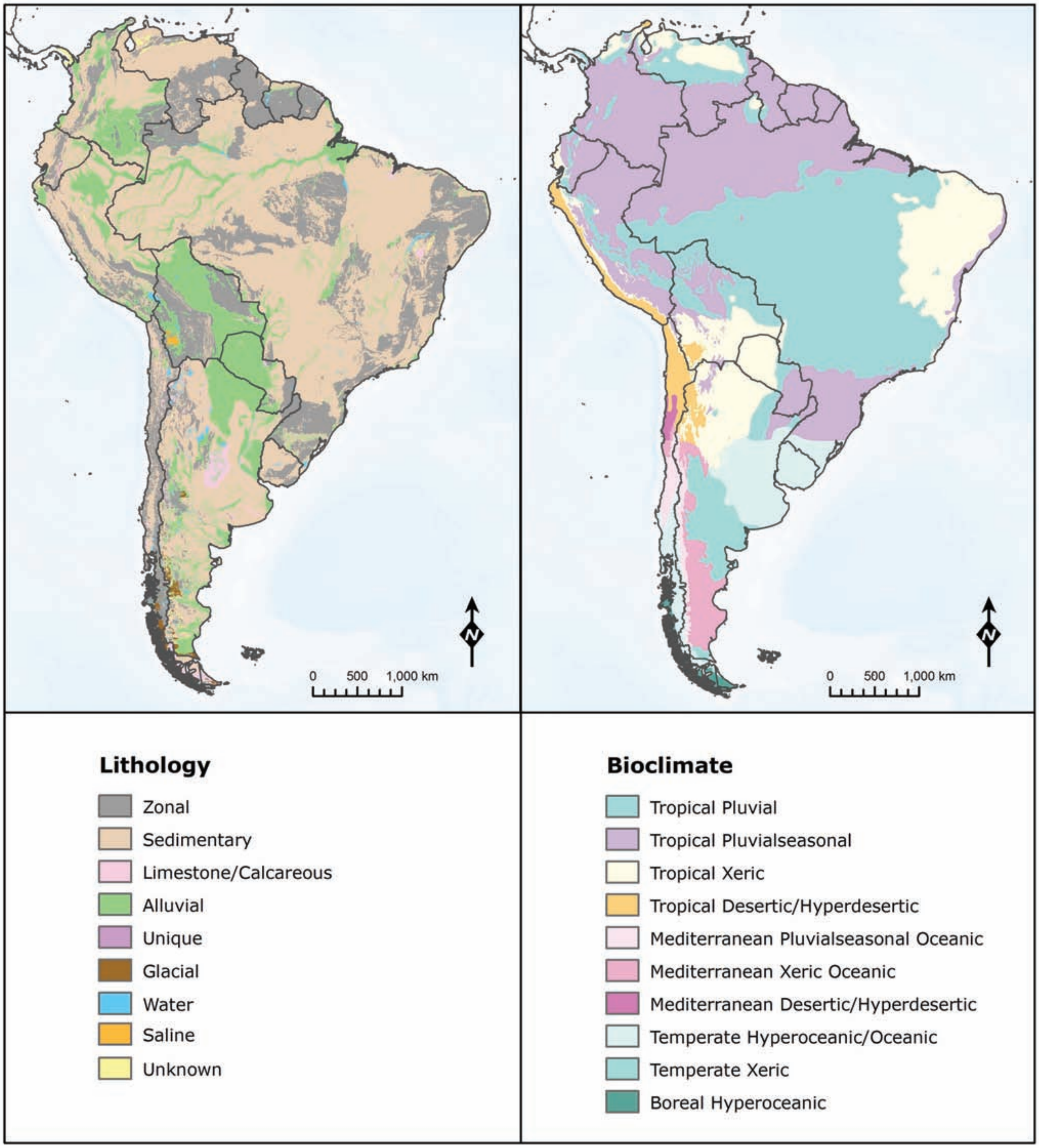

Figure 4 – Lithology and bioclimates of South America. Lithology data were reclassed from a continental geology data-layer of spatially joined national geological maps at generally 1:500,000 scale. The bioclimate regions were modeled from 1 km^2 temperature and precipitation data.

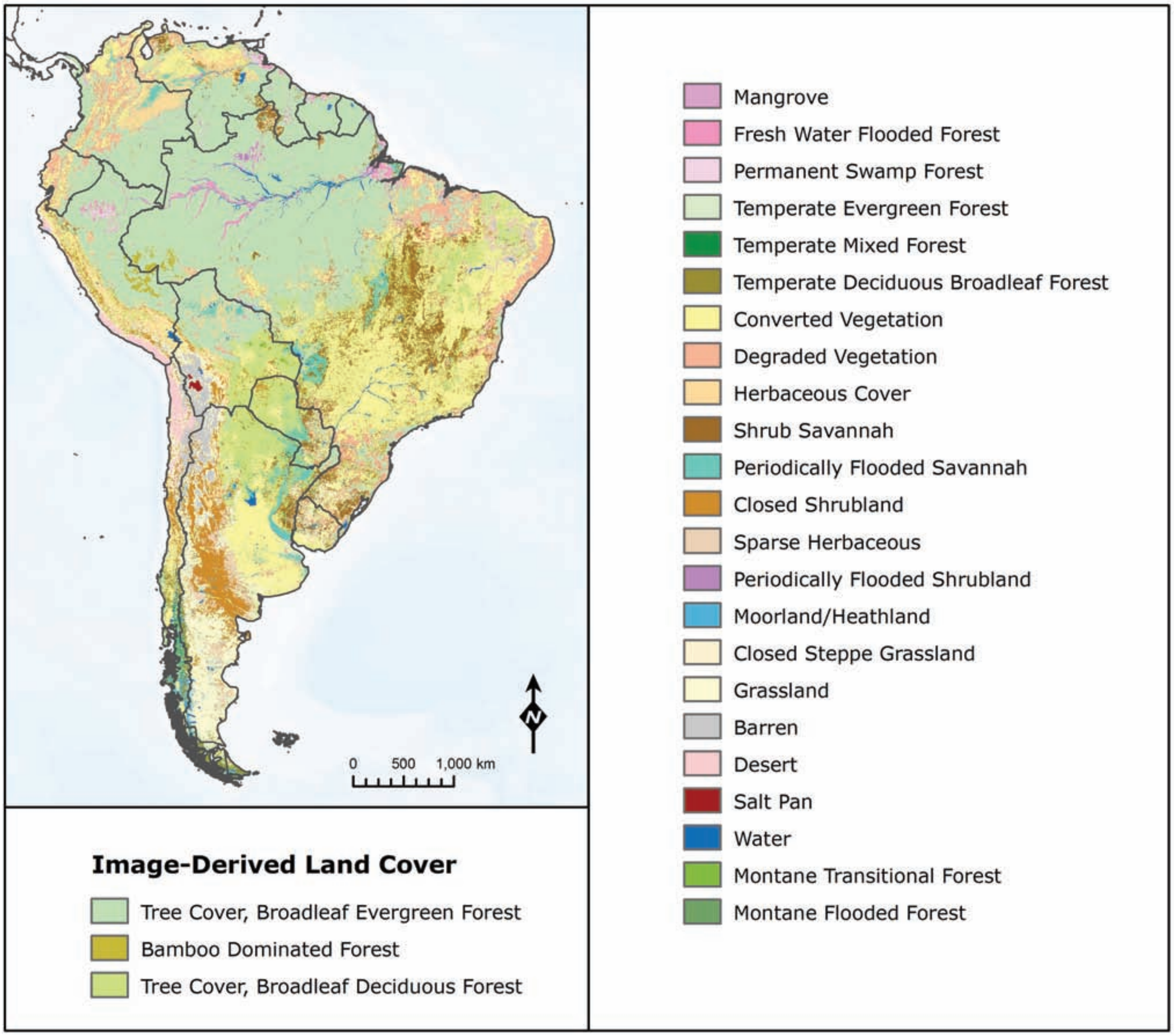

Figure 5 – Land cover of South America, from the 1 km^2 GLC 2000 (Eva et al., 2002) global land cover data, resampled from 76 to 23 classes.

number, all occurrences were sampled. A 500 m buffer and a 2500 m minimum distance between samples were used in the random sample selection process to address the issue of spatial autocorrelation. The minimum sample distance was reduced to 1000 m if the larger sample distance generated fewer than 75 samples. The mapped ecosystems in the hexagon sample units were compared with the reference data, and a crosstabulation matrix, with producer's and user's accuracy, was developed for each sampled ecoregion.

RESULTS

Input Layers – Continental data surfaces were developed for elevation class (Figure 3), landform (Figure 3), bioclimate region (Figure 4), lithology (Figure 4) and land cover (Figure 5). In addition to their use as core data inputs into the ecosystem footprint delineation process, these four continental data surfaces also describe the physical geography of the continent in general. The five elevation bands and the eight landform classes were modeled at a 450 m resolution from a 90 m DEM and characterize the regional physiography of South America in a digital data format heretofore unavailable at any spatial resolution. These "intermediate" products are intrinsically useful for a variety of engineering, land planning, and resource management applications apart from ecosystem delineation and conservation priority setting. The landforms map, in particular, could be useful for much of the infrastructural development planning underway throughout the continent.

Ecosystem Map – The resulting map of standardized, meso-scale terrestrial ecosystems of South America is shown in Figure 6. The combination of input datasets produced a total of 9,352 unique gridcodes, identification codes for each grid cell. Vector polygons were created from contiguous raster cells with the same gridcode in a standard raster-to-polygon conversion, and these ecosystem footprints were labeled to produce a total of 659 unique, mapped, multi-occurrence ecosystems for South America, with a 20 hectare minimum mapping unit. An additional five ecosystem classes (barren, converted, degraded, unknown and water) were also mapped, as identified from the global land cover data. These extensive areas of converted classes are very evident in the Cerrado and Caatinga regions of Brazil, and are likely soy production. Figure 7 shows a subregion of the continental eco-

Figure 6 - Ecosystems of South America. 659 ecosystems were identified and mapped at a 450 m working resolution.

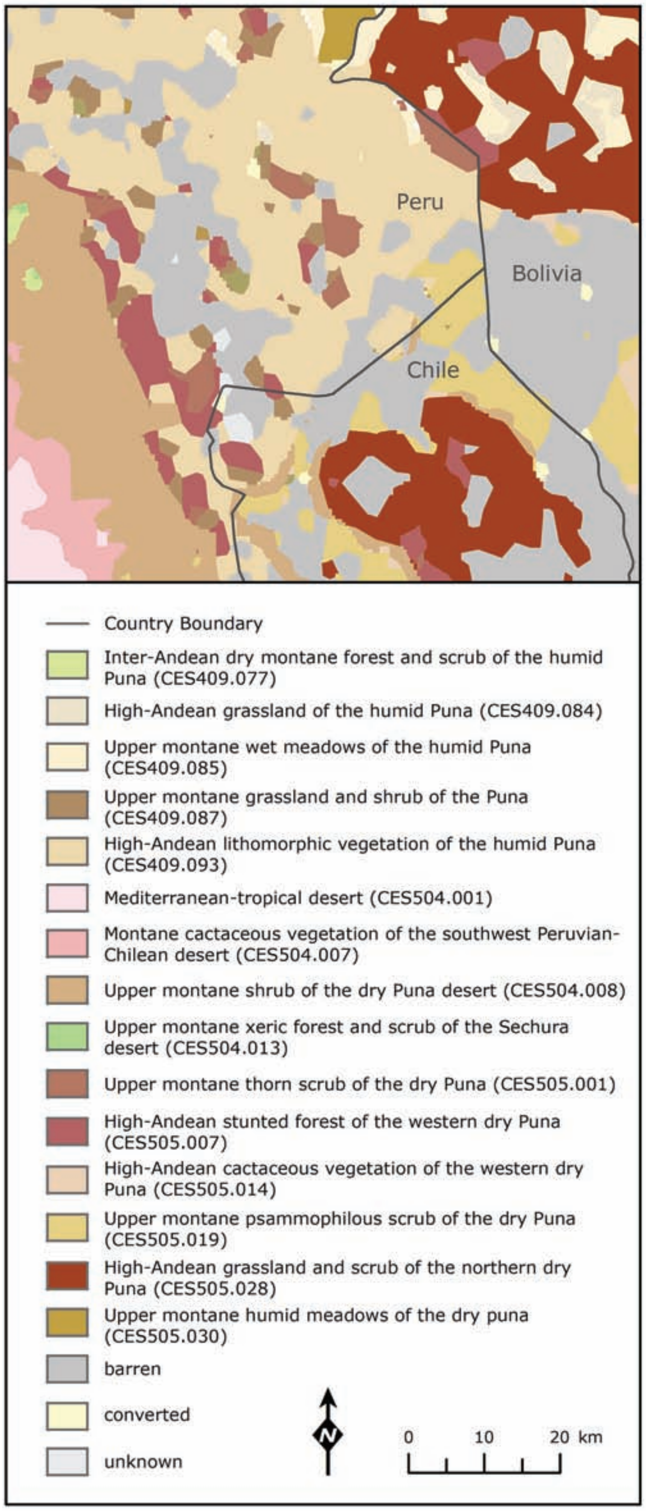

Figure 7 – A subset of the South American ecosystems as they occur near the Peru/Bolivia border, showing the detail in the polygon occurrences and classification resolution.

Ecological System Code	***User's Accuracy***	***Producers's Accuracy***
CES408.523	40.1	85.71
CES409.039	36.1	64.29
CES409.079	12.9	40.1
CES409.095	2.56	6.45
CES409.105	53.33	16.19
CES409.110	61.69	70.31
CES409.112	44.44	69.71
CES409.123	21.21	16.28
CES409.900	79.67	51.49
CES409.903	28.45	62.67
Converted	55.56	34.3

Table 1 – Accuracy assessment results presented for one ecoregion, the Eastern Cordillera Real Montane Forests (Olson et al., 2001). Overall accuracy for this ecoregion was 41.2% (KHAT Value: 0.345377; Variance: 0.00008465; Z Statistic: 37.539). Individual accuracy statistics for the four ecosystems occupying the majority of the area (area data not shown) of the ecoregion were: CES409.110 (61.7%); CES409.112 (44.4%); CES409.900 (79.7%); and CES409.903 (28.5%).

systems map, zoomed in to the area near the intersection of the Bolivia, Peru, and Chile borders. This map provides an illustrative sense of both the classification nomenclature and spatial resolution of the data at an on-the-ground management scale.

The labeling process, although intended to be automated, was complicated due to a strong many-to-one relationship between gridcodes and ecosystem types. The automated search for specific ecosystems based on their expected elevation, landform, geology, bioclimate, and land cover characteristics was confounded by ecosystems with multiple class values in the data input variables (e.g. the same ecosystem could exist in elevation classes 0-500 m, and 500-1000 m). Gridcodes not assigned into an ecosystem class by the automated labeling procedure described above were therefore subsequently labeled in a manual, interpretive process which considered gridcode similarity (i.e. variation in class values in input variables), and in particular, similarity in land cover types. Ancillary maps, usually national vegetation or land cover maps, were also consulted in the interpretive labeling process.

Accuracy Assessment - Kappa statistics, user's accuracy, and producer's accuracies were calculated for every ecosystem in each of the nine sampled ecoregions. These results are presented for one illustrative ecoregion in Table 1. Accuracies for the nine sampled ecoregions ranged from 25% to 49%, and averaging across all ecosystems that met minimum size and distribution requirements, for all sampled ecoregions, the overall accuracy of the mapped ecosystems is 35%.

DISCUSSION

The ecosystems map provides the first comprehensive and consistent delineation of standardized terrestrial ecosystems across South America at such a detailed resolution (450 m minimum mapping unit). The 20 hectare grain size, and the multi-occurrence nature of these ecosystems permits their use as management targets for a variety of on-the-ground conservation and resource management applications. The 659 multi-occurrence ecosystems are considerably finer in spatial and classification resolution than the 110 largely single-occurrence World Wildlife Fund ecoregions of South America (Olson et al., 2001). The ecosystems data are currently being used by The Nature Conservancy in continent-wide ecosystems gap analyses and conservation priority setting.

An overall accuracy of 80-85% has oft been cited as a recommended target accuracy for land cover maps (Foody 2002). However, this level of accuracy is difficult to obtain in evaluations of detailed ecological system, land cover, and/or vegetation maps. Overall accuracies from five recent accuracy assessment studies were 31%, 42%, 50%, 53%, and 59% (Reiners et al., 2000; Laba et al., 2002; Menard et al., 2002, Wickham et al., 2004; and Lowry, et al., 2005). In all of these studies, user and producer accuracies for individual classes varied widely, highlighting the fact that an overall accuracy value, while simple for users to understand, is not reflective of the often great diversity of accuracies between classes. The low overall accuracy results of these studies are not particularly surprising given the complex nature of ecological/land cover/vegetation data (heterogenous complexes and transitional ecotones) and of the unavoidable subjectivity of the accuracy assessment process itself. Several of these studies conducted secondary fuzzy type assessments, where mapped and reference samples were re-evaluated using different fuzzy metrics and similar classes were considered correct, which improved their overall accuracies (Reiners et al., 2000; Laba et al., 2000; Lowry et al., 2005).

Although the best practical alternative to rigorous field sampling across the continent, the use of a comparison analysis with multiple “reference” data sources as an evaluation of data accuracy was problematic, and likely underestimates the true accuracy of the ecosystems map. On the one hand, an inability to field validate the mapped ecosystems, and a lack of a rich set of high resolution aerial photographs to be used for verification, does require the use of a “next best” accuracy assessment method. However, a comparison analysis is an imperfect alternative because our mapped ecosystems were compared against other interpretations, which could themselves have low accuracy, or which could have been highly accurate, but difficult to satisfactorily crosswalk into our classification. It is also likely that several mismatched classes are ecologically similar and should have been classed as matches, given that there is a gradual continuum from absolutely correct to absolutely incorrect in any accuracy assessment. A fuzzy accuracy assessment (Congalton and Green, 1999) might improve the overall project accuracy and individual ecosystem mapping accuracies. Although not within the scope of this project given the size of the continent and available resources, we suggest a randomized field verification analysis where point data can be collected on both the ecosystems and all of their physical and biological structural characteristics.

This conceptual approach to spatial ecosystem delineation follows a classic tradition of ecogeographic regionalization characterized by Bailey (1996) as the science of ecosystem geography. Bailey generally mapped ecoregions at continental scales based on macroclimate regions, but also proposed mapping of finer scale “landscape mosaics” based on geomorphology in addition to bioclimatic partitioning. We consider the 659 ecosystems of South America to be conceptually and scale-equivalent to the landscape mosaics units proposed by Bailey (1996).

It should be emphasized that this approach uses only the physical and biological components (i.e. structure) of ecosystems to model their boundaries, and does not treat ecosystem function in any way. Classical functional definitions of ecosystems (e.g. open systems defined by energy and matter flows, hydrological and nutrient gradients, and complex processes) do not lend themselves to practical, management-oriented, spatial delineation of ecosystems as they are distributed on the landscape. Nonetheless, ecosystem function is a foundational element of basic ecosystem theory, and the ecosystems of South America merit further study from a functional perspective.

Land cover is used as the sole proxy for the biota that are associated with the physical ecosystem footprints. Land cover data are useful because they are generally comprehensively available, fairly current, accurate, and at a moderate spatial resolution. Good data on biotic distributions (flora and fauna, vegetation) would be preferable to land cover, but seldom exist in standardized maps over large areas.

It should also be emphasized that this map of ecosystems is a temporal snapshot of existing ecosystem distribution in the year 2000 era. Three of the physical components of ecosystems that were used in the delineation process (elevation class, landforms, and lithology) are essentially enduring physical features of the environment, and are not expected to change over time. Both bioclimate region and land cover, however, are likely to change as humans continue to dominate the planet. The ecosystems of South America could easily be remodeled using the same methodology when new land cover and climate data become available. A comparison of the two ecosystem maps would then enable a quantitative assessment of land use and climate change impacts to ecosystem distributions. The ecosystems could also be remodeled, if desired, in a sequential, hierarchical fashion using a nested scales approach such as that of Wascher et al., 2007.

The ecosystems map could represent a useful spatial analytical framework for the design of a monitoring system for associating changes in vegetation with changes in land use. In addition to its potential value for ecosystem monitoring, the South America ecosystems map could be quite useful for the spatially explicit calculation of the economic and societal values of ecosystem goods and services. Once formulas exist for the calculation of these values, the ecosystem polygon occurrences could be attributed for multiple ecosystem services values. Knowledge of the ecosystem goods and service values at the level of the polygon occurrences of ecosystems, and their location in space, will be quite useful for resource planning and conservation priority setting.

CONCLUSION

The South America ecosystems map represents the most comprehensive and finest scale characterization of the integrated physical environment of South America ever attempted, and presents the only standardized, meso-scale classification and map of terrestrial ecosystems of the continent available today. The stratification approach to produce ecosystem footprints as unique physical environments and their associated land cover is highly replicable and exportable to other large regions. The ecosystems datalayer is useful for a number of applications, including the economic and societal valuation of ecosystem goods and services. Land planning relies on the accurate delineation of many spatial entities, including property demarcations and ownership, roads, protected areas, and watersheds, and ecosystems are yet another feature of the landscape that can be mapped at management appropriate scales over large areas, as has been demonstrated herein. These ecosystems footprints also represent logical geographic reference units for assessing the impacts of climate change on South American ecosystems.

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CHAPTER 10

LAND COVER AND CONSERVATION: FROM PROTECTED AREAS TO LANDSCAPES

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ABSTRACT

Protected areas are the foundation of conservation efforts at local to global scales. Although the development of formal reserve-selection procedures and conservation planning at multiple scales has made the identification of priority areas for protection increasingly data-based, the resulting areas are often treated as if they were internally homogeneous islands in an equally featureless but unsuitable landscape. Land-cover data, however, show that such conservation areas are not only internally heterogeneous, but that they are embedded in an equally heterogeneous landscape mosaic. The conservation value of a protected area is affected by this internal structure and by the spatial structure and dynamics of the landscape context. Because protected areas by themselves cannot ensure the persistence of biodiversity, it is necessary to include the broader surroundings of these areas in the conservation equation. These are the places where people live and work, so people and their activities are important features of landscape context. Land-cover data are essential to describing the internal and external texture of protected areas, but information on land use and land-use change is equally important if the conservation perspective is to be expanded from the traditional emphasis on protecting "pretty places" to include landscapes, people, and their uses of lands and waters.

Key words: *conservation, land cover, land use, landscape, protected areas.*

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All organisms need a place to live. Recognizing this, governments and nongovernmental organizations have focused their conservation efforts on protecting important places. These protected areas – parks, nature reserves, wildlife refuges, wilderness areas, marine protected areas, and the like -- are the cornerstones of national and international efforts to preserve biodiversity and species. The emphasis on protected areas is understandable given the magnitude of land conversion and loss of native habitat in many areas of the world. Over the decade 1990-2000, for example, a yearly average of 16.1 million hectares of forest was lost to clearing (primarily for agriculture) or conversion to plantations (FAO 2000). In Brazil and Indonesia alone, forest loss averaged over 3.5 million hectares per year, but even more developed countries with "first-world" economies such as Australia lost over half a million hectares of forest cover annually. The Millennium Ecosystem Assessment (2005) reported that 2 of the World's 14 major terrestrial biomes (temperate grasslands and Mediterranean forests) had lost more than two-thirds of their area to habitat conversion (again primarily to agriculture) by 1990. It is little wonder that habitat loss has been called the greatest single threat to biodiversity (Wilcove et al. 1998).

Globally, the move to establish protected areas for conservation has gained impetus from the Convention on Biodiversity, which mandates that signatory countries will place 10% of each of the World's ecological regions under conservation protection by 2010. According to the International Union for the Conservation of Nature (IUCN), nearly 13% of the global land surface is now under some form of protection. Such global estimates are misleading, however. Not only is less than half of this in areas managed primarily for conservation (Brooks et al. 2004), but more often than not reserves are located in "the lands nobody wanted" (Shands and Healy 1977) – high elevation, low productivity areas (Scott et al. 2001). In the northeastern United States and Canada, 77% of alpine regions are secured primarily for nature while only 2% of low elevations and 1% of productive calcareous soils are similarly secured (M. G. Anderson, unpublished). Moreover, some of the world's major habitat types are severely underrepresented. For example, globally only 4.6% of temperate grasslands, savannas, and shrublands and 5% of Mediterranean forests, woodland, and scrub are under some form of conservation protection (Hoekstra et al. 2005).

How much is enough? The Convention on Biological Diversity set a goal of protecting 10% of the world's habitats, while The Nature Conservancy has a goal of protecting 10% of the world's major habitat types (or biomes) by 2015 (while recognizing that this level of protection may be insufficient as a long-term goal). Minimal estimates based on representation alone suggest that 16% to 27% will be necessary just to represent resilient examples of all ecosystem types and populations of vulnerable species (Anderson et al. 2006). Some projections (e.g., Svancara et al. 2005; Tear et al. 2005) suggest that protection of as much as 30% of the area of the world's habitats will be needed to ensure the persistence of contemporary biodiversity. Setting aside the question of whether such an ambitious goal is even feasible in a world of growing populations and accelerating demands on natural resources, it is our belief that setting aside protected areas *by itself* is not a realistic strategy to ensure the persistence of the earth's biodiversity. Instead, conservation efforts must be expanded to include the places where people live and work (Redford and Richter 1999, Miller and Hobbs 2002).

It is in this context that analyses of land cover, land use, and land-cover change become critically important to conservation. To understand what such analyses have to offer, however, it is first useful to consider how approaches to the protection of places for conservation have developed.

THE HISTORICAL VIEW

Traditionally, places were targeted for protection because they had some extraordinary aesthetic value (e.g., national parks), had recreational or indirect economic benefits (e.g., wildlife refuges for game species), because there was an opportunity to protect an area with some apparent conservation value (e.g., many nature preserves owned by land trusts or conservation organizations), or because other uses of the areas were not immediately apparent (e.g., some wilderness areas). Often such protected areas were viewed for simplicity as internally homogeneous areas embedded in a different, but equally homogeneous, matrix. Moreover, the matrix was usually considered as unsuitable or inimical to the organisms occupying the protected area. Of course, land managers and conservationists working on the ground have known and appreciated (and even managed for) the heterogeneity of habitats both within and outside of the protected areas, but it has been practical to ignore such details, for three reasons.

First, until recently most land management for conservation has been carried out in landscapes that have already suffered decades or centuries of human use. Natural habitats have been severely fragmented, and scattered pieces are all that is left to protect. These fragments are usually discrete, sharply bounded, and clearly different from their surroundings, which more often than not seem to be clearly unsuitable (agriculture, developments, and the like). It is easy to simplify the landscape into a black-and-white pattern of suitable patches immersed in an unsuitable matrix (Wiens 2007).

Second, thinking about reserves in the conservation community has been dominated by the island biogeography model. Patches of suitable habitat were often considered as analogs of real islands surrounded by ocean expanses. The formalisms of island biogeography theory (MacArthur and Wilson 1967), which model the species richness of islands as functions of colonization and extinction rates that are largely dependent on island size and isolation, provided a compelling rationalization for the design of nature reserves (Diamond 1975; Shafer 1990). This perspective was reinforced by the development of patch-matrix approaches in landscape ecology (Forman 1995; Wiens 1995; Poiani et al. 2000). Despite criticisms of the island biogeography model in the ecological and conservation literature (e.g., Zimmerman and Bierregaard 1986; Haila 2002; Lindenmayer and Franklin 2002), it continues to find an outlet in a good deal of conservation planning and management.

Third, because areas of remnant natural habitat are often small (especially in much of Europe, eastern North America, and Australia) and land ownership is diversified, land management has frequently been conducted at relatively fine spatial scales (tens to hundreds of hectares). At these scales, it is easier to view patches of habitats to be protected as being internally homogeneous than it is at broader spatial scales, where consideration (and management) of internal heterogeneity may be unavoidable.

FROM PLACES TO PLANNING

Over the past two decades, thinking about which areas to protect for conservation has progressed from an opportunistic focus on “pretty places” or places harboring remnant populations of particular species of concern to more targeted conservation planning. This planning, by both private groups and public land-management agencies, has advanced well beyond the simplistic view of "parks as islands" to consider a broader array of spatial and compositional factors. But in the end, it is still about protecting places.

Several approaches to prioritizing places for conservation have been advanced (reviewed by Groves 2003); here we briefly describe the approach developed by The Nature Conservancy (TNC).

Rather than organize planning efforts about political units (states, counties, etc.), *ecoregions* (relatively large regions distinguished by similar climate, macrotopography, and biota; Bailey 1998) are used as the basic areas within which conservation efforts are to be prioritized (Figure 1). Using structured assembly rules or formalized algorithms developed from the reserve-selection approaches de-

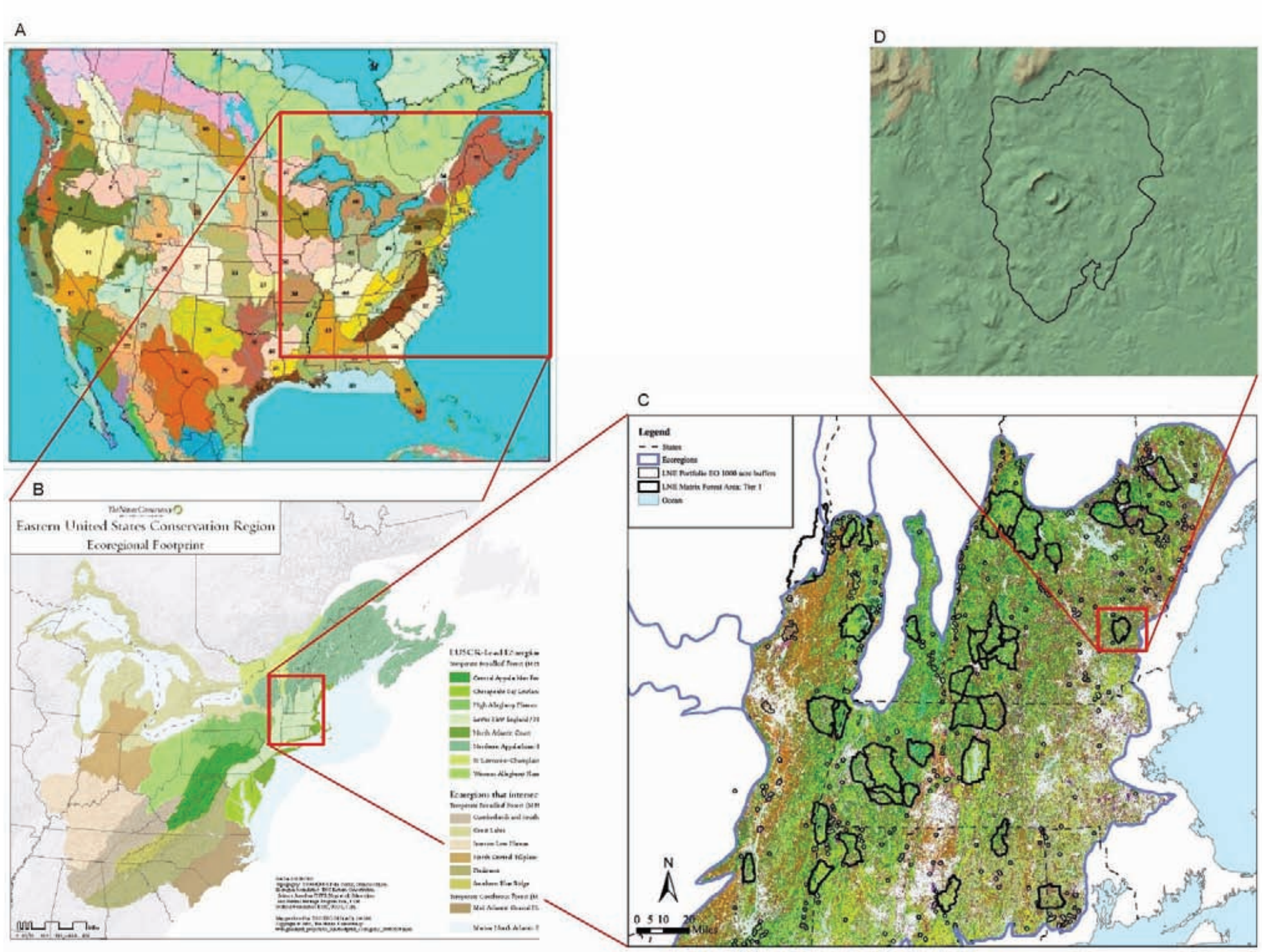

Figure 1. The sequence of The Nature Conservancy's conservation planning. A. The ecoregions of North America (modified from Bailey 1995); B. The ecoregions of northeastern United States; C. The portfolio areas identified in the Lower New England/Northern Piedmont ecoregion by the process of ecoregional planning; D. A conservation action area within the Pawtuckaway Forest portfolio area in New Hampshire.

veloped by Australian scientists (e.g., Pressey et al. 1993; Margules 2005), ecoregional planning (or ecoregional assessment) compiles information on key targets (ecosystems, ecological communities, species of particular concern) and threats to identify a set of *portfolio areas* within an ecoregion that collectively contain the key elements of the biodiversity that characterizes the ecoregion. The portfolio areas are not themselves protected areas or necessarily areas slated for complete protection, but are areas within which local conservation actions to ensure protection of biodiversity are focused to conserve the critical features and populations identified. The initial action is usually some form of land protection, often through purchase and ownership (or transfer) of land or establishment of a conservation easement that restricts uses of an area in ways that protect the plants and animals living there (Byers and Ponte 2005). A conservation action plan is developed to guide management or restoration efforts by assessing the status of key biological targets and the factors that threaten their persistence. The sequence from ecoregions to portfolios to conservation areas is depicted for a site in the northeastern United States in Figure 1. To date, TNC has completed ecoregional plans for nearly all of the terrestrial ecoregions that occur in the United States as well as several dozen international ecoregions. Over the past 10 years, more than 500 conservation action plans have been developed.

EXPANDING THE PERSPECTIVE

So how do land-cover data figure into all this planning? Land-cover maps are the basis for determining priorities among areas and selecting sites at the scale of the ecoregion, and for addressing site-selection questions. Such information contributes the base data for landscape context and habitat suitability indices as well as being an integral part of predictive modeling of ecosystem types. Consider some examples from conservation planning in TNC's Eastern US Region. First, a land-cover index was used to evaluate the degree of human alteration of the landscape within and immediately surrounding each occurrence of a species or ecosystem for inclusion in a portfolio (Anderson et al. 2006). The index is calculated by assigning a weight to each land-cover class (0 for natural to 4 for highly developed) and averaging the scores across all pixels comprising the sample area. Second, fragmentation and con-

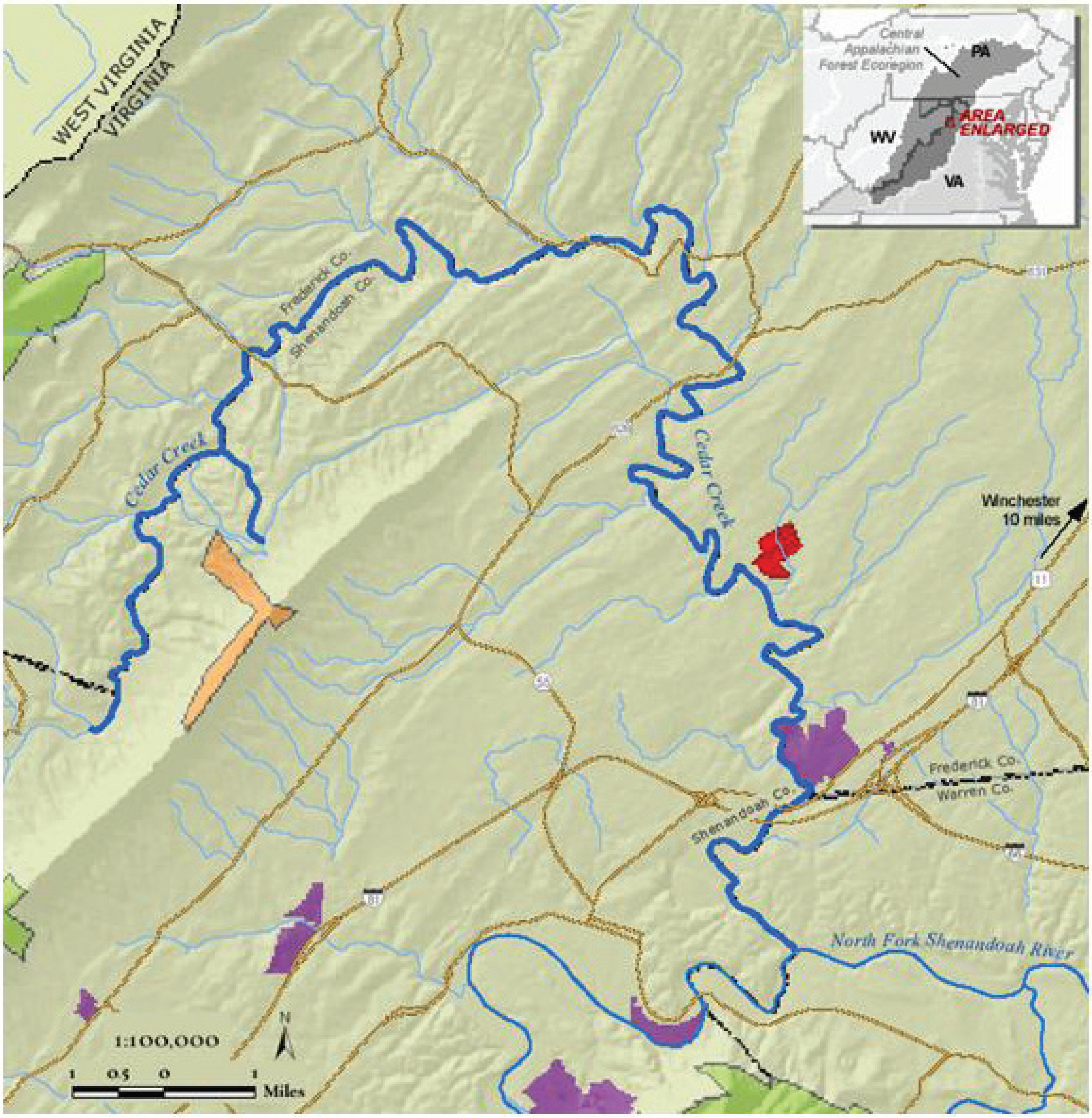

Figure 2. An example of a map accompanying a proposal to purchase a parcel of land (red) as a protected area. Green = National Forest; purple = conservation easement; orange = State Forest.

nectivity analyses (e.g., FRAGSTATS; McGarigal et al. 2002) have been used to measure the degree of continuous natural cover between conservation features based on the number, distribution and configuration of homogeneous patches. Third, high-resolution maps of ecosystems are being developed by combining National Land Cover Data (NLCD) and land-cover/canopy-closure maps with attributes of geology, elevation, and landforms to portray vegetation types such as “closed canopy conifer forest on granite ridges at high elevation” that can be linked to regional classification systems such as

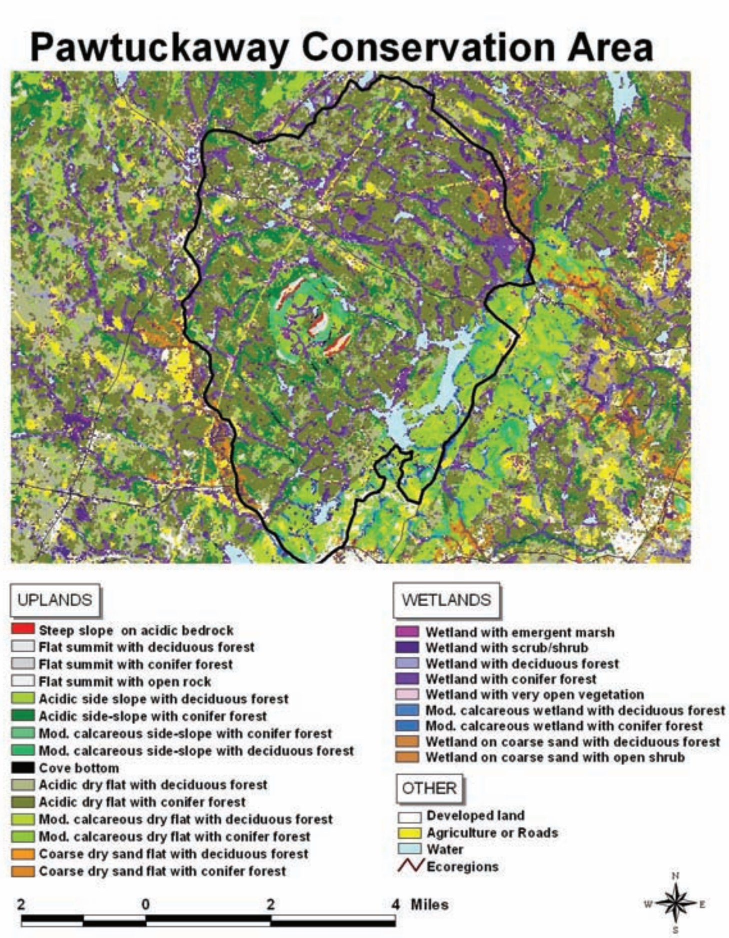

Figure 3. The Pawtuckaway Forest portfolio area, showing coverages of enhanced land-cover map. Land cover is subdivided by geology and landform to approximate an ecosystem type. For example, "acidic dry flat with conifer forest" is equal to "hemlock-white pine forest."

NatureServe's National Vegetation Classification (Anderson et al. 1998). In this example, the type corresponds to red spruce-balsam fir/mountain ash forest. Lastly, land-cover data are used to calculate the ratio of habitat conversion (loss) to protection across various ecological settings such as calcareous soils, flood plains, mountain slopes, or lowland valleys. This information is then used to prioritize action across the region (Anderson et al. 2006).

At the local site scale, however, land-cover data have generally been ignored. As an example, Figure 2 shows a map that accompanied a recent (successful) proposal to protect an area in the Central Appalachian Forest ecoregion in Virginia. The target area is shown (in red) along with some major landscape features (rivers and streams, roads, and other areas with some form of protection). But there is no indication of land cover (much less land uses), either within the targeted area or in the surrounding landscape.

Yet we know that such places are *not* internally homogeneous, and neither are the surroundings. Places invariably have an internal structure that matters to the organisms that live there (and which we are aiming to protect) and, more importantly for this discussion, the surroundings are not a featureless matrix but a richly textured mosaic. These are among the main messages that conservationists should glean from the discipline of landscape ecology (Wiens 2002), and they bring land cover to the forefront. The reality is not that shown in Figure 1D, but rather that depicted in Figure 3.

Why is this important? Landscapes are more than just large areas that are scaled in kilometers rather than hectares. Their structure is important. The ecologist Daniel Janzen observed some time ago that “no park is an island” (Janzen 1983), by which he meant that what goes on within a park or protected area is strongly influenced by what goes on and resides in the areas outside the park boundaries. Organisms – predators, competitors, pathogens, prey – move across the permeable boundary, and so also do disturbances such as fire or windstorms. The likelihood of persistence of a population of a species in a seemingly isolated patch of habitat that might be slated for protection may depend on whether

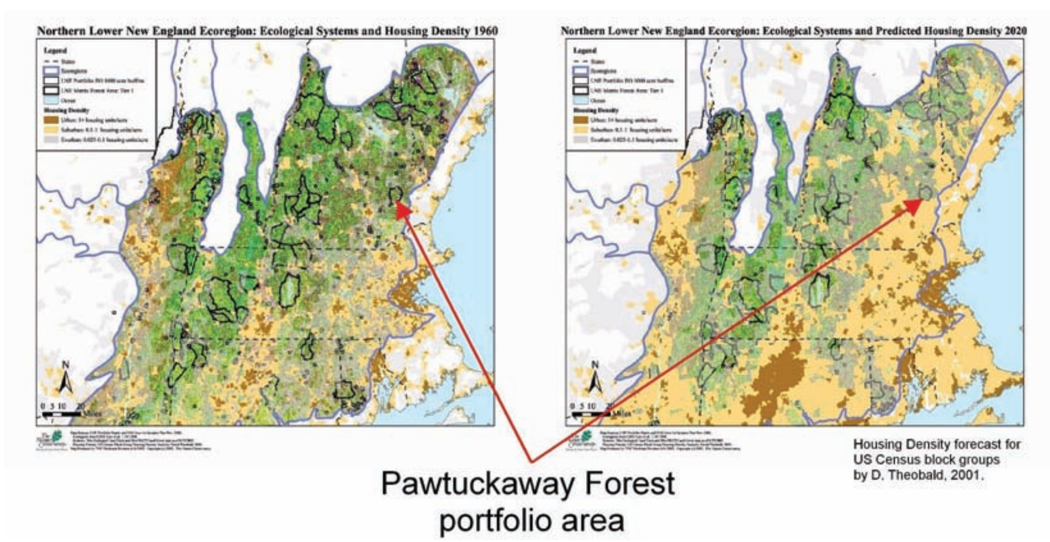

Figure 4. Left. Land cover in the Lower New England.Northern Piedmont ecoregion in 1960, when the area was predominantly rural. Right. Projected land cover in 2020, showing the expansion of urban, suburban, and exburban areas. Land-cover projections based on data developed by Theobald (2001).

the surrounding landscape provides sufficient connectivity to enable dispersing individuals to move to other suitable areas in the landscape (Hanski and Gaggiotti 2004; Crooks and Sanjayan 2006). This, in turn, depends on the composition and explicit spatial arrangement of landforms, vegetation types, and land cover in the landscape mosaic as a whole. This is the stuff of land-cover analysis.

Protected areas and the landscapes that contain them are not static. They are *dynamic*, changing over time as a result of disturbances (e.g., fire, hurricanes, insect outbreaks; Turner et al.1995), changes in human land uses (e.g., the abandonment of agriculture in areas of northeastern United States that resulted in increased forest cover; the conversion of areas of the Brazilian cerrado to soybean agriculture), or, increasingly, global climate change (Lovejoy and Hannah 2005). Models that use land-cover data from previous decades in conjunction with information on the socioeconomic factors driving land-use change to predict future changes in land cover (e.g., Theobald 2005) illustrate how dramatic these changes may be at multiple scales (Figure 4). Clearly, it is not just the landscape context of protected areas that determines their effectiveness in preserving biodiversity, but how that landscape is likely to change over time.

Another example comes from the work of the United States Geological Survey (USGS). USGS has identified the understanding and prediction of ecosystem change as one of its six strategic science goals for the next decade (see http://pubs.usgs.gov/circ/2007/1309/; last accessed 26 September 2007). This goal includes the spatial delineation of ecosystems based on the mapping of land-cover and land-use change at appropriate scales and over time. Toward this goal, USGS has been monitoring land-cover change and use in the eastern United States in order to understand the rates, patterns, and drivers of the changes occurring in the region. The spatial resolution of the analysis (entire ecoregions) is coarse and the land-cover categories very general (Anderson Level I); nonetheless, the analysis shows a 12.5% change in land cover over the region between 1973 and 2000 (Gallant et al. 2004; Loveland and Acevedo 2007). The methodology, which uses a both satellite and aerial imagery to assess land-cover changes in a subset of samples within ecoregions, is being refined and applied to other regions (Loveland et al 2002; Sohl et al. 2004)

WHY DOES CONSERVATION NEED LAND-COVER/LAND-USE INFORMATION, AND WHAT INFORMATION IS NEEDED?

We stated at the outset our belief that an exclusive focus on protected areas will be insufficient to realize the goal of preserving a substantial portion of the Earth's biodiversity. The vision must be expanded to include landscape context, texture, and dynamics. Land-cover data enable this vision. But there must be more.

Conservation will not succeed if it is cast as nature *vs.* people; it must be nature *with* people. People and their activities and uses of the landscape must be included in the vision and actions of conservation. This requires a shift from thinking about protected areas as being essentially pristine or totally natural. Such areas are undeniably important and *should* be protected where possible. Yet many human uses of landscapes have some degree of compatibility with biodiversity. By including places that people use, the overall conservation portfolio will be expanded. But there is more to it than this. Yes, it is important to protect natural biodiversity for its aesthetic and spiritual values and because we have a moral and ethical responsibility to do so (McCauley 2006; but see Reid 2006; Costanza 2006; Marvier, Grant, and Kareiva 2006). But natural ecosystems also provide many services – "ecosystem services" – that enhance human well-being (Daily and Ellison 2002; Millennium Ecosystem Assessment 2005; Kareiva and Marvier 2007), so protection of these systems goes beyond idealism to encompass economics and pragmatism.

What this means is that conservation needs more than information on land cover alone. Land-cover information should be linked with spatially referenced data on land *use*, in sufficient detail to distinguish different uses of the same cover type that may have different impacts on biodiversity and thus confer different conservation values on places. To help conservation planning move to the next level, we need multi-scale data on both land cover and land use to facilitate seamlessly integrated analyses. For example, information from local /site-level projects using very high-resolution data (such as Ikonos or Quickbird) could be incorporated into regional planning exercise using high-resolution data (e.g., Landsat and ASTER) that would be directed by global-scale prioritization analyses (derived 250 m – 1 km data such as MODIS). Such data sets must be spatially and temporally consistent and compatible, or else such integration will encounter roadblocks wherever there is a change from one data set to another. To minimize these disruptions, it is also vital to have continuity of existing sensor platforms (such as the current Landsat sensor series) and to make sure that future sensor information is comparable. Sensors that have different resolutions (either higher or lower) should be designed with the compatibility of a wide range of scales in mind. If we are interested in projecting land-cover changes (and we must be, if we are to make conservation investments that hold their value into the future), we will need time-series data sets that enable change detection and on which robust modeling of future scenarios can be founded. Because conservation dollars are hard to come by and the needs are great, the land-cover and land-use information derived from such sources must also be inexpensive and readily available.

The future of the Earth's biodiversity depends on our ability to weave protected areas into the broader tapestry of landscapes and human activities. This, in turn, is predicated on a comprehensive understanding of land cover and land use – past, present, and future. Ultimately, conservation is a geographical as well as a biological and social science.

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CHAPTER 11

USE OF MIDRESOLUTION LAND COVER DATA FOR RAPID COMPARISON OF COMMUNITY VULNERABILITY TO TSUNAMIS

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ABSTRACT

A Cascadia subduction-zone earthquake could generate tsunami waves which would impact more than 1,000 km of coastline on the west coast of the United States and Canada. The amount of development in tsunami-prone areas varies among coastal communities, creating variations in vulnerability. To illustrate the use of landcover data in comparing community vulnerability, the amount and percentage of developed land in the tsunami-prone areas of 26 Oregon coastal communities were calculated using land cover information derived from midresolution remotely-sensed imagery (e.g., 30-m-resolution Landsat Thematic Mapper imagery). Results demonstrate that in the absence of socioeconomic data or community-based knowledge of assets, information derived from the integration of hazards and midresolution landcover data provides insight on variations in community vulnerability and can identify areas for finer-scale assessments.

Key words: *vulnerability, tsunami, Oregon, Cascadia, C-CAP, LandSat Thematic Mapper, remote sensing*

INTRODUCTION

Societal vulnerability to extreme natural events is a function of how communities occupy hazard-prone land (Mileti 1999; Wisner et al. 2004). Vulnerability, defined as the characteristics of a system that increase the potential for hazard-related losses, is often described by the exposure, sensitivity, and resilience of a system and its assets relative to a hazard (Turner et al. 2002). Information on societal vulnerability helps emergency and land-use managers develop appropriate mitigation, preparedness, response, and recovery strategies to minimize the impact of extreme natural events. To assess vulnerability, managers and researchers often use geographic-information-system (GIS) tools to overlay socioeconomic databases (ex. U.S. Census Bureau population data) and hazard information in order to identify general trends and potential hot spots for further site-specific studies (Cutter et al. 2003a; Wood and Good 2004).

Land cover information derived from midresolution remotely-sensed satellite imagery is another dataset that can be used for vulnerability assessments by providing practitioners a way to determine the distribution of developed land across a landscape. If higher-resolution socioeconomic information is unavailable or an immediate response is required, managers can use the distribution of developed land to approximate the location of people, buildings, and infrastructure and can combine land cover and hazard-zone data to determine where pre-event risks and post-event response issues may be greatest. Although great effort has gone into using land cover data to model population estimates at the pixel level (for example, Bhaduri et al. 2002), less attention has been paid to examine the use of aggregated land cover data for community-level comparisons of vulnerability.

This paper demonstrates the use of land cover information derived from midresolution remotely-sensed imagery for describing hazard-prone land and comparing community vulnerability. This case study focuses on 26 communities on the Oregon coast and their vulnerability to potential tsunami hazards related to a Cascadia subduction-zone (CSZ) earthquake. The ability to compare the distribution of developed land in relation to hazard zones using land cover data derived from midresolution remotely-sensed imagery could serve as one element in a national vulnerability monitoring program to identify at-risk areas, a priority identified in recent national research agendas (Cutter et al. 2003b; McMahon et al. 2005).

STUDY AREA

Historical and geological evidence suggest that the U.S. Pacific Northwest coast has experienced numerous tsunamis and is likely to experience more (Atwater et al. 1995). The most significant tsunami threat for coastal communities is waves generated by an earthquake within the Cascadia subduction zone (CSZ), the interface of the North American and Juan de Fuca tectonic plates that extends from northern California to southern British Columbia (Figure 1A). Geologic evidence and tsunami-inundation modeling suggest that tsunami waves as high as 10 meters could reach coastal communities minutes after a magnitude 8 or greater CSZ earthquake (Cascadia Region Earthquake Workgroup 2005). Recurrence intervals of past CSZ earthquakes vary considerably, ranging from 190 to more

Figure 1. Map of (A) the Cascadia subduction zone (adapted from U.S. Geological Survey 2007) and (B) Oregon coastal communities containing potential tsunami-inundation land.

than 1,000 years between events; the latest CSZ earthquake occurred in 1700 A.D. (Witter et al. 2003). Although much has been done to describe past tsunami events, assess current hazard zones, and develop ocean-monitoring systems, far less has been done to understand the potential socioeconomic impacts of future tsunamis to communities (U.S. Government Accountability Office 2006). Occupation of the tsunami-prone land in the Pacific Northwest varies considerably, from small fishing villages to large industrial cities and these variations in development influence a community's vulnerability. A community with high-density residential and commercial development near the beachfront, for example, will fare worse after a tsunami and recover more slowly than a neighboring city with low-density residential development and open spaces in similar areas.

METHODS

This case study of tsunami hazards in the U.S. Pacific Northwest focuses on the 26 communities on the Oregon coast (Figure 1B) where 2003 city limit boundaries intersect a CSZ-related, tsunami-inundation zone developed for the entire coast (Oregon Geospatial Enterprise Office 2006). Land cover, city boundaries, and tsunami-hazard geospatial data were integrated with GIS tools to describe hazard-prone land and to assess variations in community vulnerability. Vulnerability is defined and used in numerous ways in the scientific literature and in practice by risk managers. Therefore, for the purposes of this paper, exposure and sensitivity – two components of vulnerability (Turner et al. 2002) -- are used to characterize community vulnerability and are determined by the distribution of developed land in a community (delineated by city-limit boundaries) in relation to predicted hazard zones. Exposure is determined by calculating the amount of developed land in tsunami-prone areas of a community; communities with high exposure values are assumed to have more assets in hazardous areas. Sensitivity is the percentage of developed land in tsunami-prone areas relative to the total amount of developed land within a community. Sensitivity values are calculated to approximate the overall impact to a community if developed land, and the assets it represents, in hazard-prone areas are damaged. Additional definitions of sensitivity (for example, the distribution of special-needs populations) and resilience (for example, adaptive capacity to extreme events) are not addressed here, nor are the underlying determinants of community vulnerability (Wisner et al. 2004).

The distribution of developed land is determined using 2001 land cover data of the National Oceanic and Atmospheric Administration's (NOAA) Coastal Change Analysis Program (C-CAP). C-CAP is a nationally standardized land cover database for U.S. coastal regions (NOAA CSC 2007; Dobson et al. 1995) that is part of the National Land Cover Database (NLCD) effort through the interagency Multi-Resolution Land Characteristics (MRLC) consortium. C-CAP land cover products are automatically derived from Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM) digital satellite imagery, have a 30-meter spatial resolution and have reported accuracy standards of 85 percent (Dobson et al. 1995). C-CAP data generated prior to 2005 has 22 land cover classes, with developed land represented by low-intensity developed (between 25 and 75 percent impervious cover) and high-intensity developed (greater than 75 percent impervious cover) (Dobson et al. 1995). Figure 2 demonstrates how maps of land cover, city boundaries and predicted hazard zones can quickly

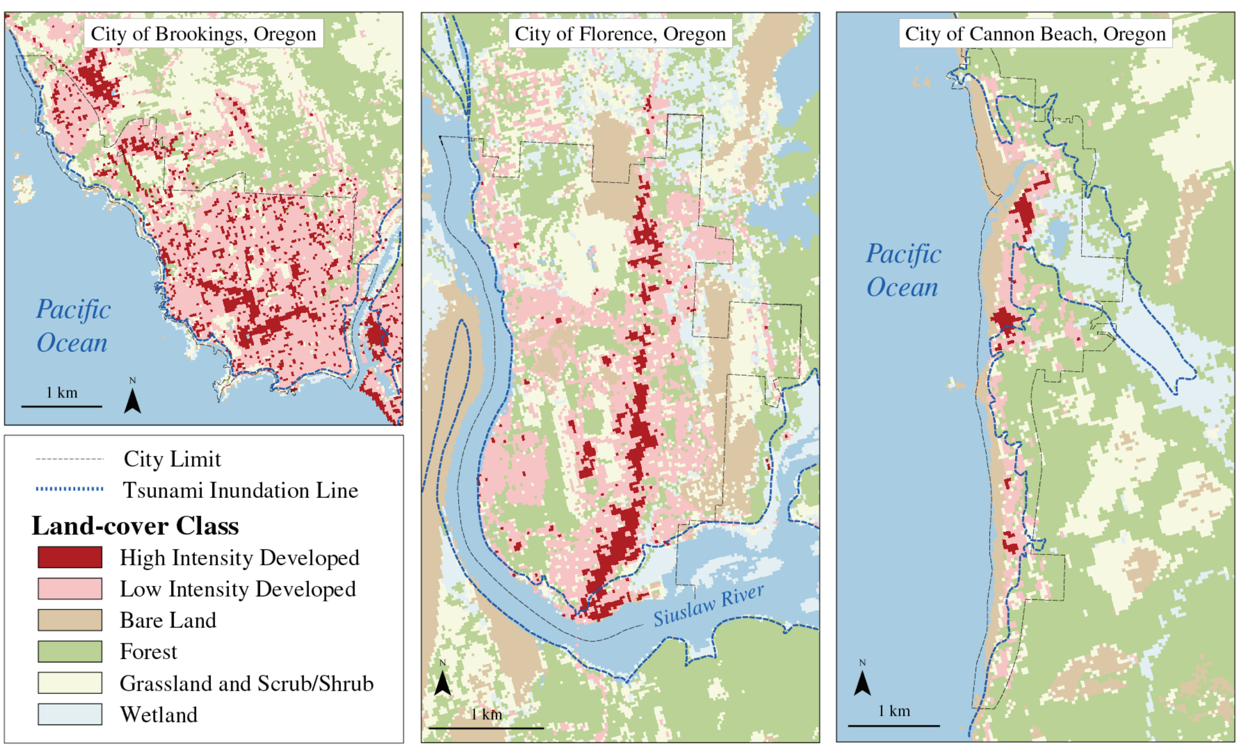

Figure 2. Examples of 2001 NOAA C-CAP land cover data for (A) City of Bandon, (B) City of Newport, and (C) City of City of Cannon Beach, Oregon.

illustrate potential community exposure to tsunami hazards. Based on the distribution of high- and low-intensity developed cells, the majority of development is outside of the tsunami-hazard zone in the cities of Brookings (Figure 2*A*) and Florence (Figure 2*B*), but inside the tsunami-inundation zone in the City of Cannon Beach (Figure 2*C*). Maps of land cover data that highlight cells classified as developed may provide quicker situational awareness to response personnel than aerial photographs, where determining developed areas require additional visual interpretation.

DESCRIBING HAZARD-PRONE LAND

A first step in understanding societal vulnerability to CSZ-related tsunamis is to determine what type of land is in tsunami-prone areas. Based on the spatial overlay of 2001 C-CAP land cover data with city-limit boundaries and the tsunami-inundation zone, the distribution of non-marine land cover classes (by area) in the tsunami hazard zone was determined for the entire Oregon coast (Figure 3). Results indicate that 95 percent of the tsunami-prone land in Oregon is undeveloped (classified as something other than high- or low-intensity developed). Wetland-related classes are the most common type of land cover found in the tsunami hazard zone (56 percent), followed by grasslands (15

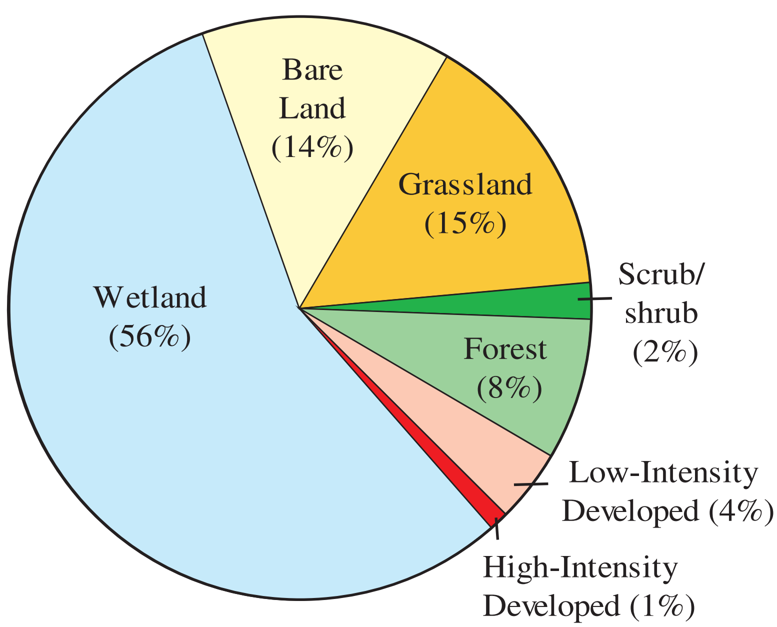

Figure 3. Distribution of land cover types (by area) in tsunami-hazard zone for the Oregon coast.

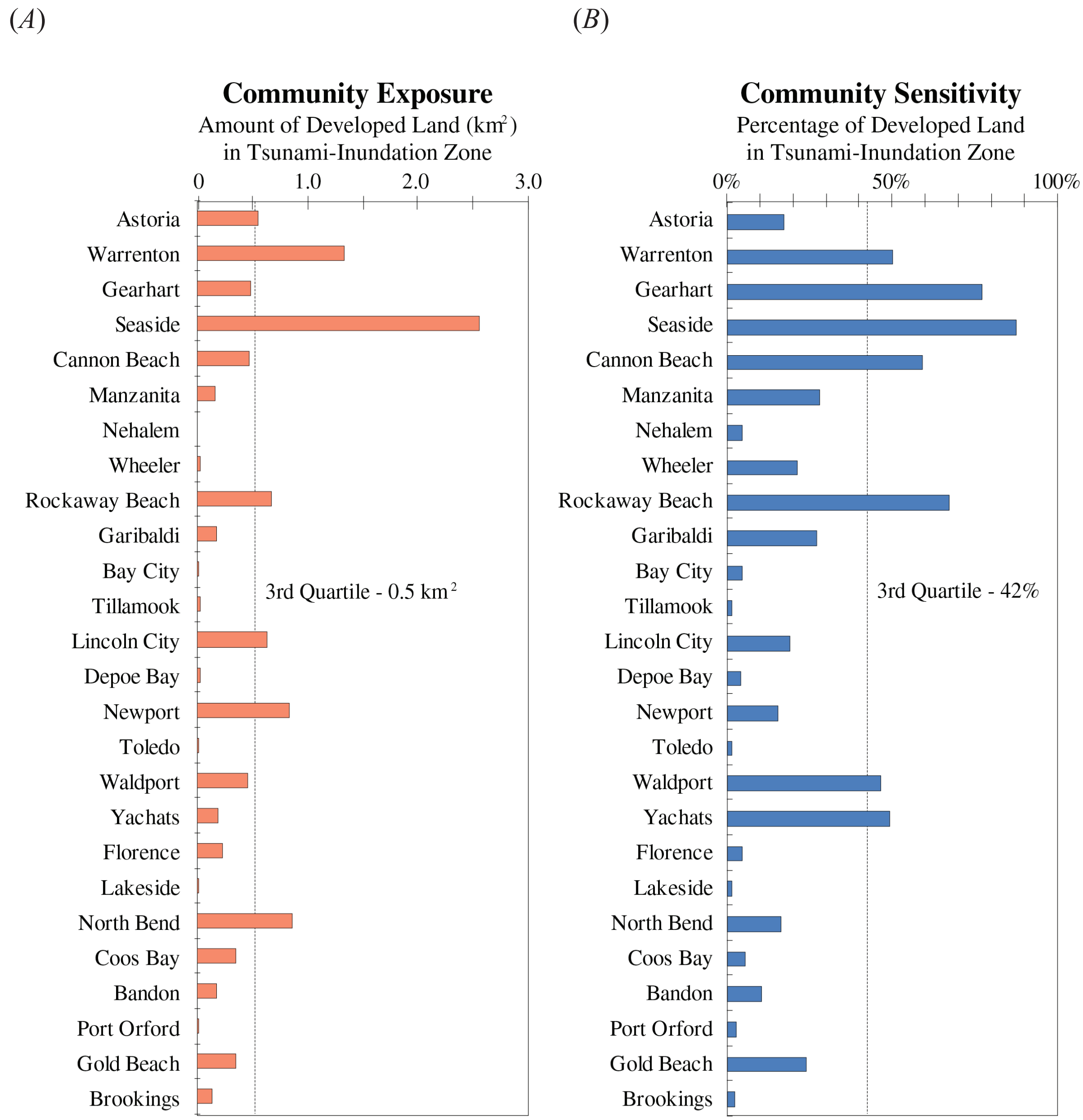

Figure 4. The amount (A) and percentage (B) of land cover cells classified as either low- or high-intensity developed in the tsunami hazard zone for each community. City names are ordered geographically from north to south, with the most northern town at the top.

percent) and bare land (14 percent). Although the majority of hazard-prone land is not classified as developed, undeveloped areas can attract recreationists, local residents as well as tourists, who could be impacted by a Cascadia-related tsunami (Wood, Good, and Goodwin 2002; Wood and Good 2004).

VARIATIONS IN COMMUNITY EXPOSURE AND SENSITIVITY

Based on the spatial overlay of 2001 C-CAP data, city limits, and the predicted tsunami-inundation zone, the amount (Figure 4A) and percentage (Figure 4B) of land cover cells classified as developed (either low- or high-intensity) in tsunami-prone areas varies greatly among Oregon coastal communities (Figure 1B). Median and third-quartile values are noted for quick identification of communities that are above regional trends and are used due to the non-normal distributions and extreme ranges of the data.

Median values for the amount and percentage of developed land in hazard-prone lands are 0.21 km^2 and 17 percent, respectively; however, some communities are much higher, including the City of Seaside with 2.57 km^2 of developed land in hazard-prone areas that represents 88 percent of its developed land. In general, results indicate that communities on the northern coast have higher exposure and sensitivity to tsunami hazards than other Oregon coastal communities. Some communities have high amounts of developed land but these amounts represent small percentages of total land; for example, the cities of Newport and North Bend exceed the third-quartile (0.53 km^2) in the amount of tsunami-prone developed land, yet these amounts represent only 15 and 16 percent, respectively, of each town's overall developed area and well below the third-quartile value (42 percent). Conversely, the cities of Gearhart, Cannon Beach, Waldport, and Yachats have less than 0.53 km^2 of developed land in tsunami-prone land but these low amounts represent the majority of each town's total development. Therefore, some communities have high exposure to tsunamis (ex. Newport) and other communities have high sensitivity (ex. Cannon Beach). It is up to managers to decide where to allocate limited risk-reduction resources—to the communities with high exposure and likely high loss potentials or to communities with high sensitivity that may be incapable of adapting to the loss of significant percentages of their assets.

The threat of Cascadia-related tsunamis in the U.S. Pacific Northwest has been recognized only in the past few decades and future studies of land cover patterns and land cover change will shed light on whether development increases or decreases in tsunami-prone areas of these 26 communities. A subset of the National Land Cover Database that characterizes land cover change at the 30-meter resolution and temporal periods of ten years or less, with specific attention to class transitions from natural classes (for example, forests, grasslands) to developed classes (either high- or low-intensity), would facilitate studies that focus on determining how and why societal vulnerability to tsunamis, or any natural hazard for that matter, changes over time. This information and subsequent studies would help communicate to policymakers and the general public that vulnerability is a dynamic characteristic of a society that changes over time due to social, political, and economic forces.

SUMMARY

This case study of tsunami hazards on the Oregon coast demonstrates how land cover information derived from midresolution remotely-sensed imagery can be used to compare variations in developed land relative to predicted hazard zones. Although the potential for tsunami hazard inundation is similar for low-lying portions of the Oregon coast, communities have made different decisions about where development occurs and these decisions shape each community's vulnerability to future tsunamis. Estimation of vulnerability based on land cover patterns may be a starting point for many communities -- to be refined later with higher-resolution geospatial data and/or community-based socioeconomic information. For other communities or for agencies with national perspectives, the use of land cover data and other national databases may be the only approach available if the geographic scale of a hazard is so large that the collection of higher-resolution data is not feasible or if resources are not available for further studies. Whether it is a first step or the only step, the approach outlined here could provide practitioners and policymakers with methods for visualizing how development decisions influence the magnitude of future disasters.

ACKNOWLEDGEMENTS

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CHAPTER 12

The Critical Ecosystem Assessment Model (CrEAM): Identifying Healthy Ecosystems for Environmental Protection Planning

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ABSTRACT

The Critical Ecosystems Assessment Model (CrEAM) is a screening tool that evaluates the ecological condition of undeveloped landscapes across the Midwest States of Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin. Landscape-level ecological condition is defined by three equally weighted assessment criteria: 1) ecosystem diversity, 2) stressors, and 3) rarity. We defined ecological diversity as the predicted diversity of populations, communities, and ecosystems; stressors as the amount of fragmentation, and chemical and physical pressure; and rarity as both land cover rarity and biological rarity. The Critical Ecosystems Assessment Model (CrEAM) integrates data that describe these three criteria in a geographic information system (GIS). The base map of the CrEAM is a matrix of 300m x 300m cells generated by aggregating the 30 x 30 meter pixels of the 1992 National Land Cover Database (1992 NLCD). Data from the 1992 NLCD, along with twelve other pre-existing data sets were processed to generate twenty indicators of condition: four for diversity, twelve for stressors, and four for rarity. The data in each layer provide a measurable output for each of the cells in the matrix. These measures were normalized. Results were generated for each criterion and combined into a final composite map depicting landscape-level ecological condition. Field validation is underway. The resulting scores from these maps were compared with a previous analysis of the same six states, where natural resource partners identified the ecosystems that were most important to them and where they were concentrating their efforts. The methods developed by the CrEAM can be used as a screening tool to assist workload prioritization, help identify geographic initiatives, and focus geographic targeting.

Key words: *Landscape ecology, diversity, geographic information systems, indicators, ecosystem assessment*

INTRODUCTION

The Region 5 Office of the United States Environmental Protection Agency (EPA) is responsible for federal environmental programs in the Midwest States of Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin. These programs are developed to ensure compliance with federal laws through assistance and enforcement, build partnerships with state, tribal and local environmental regulators, foster stewardship and further voluntary efforts to protect human health and the environment. Often these programs have similar objectives, such as targeting critical ecosystems for protection and restoration efforts. To that end, Region 5 created the Critical Ecosystems Team, tasked with identifying ecosystems of high quality and importance within the Region 5 states. Early on, the team found that some states and environmental and natural resource partners had identified important ecosystems in these states using various approaches at different scales. (Mysz, Maurice, Beltran et al. 2000). The team sought to establish its own systematic and objective method to assess ecological condition throughout the Region using scientifically defensible data or proxies for data.

For the CrEAM effort, ecological condition is defined as the integration of three independent criteria: 1) ecosystem diversity, 2) lack of ecological stressors and 3) locations with rare species and land cover. In addressing each criteria, ecosystem diversity is defined as the presence of community, and/or ecosystem diversity (Chapin, Zavalet, et al. 2000, Ehrlich and Wilson 1991). Ecological stressors are the agents whose cumulative effects result in loss or decline of ecosystem integrity without external assistance or management. (Dale, Brown, et al. 2000), (Gunderson, Holling, et al. 2002). Species and Land Cover Rarity is defined as the occurrence of rare native species, or communities and land cover types of special ecological interest. (Dobson, Rodriguez, et al. 1997, Pimm and Lawton 1998). Most ecologists agree that these measures of ecosystem organization, vigor, and resilience will indicate the health of an ecosystem (Ulanowicz 1980, Rapport, Costanza, and McMichael 1998, Costanza and Mageau 1999, Patil, Brooks, et al. 2001) and using the three criteria identified above, we hope to use existing data to identify those areas.

PROBLEM STATEMENT

Natural resource managers could make more informed decisions if they had a consistent way to evaluate the relative ecological condition of an area. Unfortunately, this information is generally not available because the evaluation of ecological condition is a difficult task at the landscape scale. Although several researchers have proposed ways to evaluate ecological condition (O'Malley and Wing 2000, Xu, Sawson, Tao et al. 2001, Campbell 2001, Day, Rybczyk, Garson et al. 1997, Costanza and Mageau 1999, Jenson, Bourgeron, Everett et al. 1996), it is difficult to find consistent and comparable data for these evaluations over large areas (Gaston 2000, Levin, Bryan Grenfell, Alan Hastings et al. 1997, Verburg, Soepboer, Veldkamp et al. 2002). The recently published materials reporting on the progress of the Convention on Biological Diversity for 2010, (Balmford, Bennun, Brink et al. 2005, Bai, Beintema, Fredvik et al. 2005) and the Millinium Assessment (Meyerson, Baron, Melillo et al. 2005) reiterate the call for scientifically defensible, repeatable assessment methods for ecological condition. In the United States, attempts have been made to address these issues in the States of Delaware, Maryland, Pennsylvania, Virginia, West Virginia and the District of Columbia (Jones, Ritters, Wickham et al. 1997, Patil, Brooks, Myers et al. 2002). Unfortunately, a similar analysis does not exist for ecosystems in the Midwest States of Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin (Figure 1).

METHODS

To systematically and objectively assess the ecological condition of undeveloped areas, the team developed a model using available data. We present this as a model because the intent is to predict the condition in areas for which we have very little ecological data from datasets we think will characterize the condition. It is a spatial model rather than a temporal model. The results of the model are three major data layers that predict the three characteristics (criteria) that would identify a high quality, or ecologically important portion of the region (Table 1).

A Geographic Information System (GIS) was selected as the analysis platform because it allows investigators to efficiently aggregate multiple geographically referenced data sets. GIS can also be

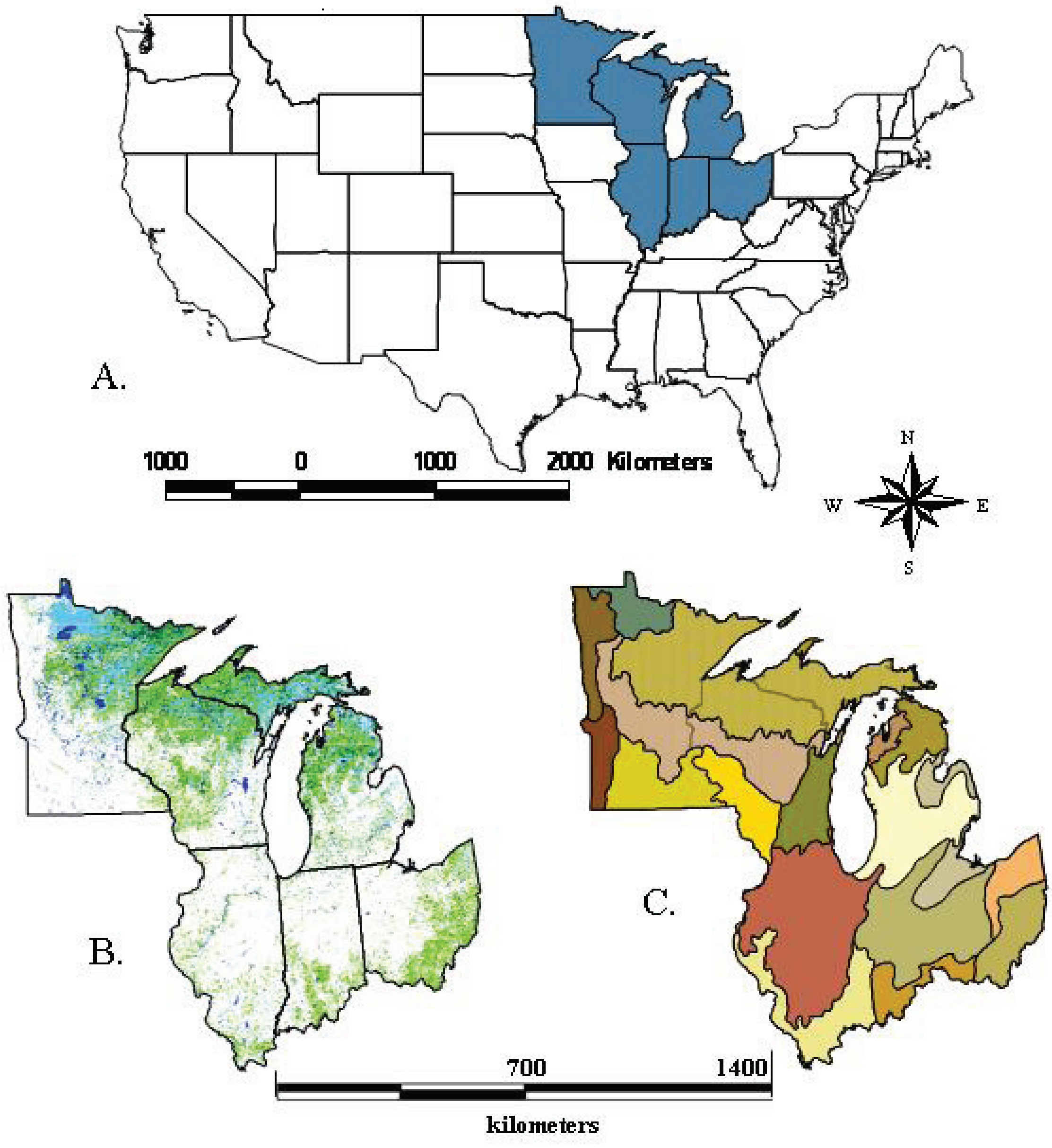

Figure 1 (A) The study area is the U.S. Environmental Protection Agency Region 5 which includes Illinois, Indiana, Michigan, Minnesota, Ohio and Wisconsin (shaded). (B) The study area shown with 1991 National Land Cover Dataset (NLCD) data. Colored areas are undeveloped land cover classes, white areas are developed. (C) The study area shown with Omernik level III ecoregions.

used to effectively conduct landscape scale analysis (van Horssen, Schot, and Barendregt 1999, Aspinall and Pearson 2000), DellaSalla, Staus, Strittholt et al. 2001, Bojorquez-Tapia, Juarez, and Cruz-Bello 2002). Relevant existing data sets were sought as indicators for ecological diversity, stressors, and rarity. The CrEAM data sets were spatially and temporally consistent covering the entire six state study area and representative of conditions that existed in the early 1990's. A total of 20 data sets were used as indicators for the three criteria: four for ecological diversity (C1.1-4), 12 for stressors (C2.1-12), and four for rarity (C3.1-4); Table 1.

One of the fundamental data sets for developing the indicators was the 1992 National Land Cover Database (1992 NLCD). The 1992 NLCD is a mosaic of satellite scenes taken between 1990 and 1992 and classified into 23 land cover types (Loveland and Shaw 1996). In the six state study area, 20 of the 23 land cover categories were present (Table 2). nine of which were considered potentially undeveloped, while 11 were considered distinctly developed land cover classifications (Ebert and Wade 2000). Because the principal objective of this project is to identify ecosystems that are healthy and contain

ECOLOGICAL DIVERSITY C1	**STRESSORS C2**		**RARITY C3**
	Landscape Fragmentation	**Chemical and Physical Stressors**	
C1.1 patch size of undeveloped land	C2.1 perimeter to area analysis	C2.5 airport buffers	C3.1 land cover rarity
C1.2 land cover diversity	C2.2 patch size by land cover type	C2.6 NPL Superfund sites	C3.2 species rarity
C1.3 temperature & precipitation maxima	C2.3 weighted road density	C2.7 RCRA corrective action sites	C3.3 rare species abundance
C1.4 temporal continuity of land cover type	C2.4 waterway impoundment	C2.8 water quality summary	C3.4 rare species taxa abundance
	C2.12 land cover suitability	C2.9 watershed obstruction	
		C2.10 air quality summary	
		C2.11 development disturbance buffer	

Table 1. Data sets used as indicators of ecological condition.

high quality habitat, only the nine potentially undeveloped 1992 NLCD land cover classifications and open water were used. The waters and islands of the Great Lakes were not included in the analysis.

Throughout this paper, the word ”pixel” will be used to refer to the original 1992 NLCD 30m x 30m data and “cell” will refer to the aggregated 300m x 300m data. Additionally “square” will be used when data are summarized into other resolutions, “patch” will refer to pixels, cells or squares that have been aggregated by a common classification into irregular polygons (Figure 2). Ideally calculations of data for the layers would be done at one resolution and the squares defined above would be the base cell size. Unfortunately, computation limitations required all patches less than 9 hectares eliminated from the analysis and varied resolutions of squares.

The CrEAM is based on a grid of 300m x 300m cells (9 ha.) a size that has been shown to be appropriate for landscape scale habitat analysis (O’Neill, Hunsaker, et al. 1997). The base land cover data was derived by re-sampling 10 x 10 pixels of the 1992 NLCD assigning the majority to each cell.

POTENTIALLY UNDEVELOPED (used in analysis)	**1992 NLCD code**	**percent user accuracy***	**DISTINCTLY DEVELOPED (not used in analysis)**	**1992 NLCD code**
Open Water	1	96	Low Intensity Residential	21
Mixed Forest	43	75	High Intensity Residential	22
Bare Rock/Sand/Clay	31	63	Commercial/Industrial/ Transportation	23
Evergreen Forest	42	63	Quarries/Strip Mines/Gravel Pits	32
Deciduous Forest	41	61	Transitional	33
Shrub land	51	52	Orchards/Vineyards/Other	61
Woody Wetlands	91	43	Pasture/Hay	81
Herbaceous Wetlands	92	35	Row Crops	82
Grasslands/Herbaceous Vegetation	71	33	Small Grains	83
			Fallow	84
			Urban/Recreational Grasses	85

* defined in (Stehman et al. 2003), data from www.epa.gov/mrlc/region/region5.html

Table 2. 1992 NLCD Land Cover Classifications that occur in the study area and the associated 1992 NLCD accuracy (at 30m x 30m) in classification.

When more than half of a cell's underlying 10 x 10 grid of pixels were classified as potentially undeveloped, the cell was deemed undeveloped. Additionally, when more than half of a cell's pixels had a single potentially undeveloped classification, the cell was assigned the land cover of this majority classification. In cases where no single classification attained this majority, deciduous and evergreen forest pixels were reclassified as mixed forest. Mixed forest became the majority classification in all these cases.

Many data layers are calculations based on NLCD data; however other data was acquired to characterize ecological condition (Table 1). Those with continuous coverage were interpolated to the to the 300m x 300m cell using the coverage's classification or value at the cell's centroid. An example of a continuous coverage is the temperature and precipitation maxima. Data that was discrete, such as the point locations of dams, were aggregated to the 300m x 300m cell using the coverages' classification or value at its points or lines.

Calculations

Each data set was indexed on a scale of 0-100 as will be described below. Zero always indicates the lowest quality, the greatest stress, or the least valuable observation and 100 indicates the highest

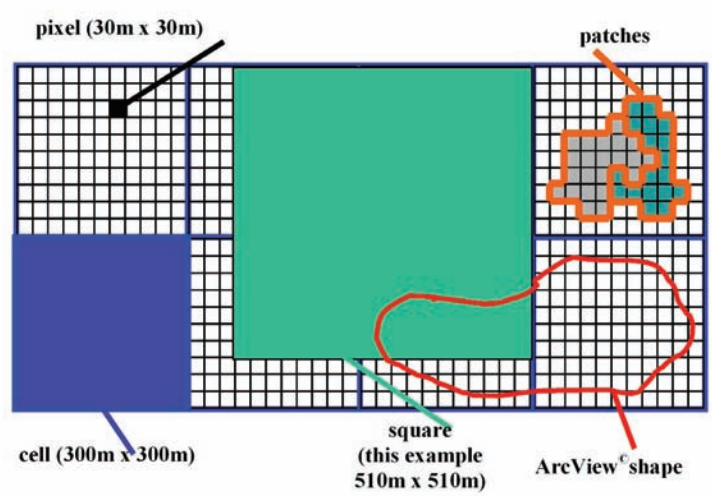

Figure 2. Examples of terminology used in this study. Pixels are the National Land Cover Database 30m x 30m land cover data. Cells are aggregates (by majority) of the pixels. Squares are various summary sizes, always larger than a cell. Patches are pixels, cells, or squares that have been aggregated by a common classification into an irregular polygon. Shapes refer to ArcView© shape files.

quality, least stress, or most valuable observation.

ECOLOGICAL DIVERSITY

Ecological diversity is the variety and abundance of species, their genetic composition, and the communities, ecosystems, and landscapes in which they occur, (Dale, Brown, et al. 2000, Chapin, Zavalet, et al. 2000, Coufal 1997). Unfortunately, indices of species and community diversity are labor and data intensive to measure. They usually require extensive field observations and data collection, so they are often only used over small geographic spans. For this reason, the CrEAM uses land cover indicators and spatial statistics as proxies for landscape, species, communities, and ecosystem diversity. These indicators include patch size of undeveloped land (C1.1), land cover diversity (C1.2), temperature and precipitation maxima (C1.3), and temporal continuity of land cover type (C1.4).

Patch size of underdeveloped land (C1.1)

The CrEAM uses the size of undeveloped land cover patches as an indicator of species richness because MacArthur and Wilson 1967, Dale and Haeuber 2000, and Wardle, Yeates, et al. 2003 have shown that species richness correlates with undeveloped patch size. To produce this layer all undeveloped pixels, regardless of land cover classification, were aggregated into patches. The area of each patch was calculated and these patch areas span seven orders of magnitude. The CrEAM converts the measure to the 100 point scale using the base 10 logarithm ($\log_{10}$) of the areas to reduce the skew caused by the few large patches.

Land cover diversity (C1.2)

Undeveloped land cover diversity measurements have been shown to indirectly reflect community diversity (White, in preparation). The CrEAM uses a form of the Shannon-Wiener (H) index (Barbour, Burke, et al., 1998) to assess the abundance and evenness of undeveloped land cover types among the cells. The model uses an index calculated by partitioning the 30m x 30m undeveloped pixels by land cover type in 1km x 1km squares. To calculate the Shannon-Wiener (H) index within each 1 km. square, let

n_i = the number of individual pixels in each land cover category.

S = the number of undeveloped land cover categories,

p_i = the proportion of individual pixels in each land cover category to the total pixels.

Then

$$H = -\sum_{i=1}^{S} p_i \ln p_i .$$

In the study area, H values for the squares range from H = 0.00 to H = 1.93.

The CrEAM then multiplied each H value by the percent of undeveloped pixels in each respective1km x 1km square to allow more influence for the abundance of undeveloped land. The model partitioned the1km x 1km squares into their respective Omernik Level III Ecoregions (Figure 1C) (Omernik, 1995). These indices were normalized from 0-100 within each of the 17 ecoregions in the study area. Finally, the model brought these normalized values back into the cell network assigning the cell centroid the value of the 1km x 1km square.

Temperature and precipitation maxima (C1.3)

The CrEAM uses the areas with the highest average temperature and precipitation in an ecoregion as an indicator of species diversity based on the ecological principle that warmer, moister climate favors higher numbers of species (Pennisi 2000, Gaston 2000, Lugo and Brown 1991). In most of the United States, elevation would be a better indicator of diversity of plant community. However in the Midwest changes in elevation are very slight and in this study area it is reasonable to use precipitation and temperature zones (Luck and Milne, 2006).

The Midwestern Regional Climate Center provided average contours for the ten year period of 1990 – 1999 from daily temperature and total daily precipitation data. Temperature contour data were in three degree (F) intervals. Precipitation contours were in five inch intervals. Omernik Level III Ecoregions were superimposed onto the temperature and precipitation maps. We identified the portion of each ecoregion containing the intersection of the highest precipitation and the highest temperature. These highest temperature and precipitation locations were given a value of 100 while all other locations were given a zero (0). The CrEAM brought these values back into the cell network using the cell centroids.

Temporal continuity of land cover type (C1.4)

Long-term, established ecosystems tend to have more complex communities with more species than younger ecosystems (Krohne 2001). The CrEAM used Küchler potential vegetation types (Küchler 1964) cross referenced with the 1992 NLCD land cover classifications to assess temporal continuity as an indicator of species diversity.

Küchler listed the physiognomy and the dominant and secondary plant species for each vegetation type. These plant species were cross-referenced with the 1992 NLCD classification of each cell. Suitability decisions are based on whether the Kuchler classification could reasonably be envisioned as existing within the 1992 NLCD classification. For example, it is reasonable that patches of oak hickory forest could exist in cells classified by the NLCD as mixed forest, since tree species are heterogenously distributed in mixed forests and the deciduous portion of the mixed forest could consist of oak and hickory trees. Conversely, it is not reasonable to assume that patches of oak and hickory trees exist in cells classified as evergreen forest. 1992 NLCD cells that were deemed compatible are assigned a score of 100 whereas cells that were incompatible were assigned a score of 0.

The cell unit values for the four data layers C1.1-C1.4, each range from 0-100, are summed to the composite Diversity layer shown in Figure 3A. Composite scores ranged from a high of 397 to a low of 0.

STRESSORS

Ecological sustainability is viewed as being negatively impacted by two classes of factors, landscape fragmentation and chemical, physical, and biological stressors (Underwood 1989). In the CrEAM, landscape fragmentation is characterized by five data sets (C2.1-C2.4 and C2.12). Stressors are characterized by seven data sets (C2.5-C2.11) (Table 1). Although non-indigenous invasive species are considered to be very important stressors in the environment, they are not included in this analysis because of the unavailability of reliable, region-wide data sets. The following sections contain a sum-

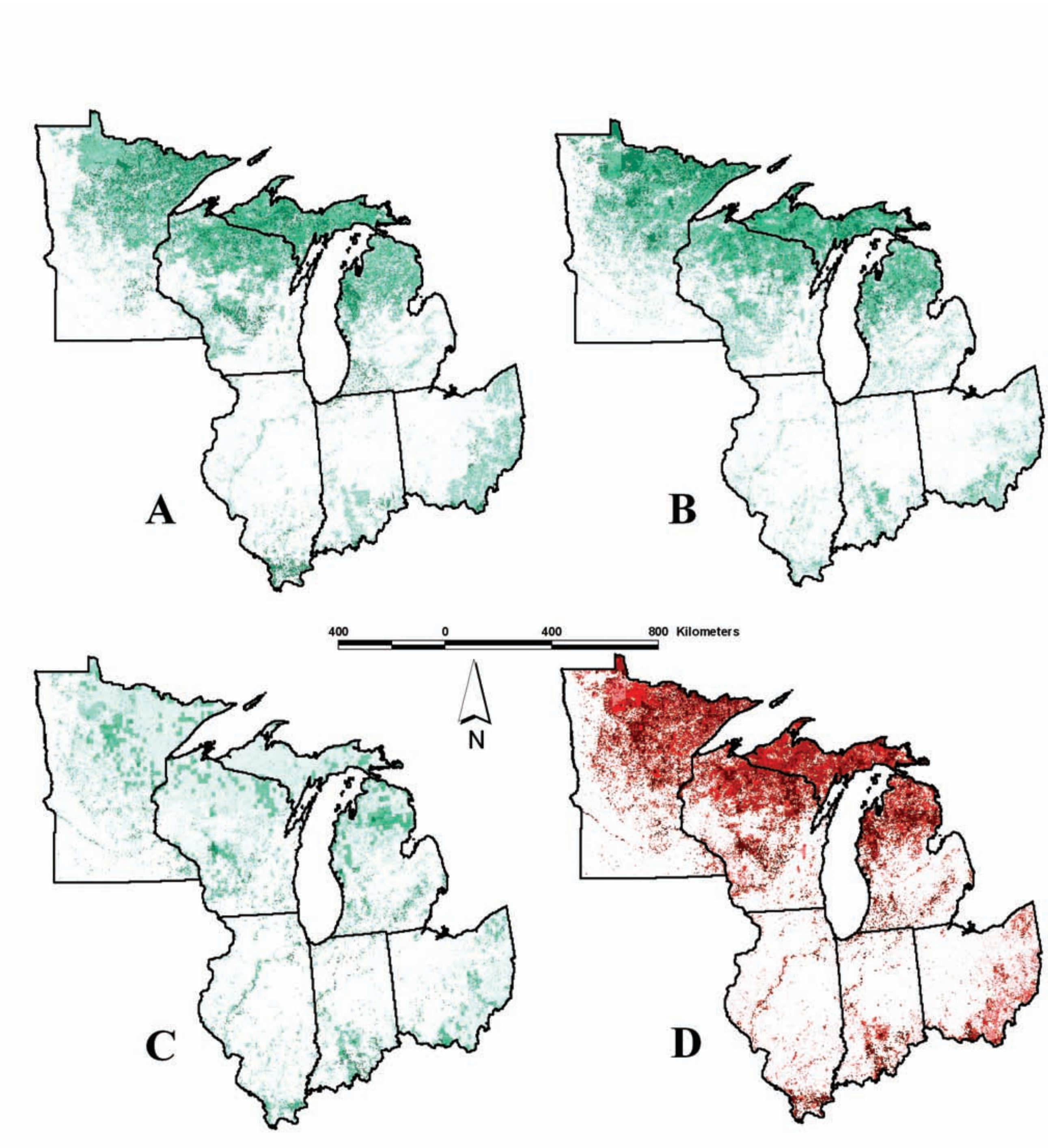

Figure 3. Results of combined data layers for A) C1-Diversity, B) C2-Stressors, C) C3-Rarity and D) the composite ecological condition derived by summing C1, C2 and C3. Darker colors indicate higher quality. Each frame was scaled independently showing five contrast levels calculated by equal area.

mary of the stressor data layers.

Patch perimeter to area analysis (C2.1)

Land cover patches are contiguous pieces of landscape of one land cover type. Their boundary regularity has been shown to be a direct measure of landscape fragmentation (Gascon, Williamson, and Fonseca 2000). Edge effects around natural communities and ecosystems include the potential for increases in invasion by exotic species and poorer survival rates (Semlitsch and Bodie, 2003, Batary and Baldi, 2004). Low perimeters to area ratios produced by more circular patch boundaries tend to minimize the stress of edge effects in terrestrial systems and thus would indicate less stress on a system. The opposite holds true for shallower waters and shorelines. Here, linear dimensions with crenulations are the most biologically active areas. These shapes also have the highest perimeter to area ratios. Thus, for open water, the perimeter to area ratio scores was inverted.

The ratio ranged from a maximum of nearly one to a minimum of 10^{-7}. The $\log_{10}$ of the ratio was used for the final scale to reduce the skew caused by a few high values and was normalized on a scale of 1 to 100. The score for the patches was then distributed in the cells as described in patch size of undeveloped land (C1.1).

Patch size by land cover (C2.2)

The inverse of the size of a patch of land is a direct measure of landscape fragmentation (Gascon, Williamson, and Fonseca 2000) and thus one way to quantify stress on a landscape. The larger the patch of the same land cover type, the more likely it is to persist (Krohne 2001, Dale, Brown, Haeuber, 2000). Based on this assumption, patch size was calculated by aggregating the contiguous undeveloped pixels of the same land cover classifications into patches and calculating the areas.

Similar to C2.1, these areas span seven orders of magnitude. The CrEAM converts the measure to the 100 point scale using the base 10 logarithm ($\log_{10}$) of the areas to reduce the skew caused by the few large patches.

C2.2 is different from layer C1.1 in that patches in the former are generally smaller (mean = 65 ha.) and are comprised of the same land cover type while patches in the latter are larger (mean = 245 ha.) and are comprised of multiple undeveloped land cover types.

Weighted road density (C2.3)

Roads fragment undeveloped areas, introduce corridors for invasive plants and animals, modify hydrology, cause disturbance zones on both sides of the road and disrupt wildlife with associated road noise (Gascon, Williamson, and Fonseca 2000, Abbitt, Scott J. M, and Wilcove D. S 2000). For these reasons, the CrEAM included a road density metric. Tiger/Line files from the U.S. Bureau of the Census for 1990 were used to calculate weighted road densities in 5km x 5km squares across the region (Table 3). The 5km x 5km squares were chosen due to computational limitations. The weighted road lengths were then summed to yield the weighted road density for the grid square. Because we are attempting to quantify stress, the highest density of roads should have the lowest score, so the inverse of the values from the 5km x 5km squares were derived, scaled, and assigned to the 300m x 300m cells.

Waterway impoundments (C2.4)

Dams fragment hydrologic systems by impeding the migration of organisms and by reducing shallow riverside habitat (Balmford, Bennun, et al. 2005, Naiman, Magnuson, et al. 1995). The locations of the dams in the region were obtained from the United States Geological Survey (USGS) for the period ending 1996. In order to identify the water bodies influenced by a dam, the total open water, forested wetland or emergent wetland patch that fell within a 500m buffer of a dam's point location (an arbitrary distance chosen to allow for possible mis-registration of the spatial data) was considered to be an artificially impounded or impacted hydrologic system. Cells containing artificially impounded open water or wetland patches were given a score of 0. All other cells were scored at 100.

Airport buffers (C2.5)

Noise from anthropogenic sources causes changes in wildlife behavior, usually with negative impacts (Weisenberger, Krausman, et al., 1996, Delaney, Grubb et al., 1999). Roads, mining activities,

Tiger Code	Road Category	Disturbance Factor
A1-A 9	miscellaneous roads	1.00
A10-A29	primary roads	3.00
A30-A39	secondary roads	2.67
A40-A49	local and rural roads	2.00
A50-A79	miscellaneous roads	1.00

Table 3 Tiger road codes and the corresponding factor that was assigned in the weighted road density.

snowmobiling, aircraft and shipping related noise are identified as disturbances, with the greatest emphasis on airport and aircraft noise. This data layer addresses the disturbances from aircraft and airports.

Aircraft noise is assumed to be proportional to the size of the aircraft which is proportional to the length of the runway required by the aircraft, (Dillingham and Martin 2000). Buffer sizes were assigned based on the length of the runway and were extended from the runway in every direction (Table 4). Undeveloped cells that fell within the buffers were considered to be stressed by aircraft noise and given a score of 0. Those outside the buffers were considered to be beyond the zone of noise impact and were given a score of 100.

NPL Superfund sites (C2.6)

Superfund is the Federal government's program to clean up the United State's uncontrolled hazardous waste sites. To capture the surface effects of these sites on critical ecosystems, polygons of active US EPA's National Priority List Superfund sites were mapped and buffered with a 300m radius. This buffer size was based on evidence that the disturbance to forests due to edge effects can extend as much as 300m into the undeveloped area (Gascon, Williamson, and Fonseca 2000). Subsurface and atmospheric impacts due to Superfund sites are much more difficult to spatially characterize and will be left to a future version of this analysis. Undeveloped cells within the 300m radius buffer were considered to have been impacted by the chemical stresses arising from hazardous waste releases as well as the disruptive stresses associated with cleanup and other activities at these sites. Cells within the radius were scored 0. Those outside the buffers were scored 100.

RCRA corrective actions sites (C2.7)

Points of corrective action sites regulated under the United State's Resource Conservation and Recovery Act (RCRA) were mapped (EPA 2002). Only current sites identified as "known or reasonably suspected to contain contamination at unacceptable levels in groundwater or other media to which

Airport Category	Runway Length (meters)	Buffer (meters)
Very large	> 2000	7500
Large	>1500 to 2000	5300
Medium	>1200 to 1500	3100
Small	> 500 to 1200	900
Very small	< 500	610

Table 4 Buffer size around airports determined by runway length

human exposures could occur" were included. Again in this analysis as in the Superfund layer, the surface effects only are considered. In addition, RCRA criteria are based on human health. Ecorisk endpoints rarely have data to support them and our assumption is if human health can be impacted, ecosystem health would suffer also. These locations were buffered by 300m (using the same evidence that was used in C2.6). Undeveloped cells falling within these buffers were assigned scores of 0. Those lying beyond the buffers were assigned scores of 100.

Water quality summary (C2.8)

Dissolved oxygen (DO), nitrate and nitrite nitrogen (N), phosphorus (P), and total suspended solids (TSS) are water quality parameters frequently associated with impacts from agriculture and urban development (Matson, Parton, Power et al. 1997), (Meador and Goldstein 2003). The STORET (STOrage and RETrieval) database is an EPA repository of water quality, biological, and physical data collected from monitoring programs throughout the United States. Three parameters (DO, N and TSS) are widely available water quality parameters recorded in the STORET database for the Region 5 area. Unfortunately, phosphorus observations were insufficient for modeling purposes.

The CrEAM used data from EPA BASINS (Better Assessment Science Integrating Point and Non-point Sources) software to average DO, N, and TSS levels reported in STORET for Region 5 during the years 1990-1994 within the system of eight digit hydrological units (HUCs).

A HUC was assigned a score of 100 when none of the three parameter averages exceeded 85% of the threshold water quality limits. If one parameter average exceeded 85% of the limit, the HUC received a score of 66; if two parameter averages exceeded 85%, the HUC received a score of 33; and if all three parameter averages exceeded 85%, the HUC received a score of 0. Cells acquired the value of their respective underlying HUCs.

Watershed obstructions (C2.9)

In order to obtain an indication of the intensity of hydrologic alteration within a watershed, the number of dams (from C2.4) within each eight digit HUC was summed. The number of dams ranged from a high of 209 in southern Minnesota to 0 in portions of northern Minnesota, Wisconsin and Michigan. This measure is different from C2.4 in that it is applied basin wide as a measure of change of hydrologic conductivity as opposed to identifying specific land cover features that have been modified. The numbers were normalized with the highest number of dams given a score of 0 and the lowest number given a 100, and cells acquired the value of their respective underlying HUCs.

Air quality summary (C2.10)

Poor ambient air quality causes stress on ecological systems (Cunningham and Saigo 1992, Likens, Driscoll, and Buso 1996). Monitoring data for air toxics are limited in geographic extend and in the constituents analyzed (Kelly et al. 1994). Therefore, the CrEAM used the Assessment System for Population Exposure Nationwide (ASPEN) air quality model to estimate ambient air pollution concentrations. Unfortunately, chronic stress on ecological endpoints was not available, so the CrEAM used the human health benchmarks of the 85 pollutants modeled. When the ratio of predicted ambient concentration over the corresponding non-cancer chronic health benchmark was calculated, ratios greater or equal to one indicate that the benchmark was exceeded. In the study area as many as 5 pollutants in each census tract exceeded the benchmark. Tracts with no exceedances were assigned scores of 100, those with 5 were assigned a score of 0, and the remaining scores (i.e., 1,2,3,4) were distributed linearly (i.e. 20, 40, 60, 80 respectively). The cells acquired the value of their respective underlying tract values.

Development disturbance buffer (C2.11)

Using the same rationale as C2.6, undeveloped zones immediately adjacent to the patches of development were presumed to be stressed. The developed pixels (Table 1) were aggregated into contiguous patches and a 300m buffer zone was created outside of each patch. Undeveloped cells in the buffer zones received a score of 0. Undeveloped cells not in a buffer zone received a score of 100.

Land cover suitability (C2.12)

In contrast with C1.4, poor vegetation potential of unsuitable land cover is an indicator of stress of an ecosystem. This data set used the Küchler potential vegetation designations (Küchler 1964) from C1.4. Cells of undeveloped land with land cover that corresponded to the same types given in the Küchler table were considered to be appropriate and given the maximum score of 100. In some cases, land cover categories such as open water or bare land did not map into a potential vegetation type. In order to not penalize these land cover cells, they were also given the maximum score of 100. Those that were a different cover type were given a score of 0.

The twelve data layers C2.1-C2.12, each ranging from 0-100, were rasterized to the cell unit and summed to the composite stressor layer shown in Figure 3B. Composite scores ranged from a high of 1157 to a low of 464.

RARITY

The CrEAM incorporates measures of the rarity of land cover, species, and taxa to represent biota rarity. Land cover rarity (C3.1) is a direct measure of the 1992 NLCD land cover rarity within Omernik ecoregions. The other three data sets (C3.2, C3.3 and C3.4), were based on rare species inventories of the six state's Natural Heritage Programs (NHPs). This course scale of analysis was required by the Confidential Business Agreement that the Region has negotiated with the individual state Heritage Programs. The CrEAM applied the G1-G5 Global Heritage Ranking System (GHRS) used by the NHP to score their data (Table 5) (Stein 2001). The NHPs of the six Region 5 states provided these data to EPA under confidential business information (CBI) protection. Due to the legal agreement with the six NHPs, the data can only be summarized by USGS 7.5 minute quadrangle (quad).

Land cover rarity (C3.1)

Ecological rarity is not just a listing of rare and endangered species. It should also include rare land forms. In the absence of rare landform data, 1992 NLCD pixels of undeveloped land cover (Table 2) were analyzed by ecoregion. Some ecoregions had as few as three land cover types and some as many as six, but the frequency distribution by land cover was always logarithmic. The land cover type with the fewest cells in the ecoregion, thus the rarest land cover type, was given the score of 100. The land cover type with the most cells in the ecoregion, thus the most ubiquitous, was given the score of 0. The scores of the remaining land cover are linearly distributed between 0 and 100.

Species rarity (C3.2)

The Heritage Program data for any individual quad contained observations with a possible GHRS rank as rare as G1 or as common as G5. Within a quad, the rarest GHRS rank determined the score for the entire quad. If the highest observation in the quad was G1, the whole quad received the score of 100. A score from 100-0 was assigned to each quad in the region (Table 5), and each cell was assigned the score of the quad in which it was located.

Rare species abundance (C3.3)

The number of rare species sighted in a quad was used as a measure of rare species abundance. The data layer consisted of species having the rarest GHRS ranks of G1-G3. The maximum number

Cell Score	C3.2 GHRS Rank	C3.3 number of G1, G2 and G3 species in quad	C3.4 number of taxa of G1,G2 and G3 species in quad
1	G1-Critically imperiled	>15	>6
7	G2-Imperiled	10-15	4-6
5	G3-Vulnerable	3-9	2-3
2	G4-Apparently secure	1-2	1
0	G5-Secure	0	0

Table 5. Cell scores for data layers C3.2, C3.3 and C3.4. GHRS Ranks refer to the Global Heritage Ranking System and quad refers to 7.5 minute USGS quadrant maps.

observed in any 7.5 minute quad was 30 and the minimum was 0. These groups of species counts were then assigned scores as shown in Table 5 where breaks between scores were determined by natural breaks in the number of species. Each cell was assigned the score of the quad in which it was located.

Rare species taxa abundance (C3.4)

This data layer used the broad taxonomic groups represented by the G1, G2, and G3 species in a quad. For this indicator the broad taxonomic group designations established by the NHP are amphibian, bird, bryophyte, chelicerate, crustacean, dicot, fish, gymnosperm, insect, lichen, mammal, mollusk, monocot, platyhelminth, pteridophyte, reptile, and uniramian arthropod.

In the study area, the maximum number of taxa observed in any 7.5 minute quad was 10 and the minimum was 0. Scores between 0 and 100 were then assigned to the taxa count groupings as shown in Table 5.

The four data layers C3.1-C3.4, each ranging from 0-100, were rasterized to the cell unit and summed to the composite Rarity layer shown in Figure 3C. Composite scores ranged from a high of 331 to a low of 0.

RESULTS

The 20 summary scores generated from the GIS data layers were summed by criterion for each undeveloped cell across Region 5. This aggregation resulted in three sets of raw composite scores, one set each for Diversity, Stress, and Rarity. The three sets of composite scores representing the three criteria were weighted equally in the final ecosystem score as well, based on the same logic applied to the twenty individual data sets. Each set of composite scores was normalized from 1 to 100 so that each criterion exerted an equal influence on the final scores. The final scores for each cell were generated by summing the three composite scores. Thus, each undeveloped land cover cell across Region 5 was assigned a relative rating potentially ranging between 0 and 300.

It is important is that none of the data layers *within* the composite criterion duplicate another. If there were a high correlation between two data layers, it would be equivalent to applying a weight to the layer. Within the Diversity composite, the highest correlation is .41, between layers C1.1 and C1.2 (land cover diversity and patch size of undeveloped land). Within the Sustainability composite, the highest correlation is .45, between C2.3 and C2.11 (weighted road density and development disturbance buffers). And finally, within the Rarity composite, the highest correlation is .52, between C3.3 and C3.4, (rare species abundance and taxa abundance). None of these are exceptionally high correlations (maximum variability explained is less than 30%; n=3,634,183; p<.0001, all correlation were Kendall) indicating that if any of the individual data layers were omitted, information toward the

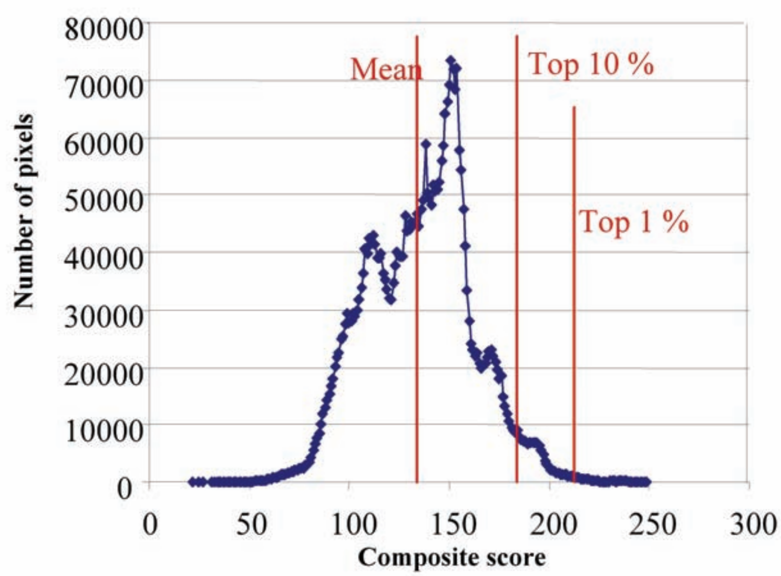

Figure 4. Frequency distribution of the composite scores obtained by adding summary scores of C1 (diversity), C2 (stressors) and C3 (rarity). Vertical lines indicate the score of the mean (139) and the top 10 and 1 percent of the study area.

final criteria scores would be lost. Factor analysis could not be conducted to determine the individual contribution of each layer on the final score because a number of the layers were not continuous (that is, some were scored 0 or 100 rather than a continuous distribution between 0 - 100).

While the potential highest score was 300, the actual distribution of final scores ranges from 23 to 253 with a mean of 139. Visual summaries of the composite scores for Diversity (C1), Stressor (C2), Rarity (C3) and the total of all three are shown in Figure 3. The frequency distribution of the final scores is shown in Figure 4.

DISCUSSION

Several assumptions went into the CrEAM's design. Although the influence of underlying metrics in the model are likely to be nonlinear with feedback from different factors influencing the criticality of ecosystems more than others, in this first analysis we assumed the model to be linear and all of the data layers were weighted equally. Part of the reasoning for this assumption is it fulfills Myerson's argument that an index be simple and convey concise information on large scale trends (Meyerson, Baron, et al. 2005). It is also known that providing unequal weight could potentially introduce larger artificial biases than the errors that they were intended to alleviate (Dawes 1986).

Similarly, an important consideration in using the composite criteria is that they measure separate characteristics and are not confounded by interactions with other criterion. Kendall correlations for the interactions between criterions as well as their correlations to the final composite score are shown in Table 6. The highest correlation between any two criterion is .40 thus the highest variability explained by any two layers in combination is only 16%. This indicates that each composite score does indeed measure a different set of information. Diversity and Stressors contribute more to the total composite score than does Rarity.

Because the three criteria scores are orthogonal they can be used individually or in combination to inform issues surrounding landscape quality. For example, in Figure 5 the scores for diversity and stress are plotted against each other. Those locations that fall into the upper left quadrant of the plot

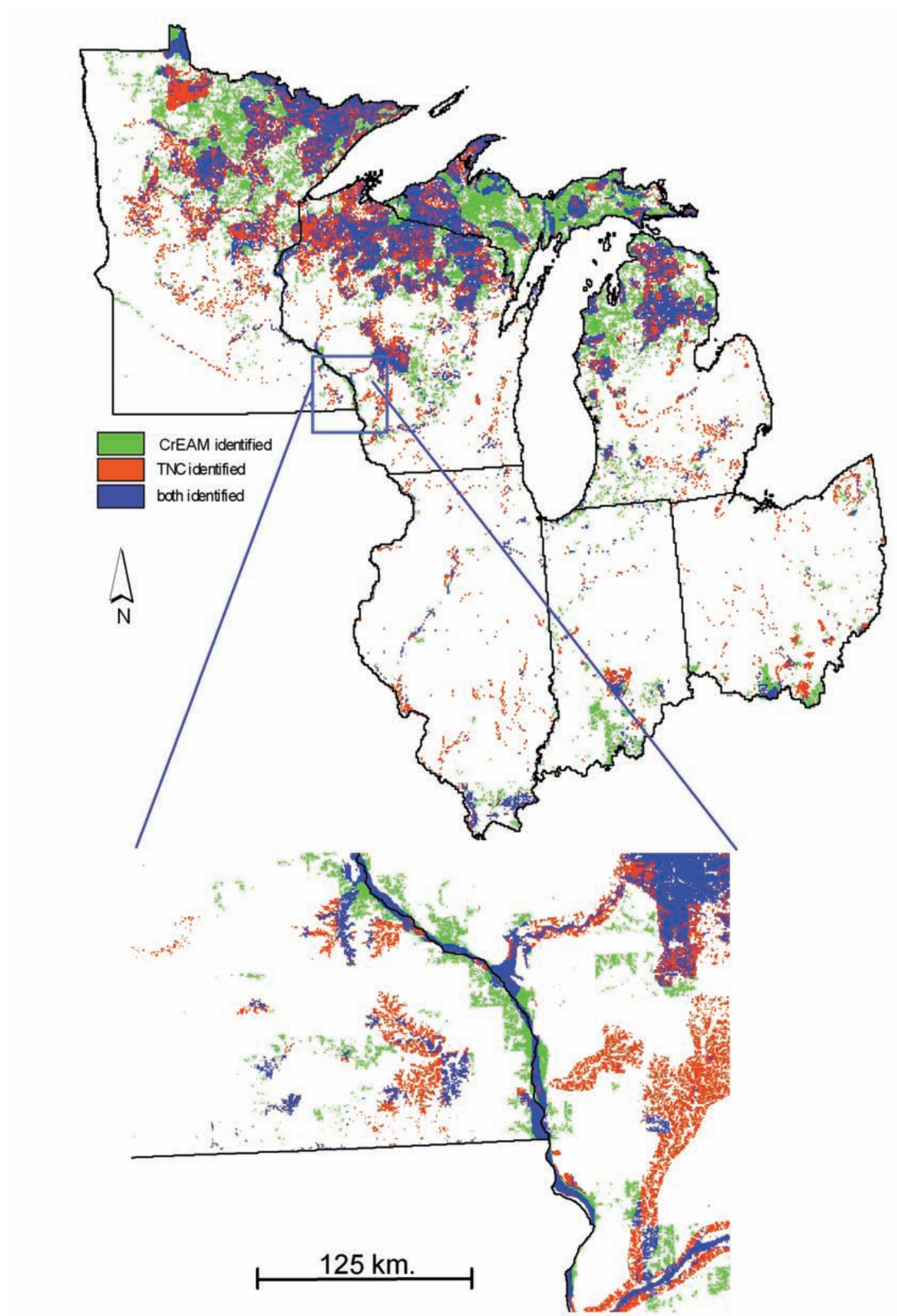

Figure 5. Example use of CrEAM metrics. The criteria scores for each cell can be plotted against each other to produce a scattergram. In this case C1 is plotted against C2 which will allow the user to identify diverse cells of highest risk to target for restoration.

are high in diversity and are experiencing relatively low environmental stresses. The majority of these sites are already in protected areas or are far away from urban centers. However the sites that plot into the upper right quadrant are high in diversity and high in environmental stress. These are natural areas outside of Chicago in the dune landscape of northwest Indiana and along the Mississippi River southeast of Minneapolis-St. Paul. Choosing and ranking locations for restoration and protection can be based on a quantitative, scientific basis.

The CrEAM is a snapshot that does not take into account feedback and catastrophic shifts in ecosystems, (Rietkerk, de Ruiter, and van de Koppel 2004). A time series might be able to inform this discussion, but when the analysis was conducted, additional years of comparable data were not available. The recent edition of the 2001 NLCD could potentially provide a great deal of information in this regard.

	Total Composite Score	Diversity Composite Score	Sustainability Composite Score	Rarity Composite Score
Total Composite Score	1.00	.59	.51	.34
Diversity Composite Score	.59	1.00	.40	-0.02
Sustainability Composite Score	.51	.40	1.00	-0.08
Rarity Composite Score	.34	-0.02	-0.08	1.00

Table 6. Correlations between individual criterion and their relationship with the total composite score. Because C2 and C3 are not normally distributed, Kendall correlations were used. All correlations are significant at $p < .0001$; N = 3,634,183.

Finally, the most direct and quantitative way to validate an effort is to assess a statistically significant number of randomly selected undeveloped cells in the field and compare the results to the corresponding model predictions. Comparison of the CrEAM results to another closely related data set is an indirect technique to evaluate the model. We are not aware of any other attempts to measure landscape scale ecological significance from existing data as we have defined it. The results of The Nature Conservancy's (TNC) ecosystem conservation planning assessment is an analysis that is somewhat similar in scope and intent (Poiani and Richter 2000). Although TNC's objective, and therefore analysis, is not equivalent to the CrEAM areas of high ecological significance, in a general way both analyses can be compared visually to yield an indication of consistency (Figure 6). It is apparent that the overlap for the composite CrEAM score is not very good; however this may be further improved by comparing the TNC scores with the individual criteria scores in order to see whether the TNC analysis emphasized diversity, stressors or rarity.

Another method of validation would be best professional judgment. For this we compared the CrEAM composite scores with work previously done by the Critical Ecosystems Team (Mysz, Maurice, et al. 2000). Federal, state, tribal and non-governmental agency personnel were contacted and asked to identify the areas of critical ecosystems. The information request did not define the term "critical" or address scale so that the organizations could respond according to their own perspectives and priorities. Over 400 areas, called Partner Identified Ecosystems (PIES), were identified by the various partners as being critical (Figure 7). In many cases the areas overlapped, usually imperfectly, since the scale of the analysis was different for the various agencies. However there are some cells that had as many as ten agencies or groups identify the area as a critical ecosystem and these locations track well with the higher scoring cells predicted by CrEAM. At the time of this publication, field validation was not available for the model. Results for a limited field validation effort should be available as an internal EPA report in the fall of 2007 (Mayer, White, Maurice et al. 2007).

Despite its limitations, the CrEAM has been used to support the missions of a number a programs in Region 5. The Science Advisory Board (SAB) of the EPA has reviewed the model and results and has given guidance for its use. (http://www.epa.gov/sab/pdf/cream_report_12_14_04.pdf) CrEAM products were incorporated in the Water Program's State of the Water Report to help the program describe how reach their goal of maintaining or improving the quantity and quality of critical habitat in Region 5. (Holst, Garra, et al. 2002) An analysis was also included in the Lake Michigan Management Plan for 2002 to help refine restoration and protection targets as well as provide a baseline for changes and trends. (Beck 2002)

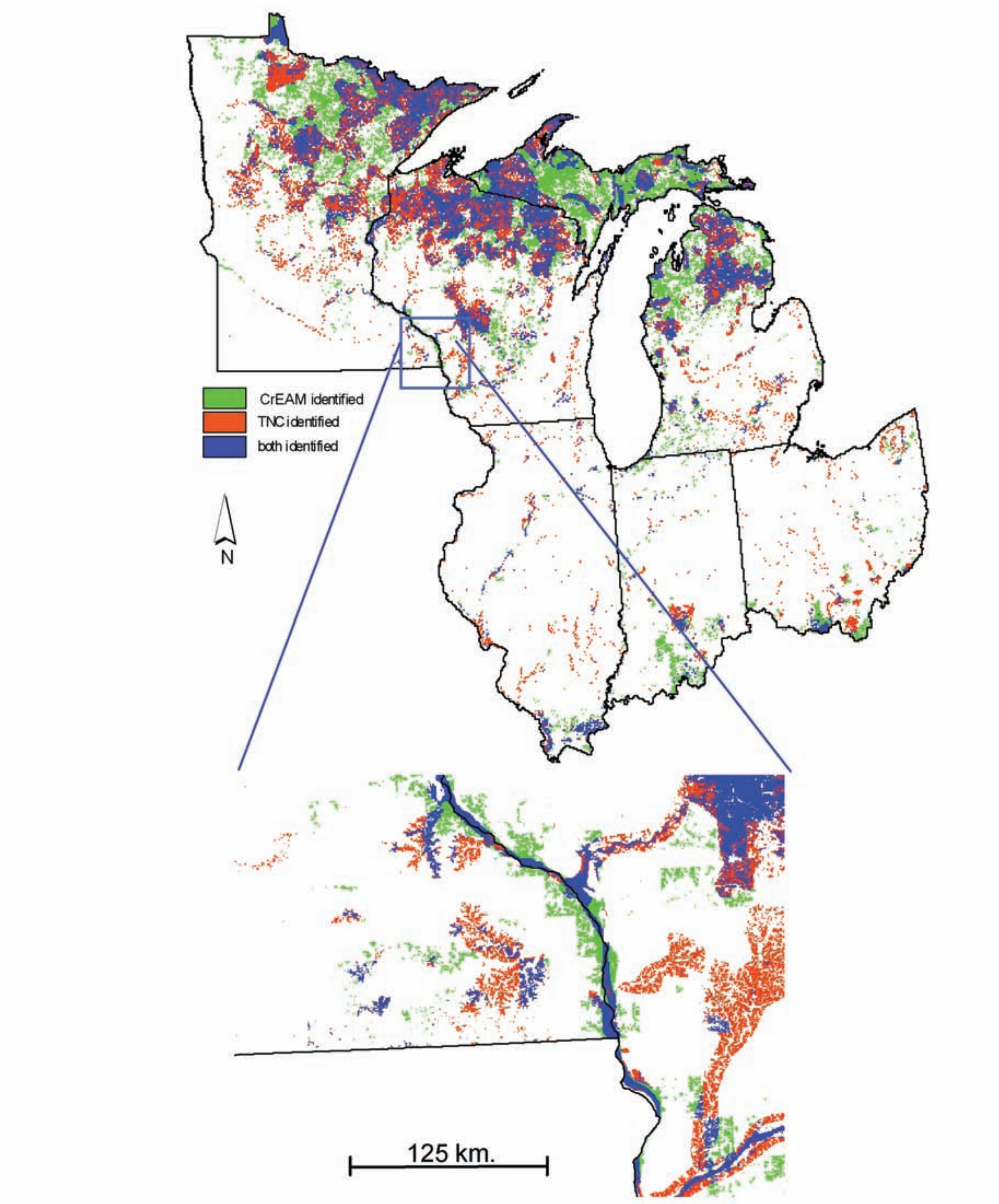

Figure 6. Comparisons of the CrEAM predictions to TNC portfolio sites. Undeveloped cells with top 45% the CrEAM predicted scores are shown in green, undeveloped cells within TNC portfolio polygons are shown in red, and undeveloped cells identified by both are shown in blue.

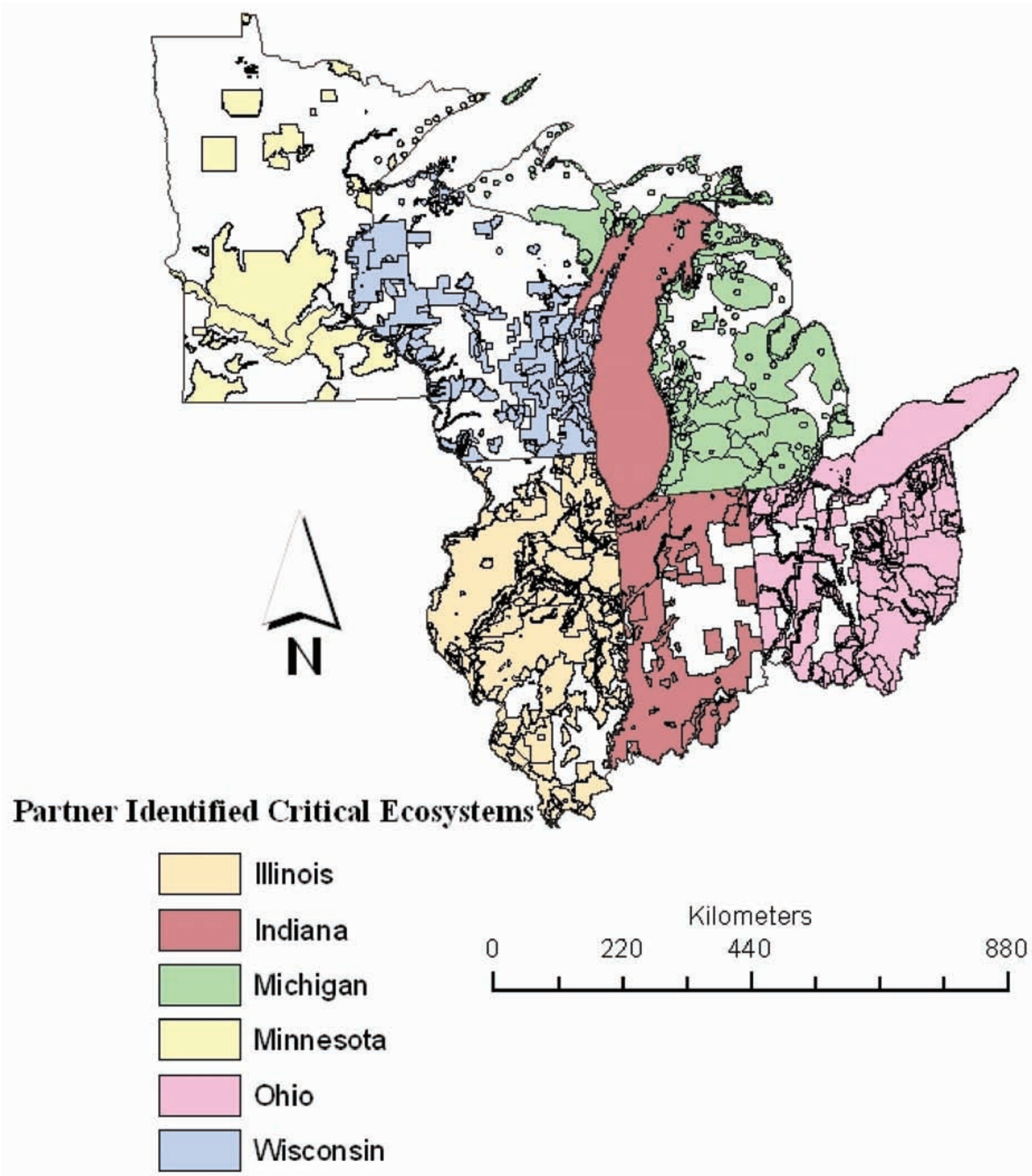

Figure 7. Partner Identified Ecosystems (PIES) by state. Data collection as described in Mysz et al, 2000, included 448 areas identified by partners as "critical ecosystems".

CONCLUSIONS

The CrEAM was designed as an attempt to systematically and objectively assess ecological condition throughout the Region to better inform several diverse programs and their partners. Despite its limitations, the information has been used to inform the process of making decisions within these programs. There has recently been a call for renewing this type of landscape level assessment (Meyerson, Baron, et al. 2005). It is hoped that such momentum will help forward and improve the efforts the Critical Ecosystems Team started when they began the CrEAM.

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CHAPTER 13

Importance of Land Cover and Biophysical Data in Landscape-Based Environmental Assessments

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ABSTRACT

Land cover and other digital biophysical data play important roles in environmental assessments relative to a large number of environmental themes and issues. These data have become especially important given the pace and extent of land cover change across the globe and world-wide concern for issues such as global climate change. However, land cover and digital biophysical data by themselves are not sufficient for broad-scale environmental assessments. These data must be combined with in situ data collected from comprehensive research and monitoring programs to derive and interpret broad-scale environmental condition. I summarize important uses of land cover and other biophysical data in environmental assessments and emphasize the importance of spatially explicit integration of these data to address critical environmental issues. I also discuss the importance of comprehensive, regional and national in-situ data in the development of landscape indicators and models and the need to maintain and develop new in-situ monitoring programs.

Key words: *Land cover, environmental assessments, landscape indicators, biophysical data, multi-scale analysis*

INTRODUCTION

Spatially continuous digital databases on land cover and other important biophysical attributes (soils, elevation, topography, etc.) have become increasingly available via websites and data portals. Coupled with advances in computer technology, including processing speed, data capacity, software development (e.g., geographic information systems and statistical programs), and distributed network capabilities, this availability now makes it possible to conduct environmental assessments at multiple scales over relatively large geographic areas (Wascher 2005, Jones et al. 2008). This is especially true of land cover data, which are now available for the entire conterminous United States at a 30 m resolution for two time periods (early 1990s and early 2000s, Homer et al. 2004). This provides for an unprecedented evaluation of land cover change and the consequences of change on a wide range of ecological goods and services. Here I highlight several examples of the use of land cover and other wall-to-wall biophysical data in environmental assessments, including those related to environmental status and trends, impact analysis, vulnerability and risk assessments, ecological forecasting, and alternative future landscape analyses. I also emphasize the importance of combining land cover with other wall-to-wall biophysical data to enhance environmental assessments. I conclude with a discussion of key components of landscape assessments.

LANDSCAPE-BASED ENVIRONMENTAL ASSESSMENTS

Landscape-based environmental assessments generally fall into one or a combination of five categories: (1) status, change, and trends; (2) relationships between pressures or drivers of landscape conditions, changes, or trends and base biophysical conditions; (3) vulnerability and risk analysis; (4) forecasting; and (5) alternative future landscape analyses.

Status, Change, and Trends

Numerous landscape-based assessments of environmental status have been conducted at a range of scales for a relatively large number of environmental themes or issues using land cover and other biophysical data. These include assessments of forest fragmentation (Riitters et al. 2000, 2002), urbanization (Galleo et al. 2004), agricultural sustainability (Reuter et al 2002), road distribution and density (Watts et al. 2007), bird distribution (O'Connor et al. 1996), biological diversity (Zurlini 1999, Magura et al. 2001, Scott et al. 2003, Burkhardt et al. 2004), watershed condition or health (Walker et al. 2002; Jones et al. 1997, 2006), water quality and quantity (Behrendt 1996, Wickham et al. 2000, Jones et al. 2001a, Smith et al. 2001), aquatic biological condition (Hale et al. 2004, Donohue et al. 2006), soil loss (Van Rompaey and Govers, 2002), and multiple environmental themes (Jones et al. 1997, 2007, Wickham et al. 1999). All of these studies depend on the development of wall-to-wall biophysical data including land cover and application of metrics, indicators, and models (see later discussion).

When two or more dates of wall-to-wall biophysical data are available, it becomes possible to conduct change and trends analyses. The NOAA Coastal Change Analysis Program (C-CAP) has been conducting land cover change analysis of coastal regions over the past several years (http://www.csc.noaa.gov/crs/lca/ccap.html), and the program contributes substantially to the Multi-Resolution Land Characteristics Consortium (MRLC, see below).

Landscape-based change and trends assessments have been conducted on ecosystem productivity (Minor et al. 1999, Young and Harris 2005, Nash et al. 2006) and land cover (Griffith et al. 2003). Moreover, there have been numerous assessments of landscape change and potential consequences to specific environmental themes, including wildlife populations and habitat (Vogelmann 1995, Jones et al. 2001b, Theobald and Romme 2007), biological diversity (Saunders et al. 1991, Ojima et al. 1994, Kattan et al. 1994, Koopowitz, et al. 1994), and water quality and quantity (Mattikalli and Richards 1996, Jones et al. 2001a), and watersheds and forests (Lathrop et al. 2007). Numerous other landscape-based assessments have analyzed land cover and other biophysical changes with regard to specific environmental drivers or stressors (see next section). Findings associated with these types of assessments are critical to vulnerability and risk assessments, ecological forecasting, and alternative futures analysis (see later sections).

Land cover data for two dates (early 1990s and 2000s) for the conterminous US make it possible to conduct a similar landscape change analysis across the entire lower 48 states at relatively fine spatial scales (30 m). To facilitate change analysis between these data, the MRLC is reclassifying the early 1990s imagery using the algorithm that was used to classify the 2000 imagery (see Wickham et al. 2007 for an application of this approach). Nationally consistent change information is available for the conterminous U.S. (http://www.mrlc.gov). The MRLC has proposed future US-wide land cover databases on five-year intervals. Such a program would permit an unprecedented assessment of landscape trends and consequences to a range of ecological services and environmental themes. A national-scale, sample-based, landscape trends program was initiated by the USGS and partner agencies and organizations in the late 1990s (Loveland et al. 2002). This program has already reported on key landscape transitions that have occurred over the time period from the early 1970s to the early 2000s (see Griffith et al. 2003). The results from this program will provide a good foundation upon which to build a wall-to-wall trends program (e.g., from future MRLC efforts). Finally, land cover change and trends offer the most comprehensive way to track and evaluate the consequences of surface changes on a wide range of landscape processes affecting important ecological goods and services.

Relationships between Pressures/Drivers and Condition, Changes, and Trends

Quantifying linkages between environmental pressures and drivers (e.g., population change, road and energy development, increased, and water use) and landscape conditions and change is essential for understanding threats to and vulnerabilities of a wide range of environmental values and ecological services. This is also critical in formulating alternative future landscape scenarios to protect and improve environmental conditions. Some assessments involve retrospective or historical analysis of landscape change and pressures in an attempt to understand important drivers of landscape change (Mattikalli and Richards 1996, Wickham et al. 2000b, 2007, Jennings and Jarnagin 2002, Hostert et al. 2003, Wamelink et al. 2003), whereas some establish relationships from spatial patterns derived from single data layers (Wade et al. 2003). Others use rule-based and empirical models to evaluate the consequences of historical change (Hernandez et al. 2003). For example, Jones et al. (2001b) assessed the consequences of land cover change across the five-state, Mid-Atlantic region by creating a historical land cover database for the early 1970s from Landsat Multi-Spectral Scanner data, and applying a combination of empirical and rule-based models related to land-based nitrogen export and bird habitat quality. Land cover was a key component of both models and extrapolation to the regional scale. The most robust quantitative relationships are created when changes in land cover and biophysical data can be linked to changes in important environmental response variables (see later discussion).

Vulnerability and Risk Assessments

Existing spatial data, indicators, and models of pressures and states can be used to assess relative vulnerability and risks of habitats and areas to future decline in overall environmental quality due to a combination of pressures (Wickham et al. 1999, Bradley and Smith 2004, Zurlini et al. 2004, Theobald and Romme 2007). These approaches generally involve integration of multiple biophysical databases, including land cover. Vulnerability can be assessed by integrating (in a spatially explicit manner) landscape classifications of resilience or sensitivity (based on inherent biophysical conditions), current conditions, and current levels of pressures or stresses (Bradley and Smith 2004). Vulnerability also can be assessed by modeling future landscape changes (Claggett et al. 2004, Theobald and Romme 2007). Future change models are often constructed from knowledge of historical patterns of change and drivers. Results of spatially explicit landscape change are then intersected with distributions of sensitive and/or resilient resources and associated processes to evaluate potential vulnerability. When the probably of change can be estimated and intersected with estimates of sensitivity or resiliency, it is possible to assess risk (Allen et al. 2006).

Land cover and other biophysical and human demographic data have been used to evaluate vulnerability and risks related to natural hazards such as fire (Rollins et al. 2004), tsunamis and earthquakes (Wood et al. 2002), and flooding (Sanders et al. 2006). These data also have been used to address vulnerability of specific geographic areas to spread of invasive species (Allen et al. 2006), and to evaluate distribution of and risks to Lyme disease (Jackson et al. 2006), and to assess environmental justice issues with regards to pollution exposure (Mennis 2005, Mennis and Jordan 2005).

Several organizations have embarked on broad-scale vulnerability assessment that involve the use of land cover and other biophysical data. These include the U.S Environmental Protection Agency's Regional Vulnerability Assessment Program (ReVA; Bradley and Smith 2004, http://www.epa.gov/reva/), the U.S. National Park Service's Watershed Condition Assessment Program (http://www.nature.nps.gov/water/ watershedconds.cfm), and the US Forest Service's Forests on the Edge Assessment (Stein et al. 2005).

Environmental Forecasting

When sampling networks permit the use of near-real time and seasonal data (e.g., climate and satellite data), it is possible to integrate these data with relatively static landscape data (e.g., slope, elevation, soil type) and process models to produce forecasts. For example, these types of data and models have been integrated to forecast crop yield (Reynolds et al. 2000, Kastens et al. 2001, Domenkiotis et al. 2004), species transitions (Peters et al. 2006), famine (Hutchinson 2001), risk of fire (Rollins et al. 2004), and vulnerability to continued urbanization (Kohiyama et al. 2004).

Examples of programs that integrate field and spatial data to conduct ecological forecasting include the Invasive Species Science Program (https://bp.gsfc.nasa.gov/ isfs.html), the US Forest Service's climate change atlas (Iverson et al. 1999, http://www.nrs.fs.fed.us/atlas/), NOAA's ecosystem forecasting program (see Valette-Silver and Scavia 2003, http://www.oceanservice.noaa.gov/topics/coasts/ecoforecasting/ welcome.html) and the Terrestrial Observation and Prediction System (http://www .ntsg.umt.edu/tops/). The Global Earth Observation System of Systems (GEOSS) offers significant potential to improve regional to global scale environmental forecasting, including water scarcity, drought, hazards, biodiversity, and food security (GEOSS 2005).

Alternative Landscape Futures and Conservation

When metrics, indicators, and models can be quantitatively linked and applied to spatial data, it becomes possible to assess the consequences and outcomes of management scenarios and activities that modify the land surface (Theobald and Hobbs 2002, Baker et al. 2004, Kepner et al. 2004). This generally involves a characterization of the current environment relative to one or several environmental themes and a series of workshops with the general public to identify a set of alternative future environments. Each alternative future scenario includes a set of spatially explicit management actions (or lack thereof) that influence the spatial elements and processes related to important environmental resources. Generally, there is a scenario that maintains the existing trend, one that promotes ecosystem or habitat conservation, and one that promotes maximum development or urbanization (White et al. 1997, Baker et al. 2004, Kepner et al. 2004, Voinov et al. 2004). Alternative futures analysis also may include a range of economic and policy scenarios that influence key processes and environmental themes (Wamelink et al. 2003 and Berger et al. 2004, respectively). The quality of these assessments is dependent upon the quality of the data and models and the feasibility of the alternative future management scenarios. One of the great challenges to this approach is to generate effective and sustained public participation and ownership in the methods, scenarios, and results.

In some cases, landscape change models are used to forecast or project future landscape conditions given assumptions about rates and patterns of change in the models (Claggett et al. 2004, Theobald and Romme 2007). Specific management interventions are then assessed with regard to how they change projected landscape states and associated processes and environmental themes.

Landscape indicators and models can be used to identify and prioritize areas for conservation (Zhigal'skii et al. 2003). For example, land cover and other biophysical data, combined with rule-based habitat models, have been used to prioritize areas for conservation (Scott et al. 2003, Zurlini et al. 1999). At finer scales, landscape studies have been conducted to evaluate specific management options, for example, to evaluate the effectiveness of vegetation buffer strips in riparian zones (Borin et al. 2005). Additionally, landscape characterizations can be used to define areas where specific management systems might be most effective (Tenhunen et al. 2001, Jankauskas and Tiknius 2004).

KEY COMPONENTS OF LANDSCAPE-BASED ENVIRONMENTAL ASSESSMENTS

There are several aspects of environmental assessments where land cover and other biophysical data can play key roles. These include classification and characterization, metric and indicator development and application, and model development and application. Land cover and other biophysical data can provide an extrapolation framework for in-situ data on individual environmental themes of concern. This is primarily accomplished through classification schemes, indicators, and models (see below).

Classification and Characterization

A wide range of wall-to-wall biophysical data are used to classify and characterize geographic areas, including land cover, vegetation, soils, geology, topography (slope, aspect, land-form), stream networks, catchments (watersheds), climate (precipitation and temperature), and human population and infrastructure (e.g. roads and dams). These data are used individually or in combination to characterize and classify landscapes, catchments, ecoregions, large basins, and entire countries relative to a wide range of terrestrial and aquatic environmental themes. Characterization and classification are used to: (1) reduce variance in potential indicator or metric response and interpretation (Angermeier et al. 2000), (2) identify reference conditions for different biophysical settings and classifications (Schmidtlein and Ewald 2003, Smith et al. 2003), (3) stratify areas for allocation of field samples and assist in sampling designs, especially in gradient studies (Ator et al. 2003), (4) help determine the applicability of various models based on differences in biophysical settings and classifications, (5) provide an extrapolation/up-scaling framework for models and indicators (Lenz 1999, Müller and Wiggering 1999, Djodjic et al. 2004, Running et al. 2004), (6) provide a hierarchical, down-scaling framework to predict potential ecosystem states (Detenbeck et al. 2000, Jongman et al., 2006), and (7) provide a spatial characterization and classification of the potential response of a specific geography to management alternatives and conservation … "capacity of the land" (Dobrowolska et al. 2004, Mucher et al. 2004, Wascher 2005). In some cases, there have been attempts to develop single classification systems to address all of these factors (Wickham and Norton 1994, Jensen et al. 2001, Jongman et al. 2006, Sayre et al. this volume). Classification and characterizations can be applied at several scales depending on the availability of spatial data. For example, community-level assessments rely on relatively high resolution spatial data, whereas countrywide assessments often involve use of coarser spatial data (Walker et al. 2002).

Most of these data are acquired from remote sensing, although some data such as human population, climate, and other field-based data are acquired from surveys and monitoring studies. Survey data usually come in the form of point or polygon summaries for administrative units or countries, and in some cases these summaries can be spatially interpolated via statistical methods such as kriging (Lloyd 2002). Some characterization approaches are conducted within an explicit spatial hierarchy of biophysical characteristics (Anderson 2000, Detenbeck et al. 2000, Mucher et al. 2003), some are conducted simply by overlaying biophysical data in a GIS without regard to a spatial hierarchy (Van Rompaey and Govers 2002), and some involve pattern classification derived from a single spatial database (e.g., land cover, Wickham and Norton 1994). Results have to be evaluated within each particular classification and characterization framework adopted because when integrating or scaling data for different natural or administrative units the modifiable areal unit problem (MAUP) may introduce potential sources of error that can affect the results of spatial studies (Openshaw 1984). For example, this problem may arise when data are aggregated or generalized to specific assessment units (e.g., political or administrative boundaries), and then disaggregated or reapplied to different assessment units. The result is a misrepresentation of the original spatial variability in the data within and among the new assessment units.

Landscape Indicators

Indicator development is a critical step in the overall environmental assessment process. Land cover data are often a critical element of environmental metrics and indicators. For example, several important indicators in the "State of the Nation's Ecosystems Report" are based on land cover data (Heinz 2002). Moreover, national and continental-scale land cover projects, including the National Land Cover Database (NLCD) and Corine programs of the US and European Union, respectively, permit an analysis of changes in land cover-based metrics and indicators over huge geographic areas at relatively fine scales (30-100 m). Similar to other environmental indicators, landscape indicators are normally selected within a comprehensive monitoring framework, such as the Driver Pressure State Impact Response (DPSIR) framework (EU 1999, Müller et al. 2007; Figure 1).

Many different metrics can be generated from spatial data using geographic information systems (GIS). Landscape metrics include measures of composition (e.g., the percentage of specific land cover types), as well as pattern (e.g., natural land cover connectivity and the position of land cover types in a catchment). More recently metric development has included multiple spatial data (e.g., the amount of cropland on steep slopes derived from intersecting land cover and digital elevation model data, Jones et al. 1996; Figure 2). Additionally, new derivatives from the NLCD 2001 program now make it possible to estimate impervious surfaces and canopy cover over the conterminous US at 30 m resolution.

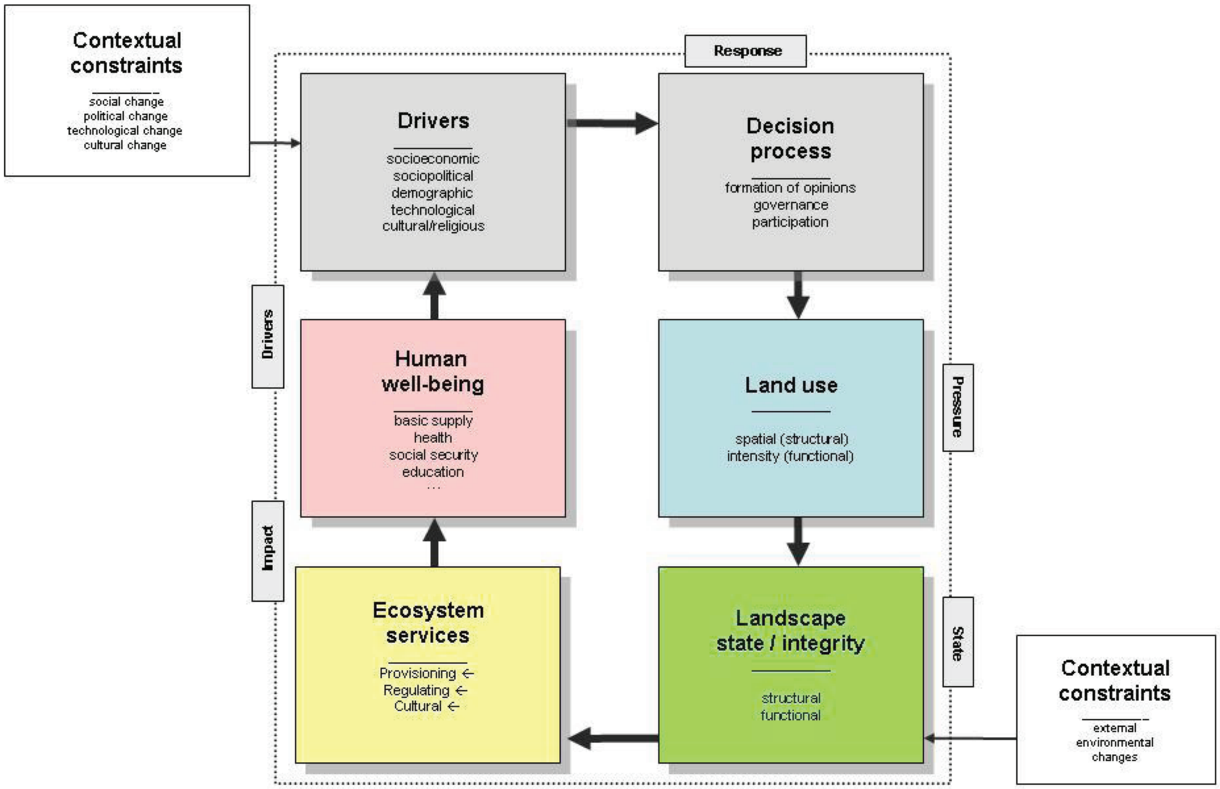


Figure 1. The Driver-Pressure-State-Impact-Response (DPSIR) indicator framework adopted by the European Union (EU 1999) and modified by Müller et al. 2007. Land cover and biophysical data play important roles in evaluating landscape state, change, pressures, and potential management responses (through Alternative Futures Analysis).

Metric development also may involve analysis of new analytical approaches to evaluate landscape composition and pattern (Riitters et al. 2000), and to measure natural and anthropogenic pressures over large areas (Imhoff et al. 1998, Steinhardt et al. 1999, Elvidge et al. 2001, Slonecker et al. 2001, Kohiyama et al. 2004, Longcore and Rich 2004). Metric studies also include analysis of colinearity and correlation among landscape metrics (Riitters et al. 1995). Generally, a metric is selected and used if spatial data are available to calculate the metric, and because qualitative relationships have been established between environmental themes (e.g., species diversity) and specific landscape composition and pattern. A landscape metric becomes an indicator when qualitative and quantitative relationships are established (Jones et al. 1996). In this way the metric becomes an indicator or surrogate of important biophysical processes, ecological states, or pressures. This is accomplished through findings from existing studies, or through new studies involving biophysical, ecological state, or pressure (stressor) gradients (Ator et al. 2003). Where historical landscape data are available (e.g., aerial photography),

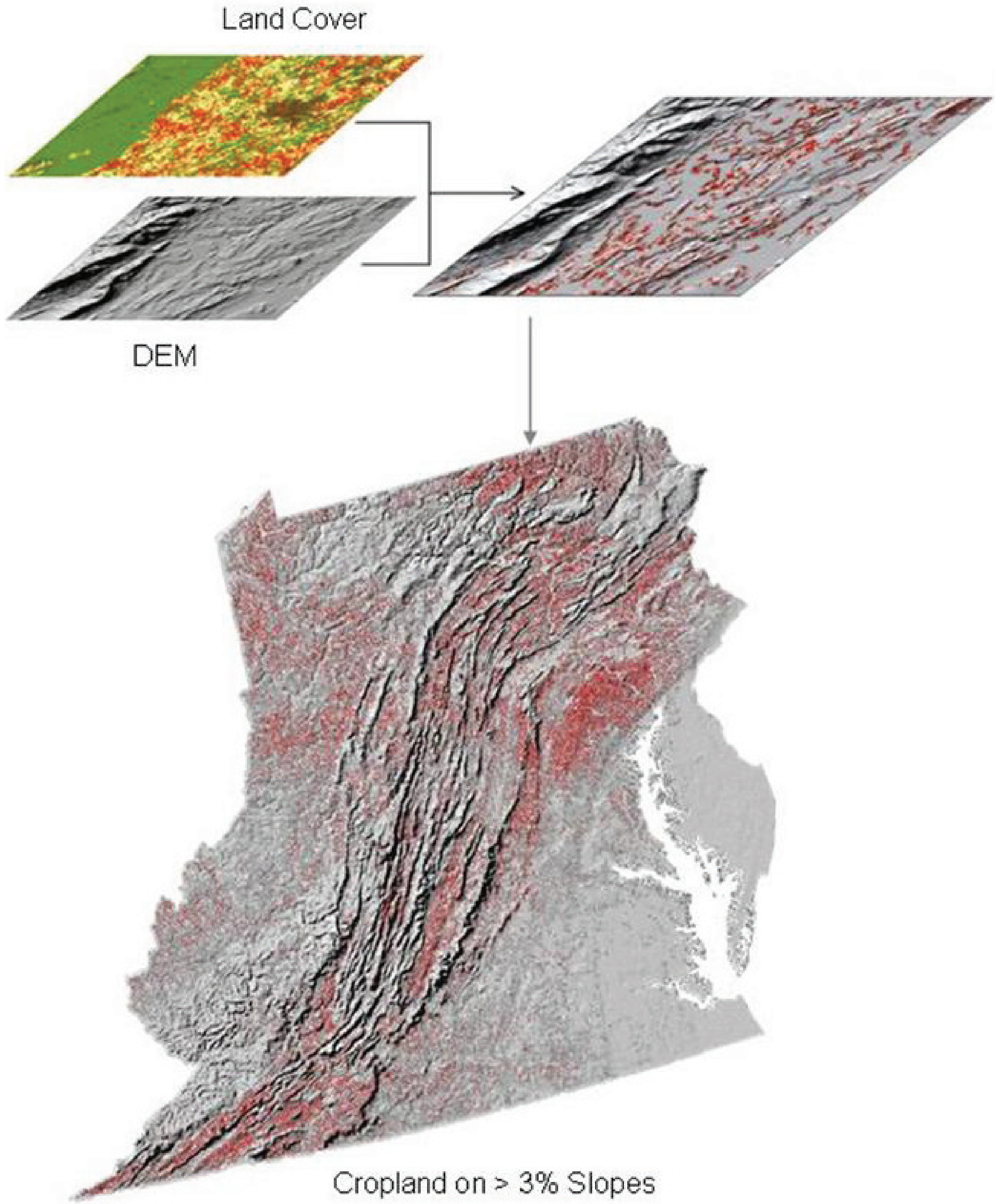


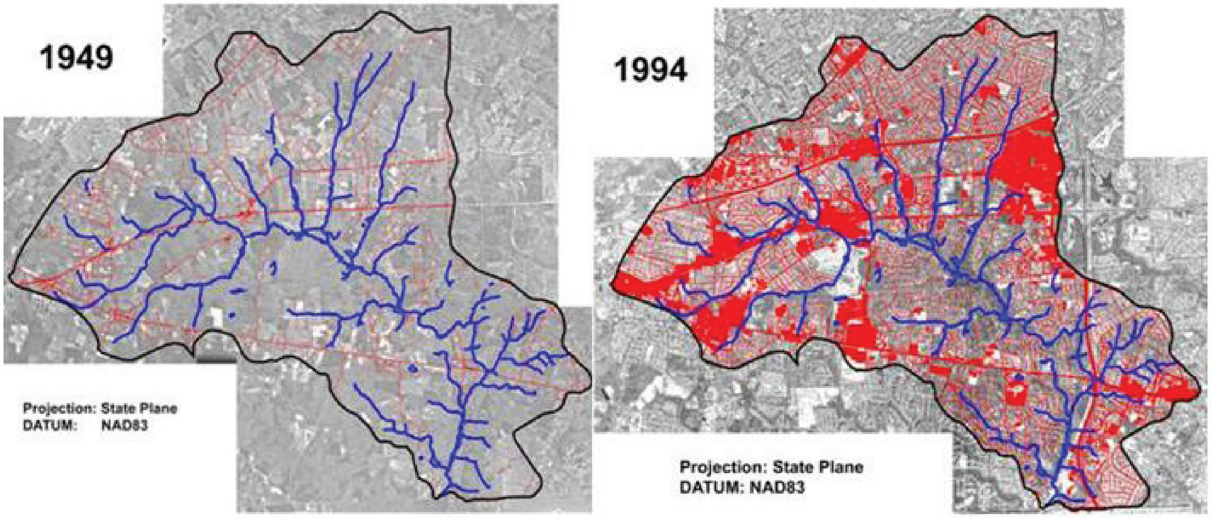
Figure 2. Intersection of 30 m slope and land cover databases to yield a metric of cropland on greater than 3 percent slope, an indicator of potential soil and nutrient loss, across the five-state area of the US Mid-Atlantic Region. Intersection of biophysical data play an important role in evaluating landscape conditions and processes over broad regions.

it may be possible to develop quantitative relationships between a particular pressure (e.g., impervious surfaces) and a state or process (e.g., stream flow and discharge, Jennings and Jarnagin 2002). In the example illustrated in Figure 3, a small watershed in Fairfax County Virginia increased from approximately 3 to 34 percent impervious surface. The result was an increase in mean daily flow, an increase in maximum flow, and an increase in the frequency of bank to bank disturbance events (Jennings and Jarnagin 2002). For this watershed, it takes 45 fewer mm of rain (from 140 to 95 mm) to achieve bank-to-bank flow levels. Increased magnitude and frequency of disturbance events , such as those generated by the increased floods, have been hypothesized to negatively influence surface water habitat and biological conditions (Slonecker 2001).

Metric and indicator development also can include a wide range of remote sensing research and applications (Victorov 1999). This includes derivation of landscape composition and pattern from archival and existing imagery such as Landsat (Tucker et al. 2004), evaluation of relatively new, high resolution spectral (e.g., hyperspectral, Shippert 2003) and spatial (e.g., IKONOS, Vina et al. 2003) imagery, analysis of canopy and vertical vegetation structure (e.g., LiDAR, Anderson et al. 2006, Streutker and Glenn 2006), more direct measures of ecological process variables (e.g., net primary productivity, Running et al. 2004), and landscape change detection (Sohl et al. 2003, Victorov et al. 2004). More detailed information on land cover composition and structure can improve the interpretability of landscape indicators and models.

Spatial filtering (Riitters et al. 1997) and morphological image processing (Vogt et al. 2007a, b) provide other ways to measure landscape metrics and levels of fragmentation or connectivity at multiple scales across broad geographic areas. Furthermore, they provide flexible ways to evaluate scale and emergent spatial properties in land cover imagery.

One of the goals of indicator development is to establish a set or suite of indicators that, in total, reflect ecological pressures, states, impacts, and responses (see Figure 1). When a common and internally consistent set of spatial data is available over large geographic areas, landscape metrics and indicators can be generated and used to estimate and compare ecological states, pressures, and impacts across broad regions (Jones et al. 1997, Wickham et al. 1999).



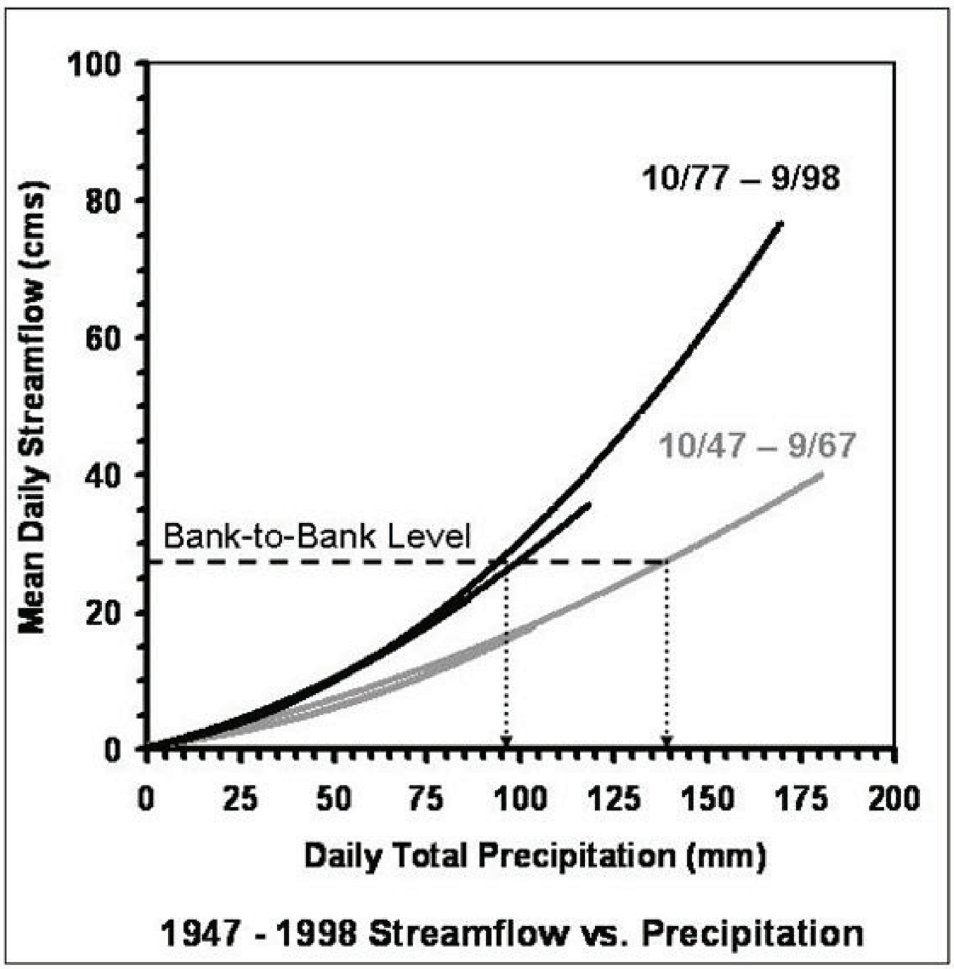


Figure 3. The impact of increasing impervious surface on peak flow events in a Fairfax, County US watershed (modified from Jennings and Jarnagin 2002).

Some assessments require only one or a few spatial databases to generate metrics and indicators, whereas others require multiple spatial databases. For example, Riitters et al. (2000) and Wade et al. (2003) assessed forest fragmentation at the global scale by applying a forest fragmentation metric to digital land cover data. Jones et al. (1997, 2008) assessed multiple environmental themes across the US and Europe, respectively, that required acquisition and use of several spatial databases. Finally, the complexity of metrics used in assessments varies depending on whether the goal of the assessment is for targeting and prioritization (Steinhardt et al. 1999, Wickham et al. 2000, Bradley and Smith 2004) or forecasting or prediction (Reynolds et al. 2000); the former generally uses more qualitative approaches (e.g., metrics, indicators, and simply models), whereas the latter generally relies on more quantitative approaches and complex models.

Landscape Models

Land cover and other biophysical data are often critical elements in spatially distributed models, but especially those related to habitat quality and distribution, water quality, soil loss, and nutrient export. The development of these models is crucial in extending (scaling) in-situ measures to large basins and regions.

Generally, two types of models are used in landscape assessments: empirical models and process models. Empirical models involve quantifying relationships between landscape/biophysical characteristics and patterns (landscape metrics) and measures of environmental values (e.g., bird species richness) or pressures (e.g., nutrient export or loadings). Generally, these studies involve pairing landscape and biophysical metrics measured on spatial supporting units (e.g., a catchment) with field samples (e.g., water quality samples; Jones et al. 2001b, Smith et al. 2001, Iankov et al. 2004). In some cases, landscape metrics are calculated at several scales surrounding field samples (e.g., headwater areas, riparian zones, catchment scale). The goal is to quantify relationships between environmental values of interest and landscape/biophysical composition and pattern through multivariate and other statistical approaches and then apply the statistical function across the larger area via the wall-to-wall data. Other statistical approaches, such as Maximum Entropy, Genetic Algorithm for Rule-set

Predictions (GARP), and Regression Tree Analysis, can be used to model species' distributions and to evaluate uncertainty in those estimates (Stockwell and Peters 1999, Garzon et al. 2006, Phillips et al. 2006). These approaches use in-situ, species-presence data as well as several spatially continuous biophysical databases including land cover. The result is an ability to estimate pressure, state, or impacts over a broader area, including areas where no samples exist. In some cases, markedly different biophysical and/or human use settings across a large region or basin require development and testing of different models. Additionally, it is often difficult to match the spatial and temporal scales of landscape processes and patterns with scales represented by data collected on environmental themes and associated variables at the site or field scale (Skoien et al. 2003).

Most empirical studies trade spatial variability for time to develop quantitative linkages between in-situ and wall-to-wall biophysical data, primarily due to limited temporal coverage of in-situ measures on environmental themes or processes of interest. This approach has been used to model bird habitats and populations (O'Connor et al. 1996, Jones et al. 2000, O'Connell et al. 2000), water quality (Jones et al. 2001b, 2006), and stream biological condition (Donohue et al. 2006). However, powerful relationships have been developed using historical landscape change and stream flow data (see Jennings and Jarnagin 2002).

A critical element of empirical studies is data from in-situ monitoring networks, such as the USGS National Stream Gauge Network (http://waterdata.usgs.gov/nwis), the USGS National Water Quality Assessment Program (NAWQA, http://water.usgs.gov/ nawqa/), the North American Breeding Bird Survey (BBS, http://www.pwrc.usgs.gov/ BBS/), the Environmental Monitoring and Assessment Program (EMAP, http:// www.epa.gov/emap/), the Forest Inventory and Analysis (FIA, http://fia.fs.fed.us/) Program, and the Natural Resource Inventory (NRI, http://www.nrcs.usda.gov/ technical/NRI/).

The other modeling approach involves the development of rule-based or process-based models. Important variables and functions for these models are generally derived from intensive studies at fine scales from existing literature, or from expert opinion. The goal in applying these models is to develop transfer functions (quantitative relationships or functions) between the model parameters and wall-to-wall landscape data. For example, estimation of soil loss over large geographic areas is possible because soil texture (a surrogate for erosivity …an important parameter in soil loss models) is an attribute in many of the digital soils databases (Van Rompaey and Govers 2002). Similarly, detailed studies have established nutrient export coefficients for different land cover types, and when these data are combined with digital land cover, it is possible to identify areas where surface waters may be impaired by excess nutrients and sediments (Wickham et al. 2000). Similarly, non-point source and point-source nutrient loads can be combined to estimate total nutrient loads into water bodies (Behrendt 1996, Kondratyev et al. 2004).

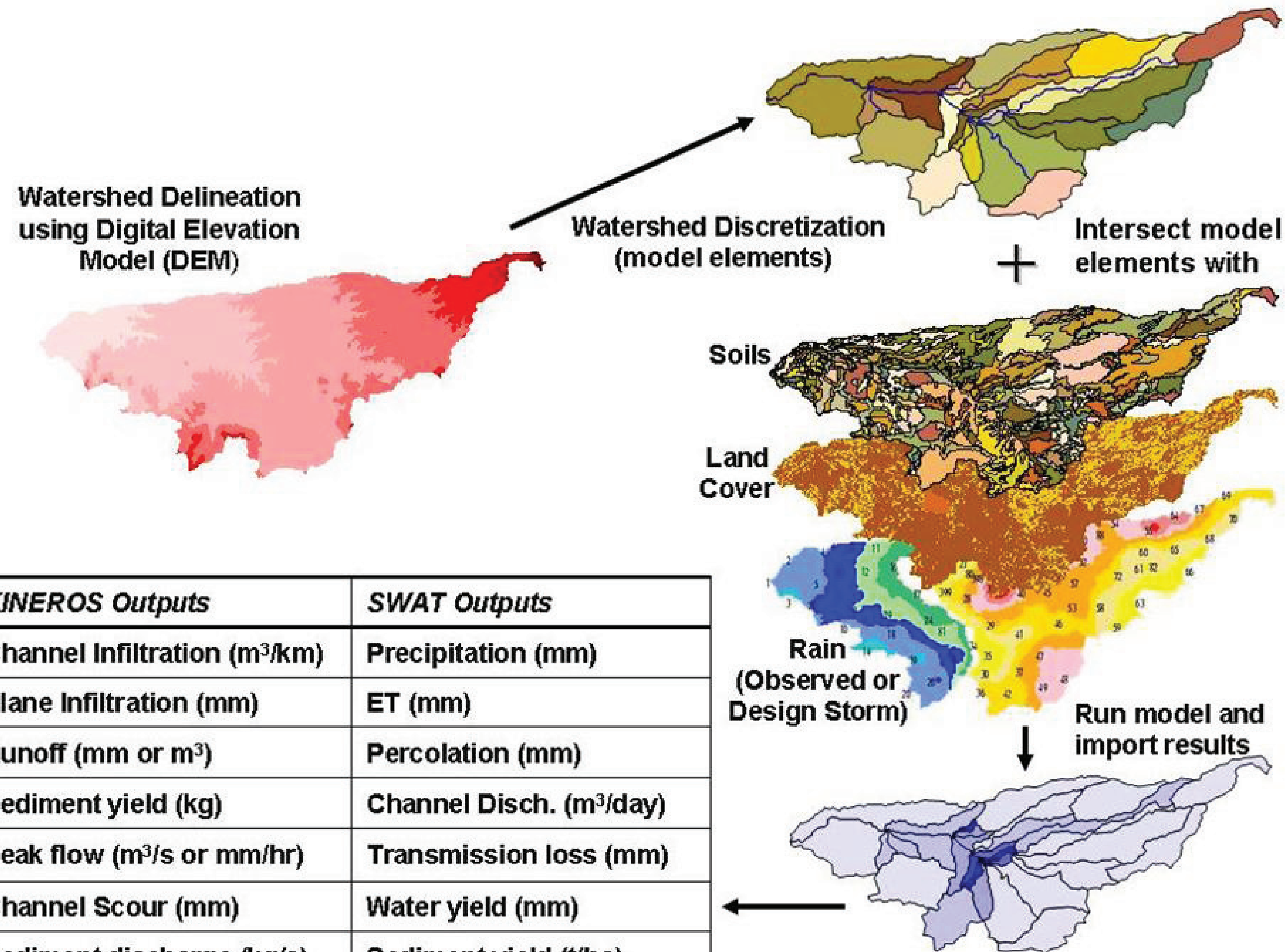
Two key issues in process model implementation are the number of parameters that go into the model and the ability to transfer key functions to wall-to-wall spatial data, including land cover. If there are too many parameters in a model, then it is difficult to apply the model over broad areas because spatial data and transfer functions are often not available for a large number of process-related parameters. However, if parameters are over-simplified and there are too few of them, then the model may fail to capture important differences in the landscape (Van Rompaey and Govers 2002), especially for relatively small areas (e.g., small catchments). The key is to develop and apply models that take into consideration the types of questions and the levels of complexity and scales that result from the types of questions being asked. Many regional- and basin-scale habitat and water quality models involving few parameters are good at targeting and prioritizing areas needing further study or potential management intervention (coarse filter, Bradley and Smith 2004), whereas more parameter-intensive models are used at local scales to evaluate local conditions and site-specific management solutions. These models often require finer-scale land cover data than those available at regional and national scales (e.g., the NLCD).

Land cover has been used to model habitat suitability for a range of species over broad scales (Riitters et al. 1997, Zurlini et al. 1999, Atauri et al. 2001, Scott et al. 2003, Tuller et al. 2004). This generally involves applying a habitat suitability rule to land cover, soil, topographical, and/or climate data. Additionally, models have been developed and applied to remote sensing and other spatial data to evaluate fundamental ecosystem processes, including forest transpiration and photosynthesis (Anselmi et al. 2004), evapotranspiration and soil water dynamics (Wegehenkel et al. 2001), fire and disturbance frequency (Keane et al. 2002, Rollins et al. 2004), and run-off, sedimentation, and water quality. Land cover (e.g., NLCD) has been used in combination with US Census data to model environmental justice issues across broad geographic areas (Mennis 2005, Mennis and Jordan 2005). Figure 4 illustrates the Automated Geospatial Watershed Assessment (AGWA) modeling tool (Miller et al. 2007). This is a GIS-based process model that evaluates the impact of land cover change on hydrologic processes affecting run-off and sediment transport.

Assessment Units

Because of the wide range of environmental themes, issues, and questions being addressed by environmental managers, landscape assessments can potentially occur at a many different spatial scales on a range of political and environmental classification units. The size of the assessment area can vary between small catchments or habitat areas (Dunjo et al. 2004) on up to entire regions, basins, and continents (Lorenz et al. 1999, Riitters et al. 2000, Walker et al 2002, Galleo et al. 2004). Finer-scale assessments generally involve the use of higher resolution spatial and field data (for example, data on vegetation structure, plant species type, etc), whereas broader-scale assessments generally involve readily available spatial data (e.g., 30 m).

Landscape assessments also involve the use of spatial data representing natural (e.g., ecoregions and catchments) and political (e.g., provinces, states, political regions, countries) boundaries. Ecoregion boundaries are created through multi-scaled characterization of biophysical characteristics (see earlier section) and catchments through the use of stream network and/or elevation data to determine the boundaries and direction of flow through a landscape. Both natural and political boundary data come in the form of digital layers that can be integrated (via a GIS) with landscape and other biophysical data to calculate indicators and implement models on specific units. When the goal of the assessment is simply to represent spatial variability in indicator and model results on a map, GIS-generated grid cells are often used (Jones et al. 2001a, Wickham et al. 2002). Additionally, assessments are conducted on buffer zones around riparian zones (Borin et al. 2005, Baker et al. 2006), surface waters, including estuaries (Hale et al. 2004), and other features (e.g., hazardous waste sites). Buffer zone



KINEROS Outputs	SWAT Outputs
Channel Infiltration (m^3/km)	Precipitation (mm)
Plane Infiltration (mm)	ET (mm)
Runoff (mm or m^3)	Percolation (mm)
Sediment yield (kg)	Channel Disch. (m^3/day)
Peak flow (m^3/s or mm/hr)	Transmission loss (mm)
Channel Scour (mm)	Water yield (mm)
Sediment discharge (kg/s)	Sediment yield (t/ha)

Figure 4. The Automated Geospatial Watershed Assessment (AGWA) tool. The tool integrates land cover and biophysical data to estimate water-related characteristics important to environmental managers and planners.

assessments require spatial data layers on streams, estuaries, other surface waters, or the landscape feature of interest.

Landscape Assessment Tools

Several GIS extensions and models have been developed that permit assessment of environmental resources and processes over a variety of scales. These extensions and models use a variety of readily available spatial data. Some calculate landscape metrics and simple models at a variety of scales (McGarigal et al. 2002, Ebert and Wade 2004), whereas some model the influence of landscape pattern and change on specific environmental resources and associated processes, including water and hydrology (Engel et al. 2003, Hernandez et al. 2003, Miller et al. 2007), forest succession and disturbance (Mladenoff 2004), and habitat (Schumaker 1998, Akcakaya 2000). These types of software and tools accept readily available landscape data and permit assessments at a variety of scales.

CONCLUSIONS

Land cover and other biophysical data play key roles in environmental assessments. They provide basic data on spatially explicit patterns of landscape features and associated processes that affect fluxes of biota, water, energy, and materials. When these data are related spatially and temporally they can provide the basic elements for modeling fundamental environmental processes at a range of scales. As such, they provide a framework for extrapolation of in-situ data to make assessments of environmental conditions and changes over broad geographic areas.

As finer-scale biophysical data become increasingly available, it will become possible to apply landscape metrics and models at local and community levels and to relate conditions at those scales to broader catchment and basin scales. Moreover, synthesis of data from sensors with different spatial and temporal resolution will improve our ability to track more frequent changes in land-surface condition (e.g., land cover patch quality and photosynthetic activity), as well as vertical structure and composition (e.g., canopy height by life form and species). This will improve our ability to track land-surface changes in response to major drivers such as climate change, and to relate those changes to important ecological services. New and enhanced statistical and modeling approaches will also improve estimates of land-surface changes and our ability to interpret consequences and opportunities for conservation.

New national and continental scale land cover change products, such as that offered by the MRLC, provide for an unprecedented opportunity to assess the potential consequences of landscape change on a wide range of ecological services. However, it is imperative to protect and expand spatially comprehensive and consistent in-situ monitoring programs, such as the USGS stream gauge network,

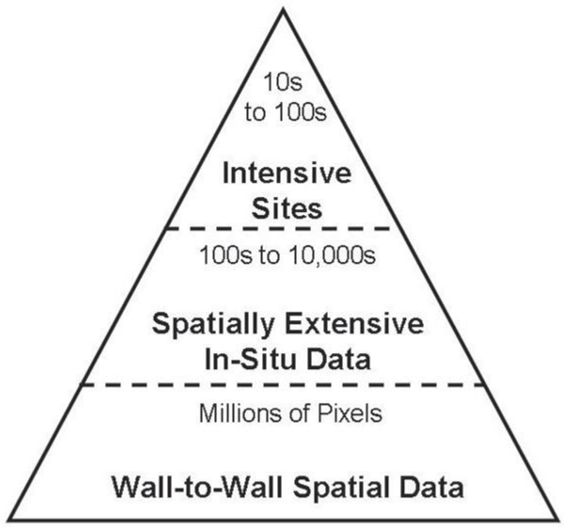


Figure 5. The three-tiered monitoring and assessment framework of the US Committee on Environment and Natural Resources (CENR, 1997). The framework emphasizes the importance of land cover and other biophysical data (base of tier), as well as in-situ monitoring data.

NAWQA, EMAP, NRI, and FIA. These programs provide the base in-situ data from which landscape models and indicators are derived, and form the critical middle component of the US Committee on Natural Resources and the Environment (CENR) monitoring framework (Figure 5). New research and monitoring programs, including the National Ecological Observatory Network (NEON, http://www.neoninc.org/) and the National Phenology Network (http://www.usanpn.org), offer significant potential to develop multi-scale landscape models and to demonstrate the multi-tiered approach recommended by the CENR.

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CHAPTER 14

THE FUNDAMENTAL ROLE OF LAND COVER DATA IN A WEB-BASED DECISION SUPPORT SYSTEM TO ASSIST LOCAL NATURAL RESOURCE MANAGERS AND DECISION MAKERS

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INTRODUCTION

Land cover mapping, characterization, monitoring, and forecasting are critical functions in environmental and land management programs used worldwide by government, industry, and non-governmental sectors. Land cover data and information provide a direct, unbiased indication of the impacts of land use changes on the conditions of natural resources, environmental and human health, and the quality and quantity of water (Meyer and Turner 1994). The use and application of land cover data provides a firm foundation for discerning and analyzing geospatial relationships between the trends, drivers, and impacts of changes on the natural landscape (O'Connell, Jackson, Brooks 2000).

This article describes first the creation of the Midwest Spatial Decision Support System (MSDSS) Partnership, a multi-agency, multi-institutional regional partnership dedicated to the development of a powerful Web-based, geospatial decision support system and the multiple functions of the Digital Watershed mapper that serves as the gateway to extensive land cover/use data and modeling at multiple scales incorporated in the Midwest Partnership System**.** Then four major land cover dimensions of the integrated MSDSS Partnership are briefly discussed including 1) the use of land cover data at multiple scales in Web mapping applications to support effective watershed planning; 2) the use of land cover data in Midwest Partnership System modeling functions; 3) the importance of understanding temporal land cover change; and 4) the future capabilities of the Midwest Partnership System.

CREATING THE MIDWEST SPATIAL DECISION SUPPORT SYSTEM (MSDSS) PARTNERSHIP

The Midwest Spatial Decision Support System (MSDSS) Partnership was formed five years ago by EPA Region V, Michigan State University, and Purdue University in cooperation with the water quality education efforts of a regional (Indiana, Illinois, Michigan, Ohio, and Wisconsin), United States Department of Agriculture (USDA)-funded project. The Wisconsin Department of Natural Resources (WDNR) and International City/County Management Association (ICMA) also provide assistance in assessing and facilitating the use of the Web-based system developed for local planners, state and federal agencies, nongovernmental organizations, and interested citizens. The purpose of the Partnership is "to develop, promote, and disseminate Web-based watershed management decision support systems for use in Midwestern watersheds and to facilitate the transfer of these systems throughout the United States" (MSDSS 2007). Local decision makers have the ability to shape future land use through comprehensive planning and zoning mechanisms, but often lack scientific data to develop plans that are effective in reaching a land cover/land use goal (i.e. protect sensitive species habitat). It is these local decision makers who make a major share of resource management decisions and particularly need the analytical capabilities and information outputs of such a system (Theobald *et al.*, 2000). For example, in Michigan alone over 1,800 units of government are responsible for making land use related decisions, but often lack the resources and expertise to acquire and integrate detailed data and perform analytical functions to support better informed decisions. The Partnership system can address this significant gap by providing critical capacity to facilitate understanding of past, current, and future land use and land cover patterns and their impacts on ecosystem services in the natural landscape.

The Midwest Partnership was created as the result of a workshop sponsored by U.S. Environmental Protection Agency (US EPA) Region 5 and co-hosted by MSU and Purdue University in April of 2002. Workshop participants included state, federal, and tribal water resource managers, land grant university subject experts, Extension specialists, watershed managers, and local government representatives. Participants agreed that linking EPA tools and databases with those of participating universities in a synergistic manner would provide substantive benefits in addressing the specific, emerging landscape analysis needs of local officials, natural resource managers, and the general public to facilitate better local land use and resource planning. In the past five years extensive progress has been made in developing inter-connected, compatible systems that provide Web-based GIS mapping capabilities and various analytical and modeling tools (e.g. Lim *et al.*, 1999, Tang *et a.,*. 2004). Extensive evaluation has corroborated the value of these tools to local land use decision makers (Lucero 2003, 2004; Lucero *et al.* 2004).

The Partnership's current goals include shifting watershed management from a reactive to a proactive collaborative model with the integration of watershed management in local planning processes. The future development of the Midwest Partnership system is designed to facilitate this integration of local planning with proactive watershed management (MSDSS 2007).

THE BASIC FUNCTIONS OF THE DIGITAL WATERSHED MAPPER

The Digital Watershed mapper provides the primary entryway to an integrated set of tools and capabilities developed by the MSDSS Partnership. Digital Watershed is a nationwide Web-GIS application with the capacity to delineate the watershed boundaries for each of the 2,149 U.S. Geologic Survey (USGS) 8-digit watersheds in the continental U.S. in conjunction with other valuable GIS functions (Shi *et al.*, 2005). The average extent of an 8-digit watershed is approximately 448,000 acres, or 700 square miles. The EPA's Section 319 Nonpoint Source Pollution watershed management program is primarily based on 8-digit watersheds. The mapping capability and related functionality of the Digital Watershed mapper (http://www.iwr.msu.edu/dw) provide a strong foundation for effective and sustainable watershed management.

The Digital Watershed mapper serves as a centralized hierarchical information repository incorporating most data from EPA Better Assessment Science Integrating Point and Nonpoint Sources (BASINS), an open source ArcView desktop analysis system (U.S. EPA 2001). EPA BASINS data and other datasets are used in conjunction with the watershed modeling and analytical capabilities of the Midwest Partnership system. The system provides dynamic and seamless integration of data from multiple sources through the extensive use of Web services. System users have access to the modeling functions of the U.S. EPA's Unit Stream Power Erosion and Deposition (USPED) and Purdue University's Long Term Hydrologic Impact Assessment (L-THIA) models. USPED calculates the rates and distribution of land erosion and sediment deposited to receiving waters (Mitas and Mitasova 1998). L-THIA can be used to calculate the extent of increased pollutant loadings from anticipated increases in impervious surfaces associated with new development (Lim et al. 1999). In addition, users have access to the results of the Spatially Explicit Sediment Delivery Model (SEDMOD; Fraser 1999) and the Revised Universal Soil Loss Equation model (RUSLE; USDA 1997) to identify high-risk sediment yield areas.

The Digital Watershed Web-GIS provides a user-friendly mapping system with multiple-scale resolution that integrates delineated 8-digit watersheds with the EPA BASINS database for the conterminous United States. Users can access Digital Watershed in three ways: by 1) entering a street address, 2) choosing a location from a map of the United States or 3) by selecting a particular 8-digit watershed anywhere in the continental U.S. from a drop-down menu (Figure 1).

Figure 2 shows an example of a Digital Watershed screen displayed in a Web browser. The star on the lower left side of the 8-digit watershed marks the location of the address that was entered. Data layers in the right column can be activated by clicking on desired layers, and then clicking on the "Get Updated Map" button in the screen's upper right above the legend. A new map with the selected data layer(s) will be shown in the center frame. There is an inset map of the entire watershed in the upper left-hand corner, which provides a frame of reference for the watershed location shown in the center. The interoperability features of the Digital Watershed mapper include seamless links (a single click) to the TerraServer (1-m resolution) or Google Earth for aerial imagery as well as Google Map. The GIS

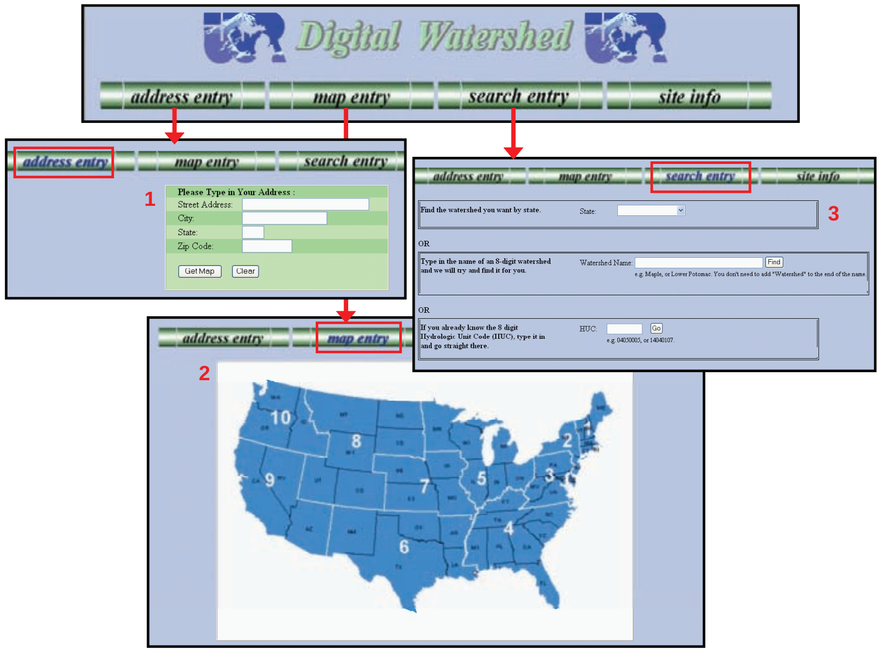


Figure 1. The three primary points of entry into the Digital Watershed Portal. Users can enter a street address (1), find their location through an interactive map (2) or search for a particular 8-digit watershed by its name, location or Hydrologic Unit Code (3).

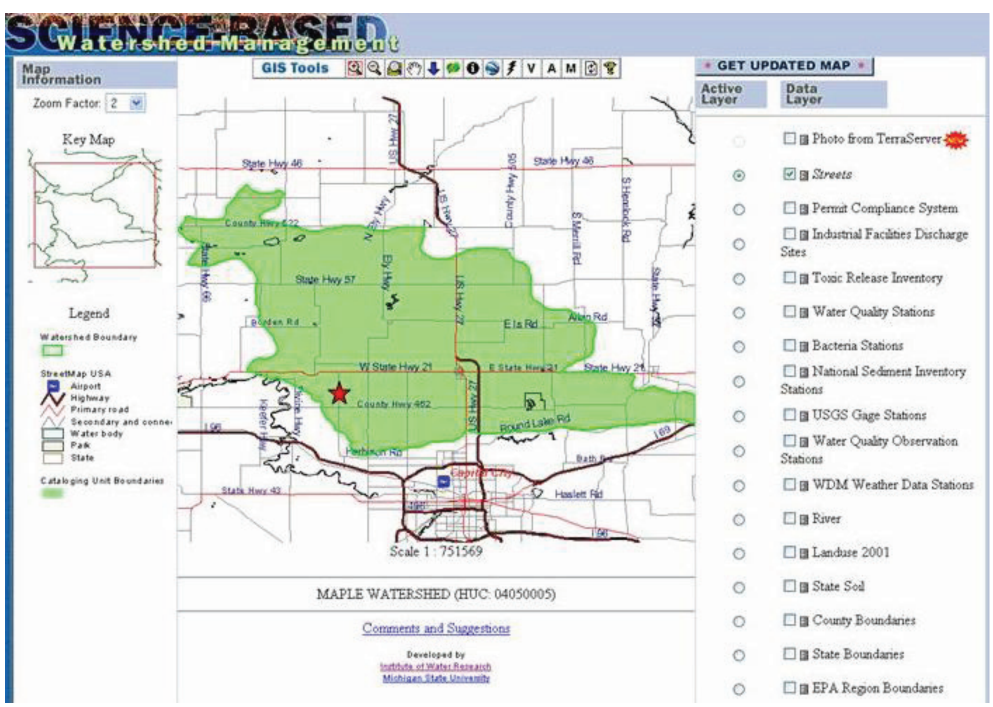


Figure 2. An example of a screen displaying an 8-digit watershed in Digital Watershed. The star indicates the location of the specific address.

tools at the top of the page allow for zooming in, panning, and several other functions (Figure 3).

USING LAND COVER DATA AT MULTIPLE SCALES IN WEB MAPPING APPLICATIONS TO SUPPORT EFFECTIVE WATERSHED PLANNING

Watershed/ecological assessments to support effective watershed management planning and implementation depend on accurate knowledge of changes in land cover and a thorough, sensitive understanding of surface landscape characteristics. Figures 3-7 show a sequence of actions using Digital Watershed to acquire spatial information that provides an immediate visualization of a watershed. Figure 3 shows the Digital Watershed toolbar. Clicking on the Google icon activates Google Earth images; Figure 4 shows a Google Earth aerial image. The teardrop-shaped "pin" indicates the user's selected location of interest, and the watershed boundaries are generated by the Digital Watershed mapper thus producing a hybrid of Google Earth and Digital Watershed functionality.

Comparative analysis of watersheds can be performed using the visualization features of Google Earth and the detailed data from Digital Watershed. Figure 5 shows the Google Earth rendition of land cover for an 8-digit watershed (Maple River Watershed in Michigan). By zooming in closer to the land surface as shown in Figure 6, it becomes possible to see specific fields and a large area of organic materials (muck soils) in the lower right-hand corner as well as highways and roads, etc.

Figure 3. Enlargement of the Digital Watershed GIS toolbar and functions.

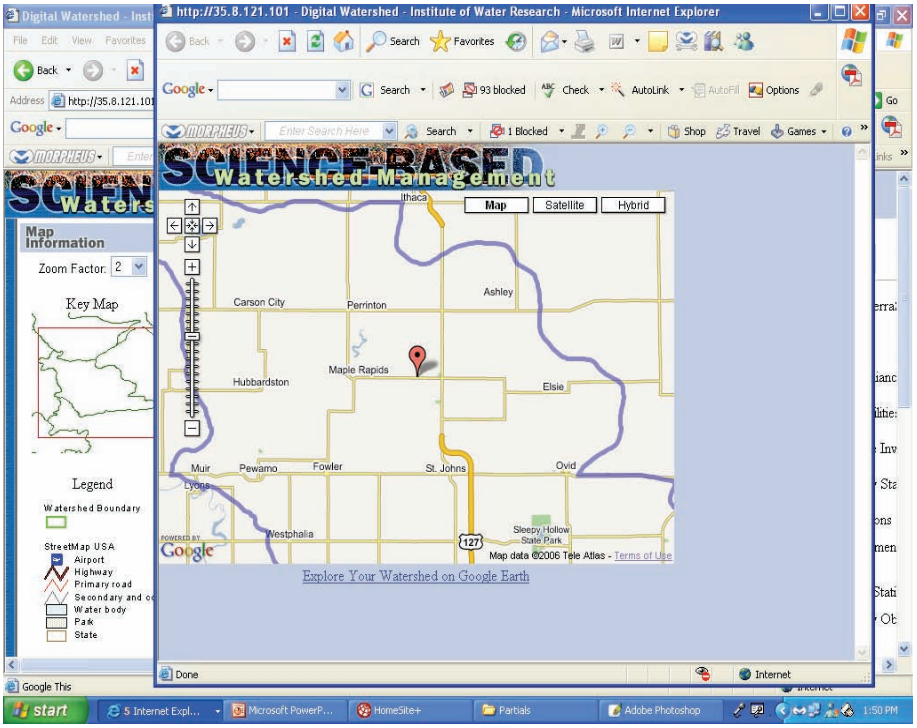


Figure 4. Google Earth image with a "pin" marking the location of interest selected by the user and the delineated blue boundary of the user-selected 8-digit Maple River watershed (Michigan).

Further zooming-in makes it possible to see buffer strips, grass waterways, specific land cover, and other best management practices (BMPs). A 3-dimensional rendition of the landscape generated by Digital Watershed is shown in Figure 7. This 3-D capability allows viewers to discern more clearly the multiple dimensions of landscape characteristics, e.g., land cover with topographical elevations.

Land cover data at multiple scales provide extremely important information from 8-digit watersheds to field scale at 1-meter resolution. For example in Figure 8, a Great Lakes Basin map from the EPA's Great Lakes Basin Landscape Ecology Metric Browser displays the quantified volumes of sediment flowing to coastal wetlands that correspond to one of the State of the Lakes Ecosystem Conference (SOLEC) indicators (Lopez *et al.* 2005).[1] This map shows 8-digit watersheds around the Great Lakes Basin that are potentially at risk according to this indicator. At this regional scale, it would be difficult

1 The State of the Lakes Ecosystem Conferences (SOLECs) are co-hosted by the U.S. EPA and Environment Canada to exchange information on the ecological conditions of the Great Lakes Basin (in response to the binational 1987 Great Lakes Water Quality Agreement). SOLECs have developed a comprehensive set of environmental indicators to support and facilitate the biannual reporting process required under the agreement.

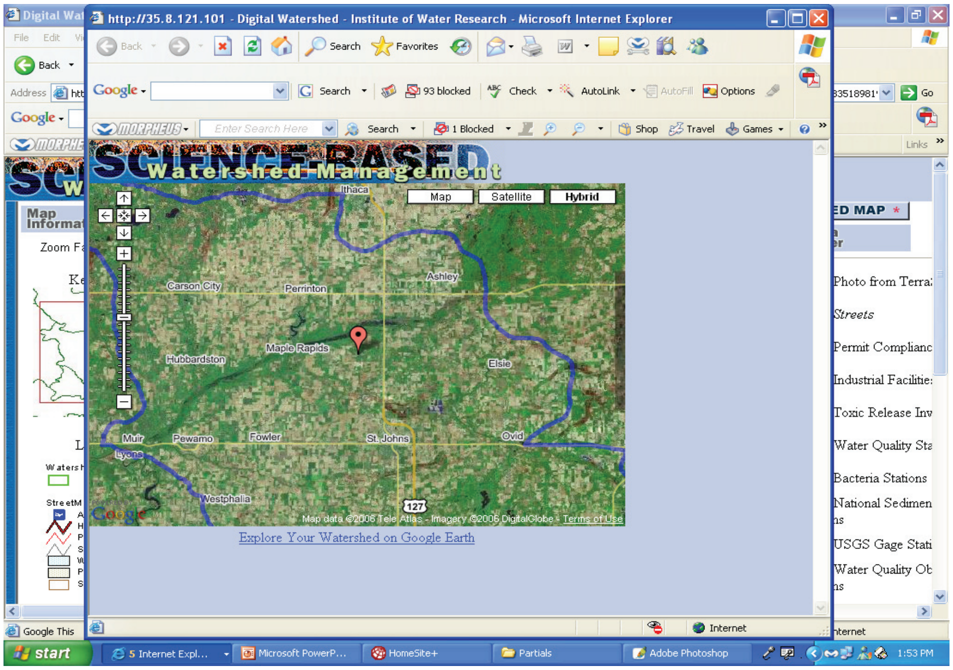


Figure 5. Google Earth rendition of land cover in the 8-digit Maple River watershed (Michigan).

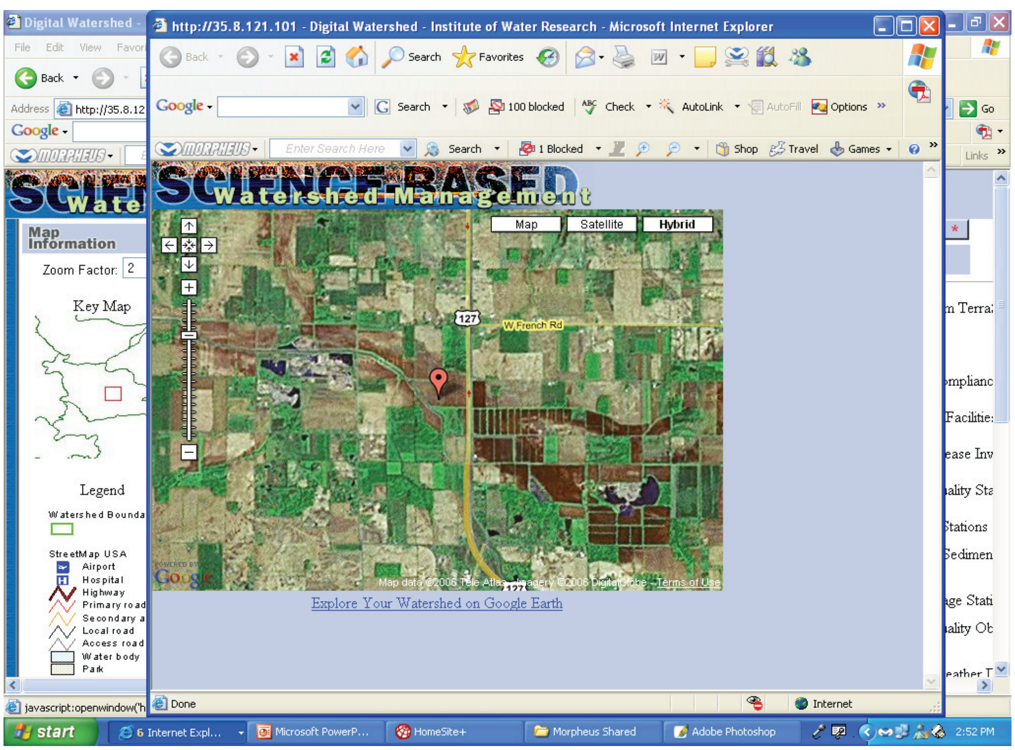


Figure 6. Zoom-in of image in Figure 5.

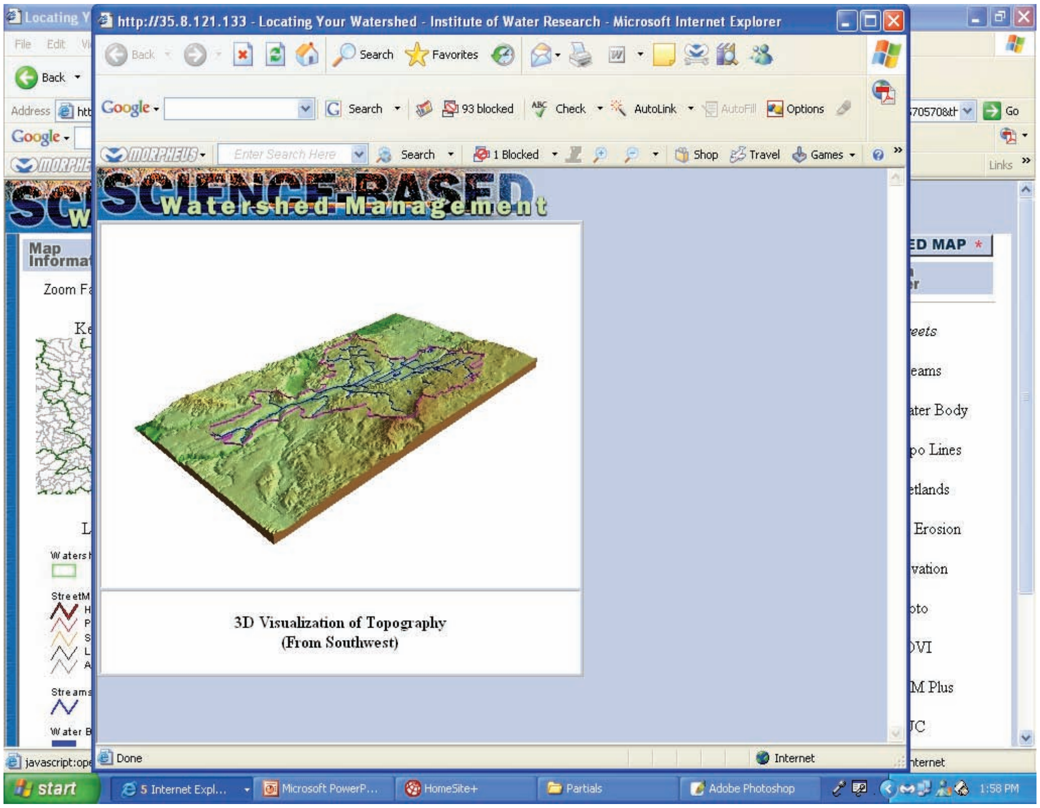


Figure 7. 3-dimensional rendition of the landscape in Figure 5.

(actually impossible) to select specific areas within those 8-digit watersheds that pose the greatest risks to coastal wetlands. In Figure 9, high risk erosion areas within an 8-digit watershed are displayed in Digital Watershed. This function, then, could be used by conservation agencies or local watershed organizations to address this SOLEC indicator. Mapping of the local coastal wetland areas could be overlain with the Digital Watershed function identifying the high risk erosion areas. Targeting implementation of appropriate BMPs on the highest risk erosion areas with proximity to coastal wetlands would optimize the beneficial impacts of those BMPs on protecting those wetlands. This type of targeting is currently being implemented in three Michigan watersheds by the MSU Institute of Water Research and the Michigan Department of Agriculture with the application of the High Impact Targeting (HIT) model (discussed in the next section).

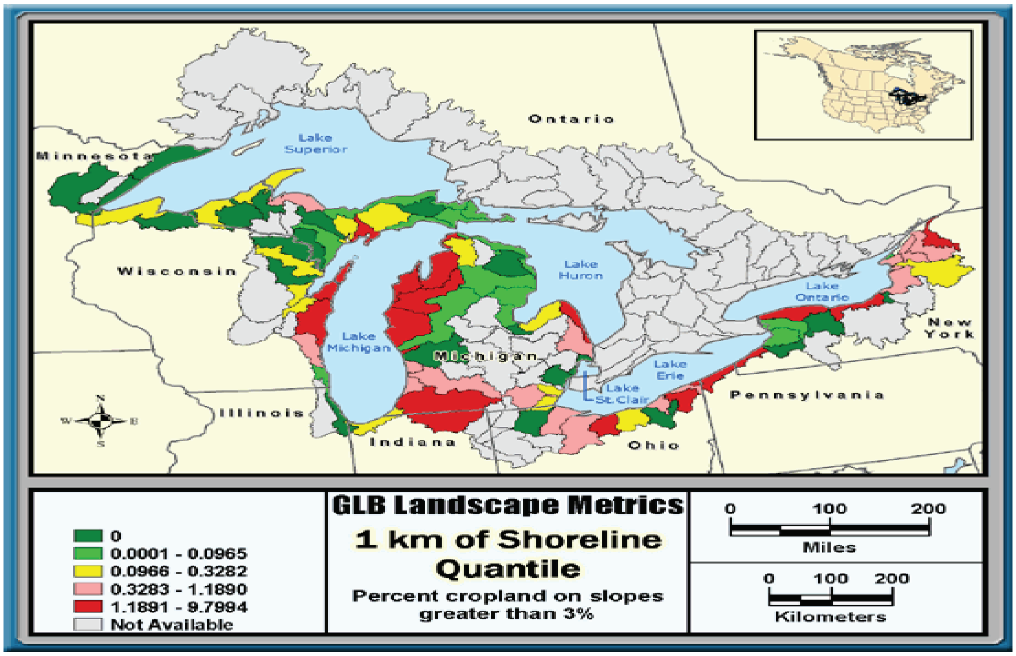


Figure 8. Sediment flowing to coastal wetlands (Lopez et al. 2005).

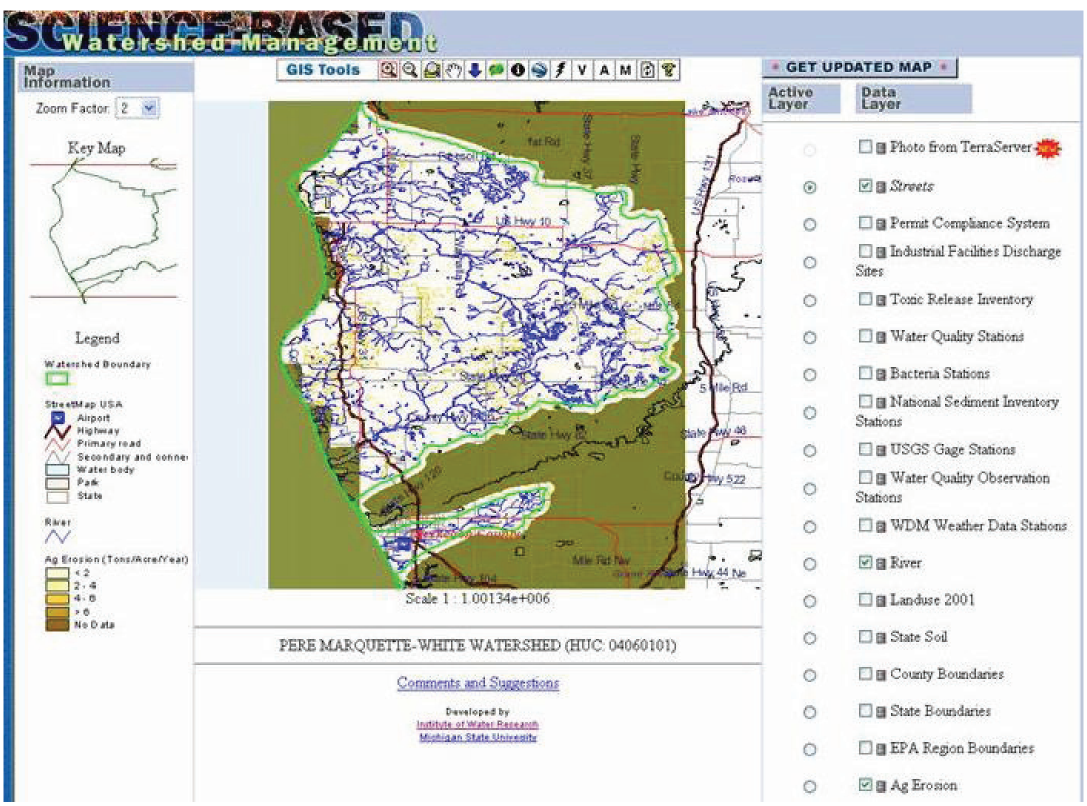


Figure 9. Pere Marquette River-White Lake coastal watershed with the high risk erosion areas data layer turned on and highlighted in brown/beige.

USING LAND COVER DATA IN THE MIDWEST PARTNERSHIP SYSTEM MODELING FUNCTIONS

Extensive land cover and use data is incorporated in the Midwest Partnership System to support a range of modeling functions. One modeling approach in the Midwest Spatial Decision Support System (MSDSS) is the High Impact Targeting (HIT) System that can be used to target BMPs on agricultural areas that contribute the greatest sediment loadings to receiving waters (Soil and Water Conservation Society 2007). The HIT approach integrates the Revised Universal Soil Loss Equation (RUSLE) model (USDA 1997) and the Spatially Explicit Sediment Delivery Model (SEDMOD) (Ouyang *et al*., 2005). Figure 10 shows a flow chart describing the integration and outputs of these two modeling approaches. As the flow chart indicates, land cover data is required as inputs to produce SEDMOD and RUSLE outputs. To derive accurate sediment yields, incorporation of the most up-to-date land cover data is critical. When finer-resolution land cover is available it can be incorporated into the HIT approach, but most analyses utilize the readily available 2001 National Land Cover Dataset (NLCD). Within HIT the 21 classes of the NLCD are re-classified to C-factors (used in the calculation of annual erosion) and surface roughness coefficients (used in the calculation of sediment delivery ratios) to calculate annual sediment delivery on a cell by cell basis. Each cell in a HIT analysis represents a separate RUSLE calculation combined with a separate delivery ratio. Therefore each high-risk cell is an area where soil is likely eroding and ending up in the nearby stream; it is not simply an area suitable for sediment conveyance. In Figure 11, the screen is zoomed-in to the field level and in Figure 12, the high risk erosion areas at the same scale are identified with red shading, the darkest red hues indicating those cells with the highest potential for erosion and sediment delivery. These red/pink-shaded cells are overlain on a digital aerial photographic layer obtained from TerraServer. The use of land cover data, then, is critical to both modeling sediment yield and to the high-resolution photographic layer which together assist users in identifying problem areas on specific farm fields.

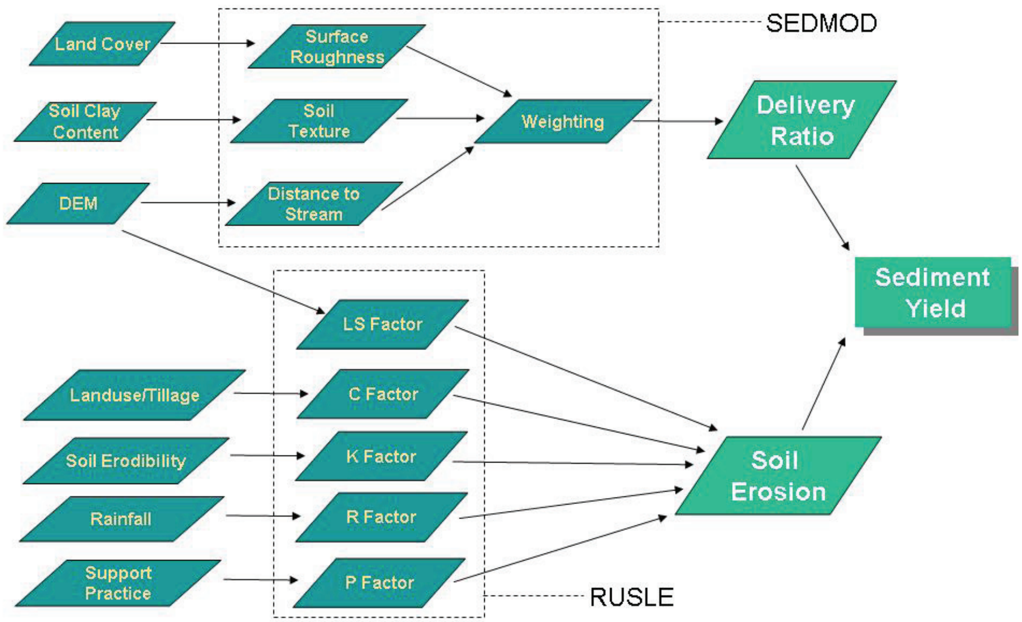


Figure 10. Flow chart of the sediment yield modeling process.

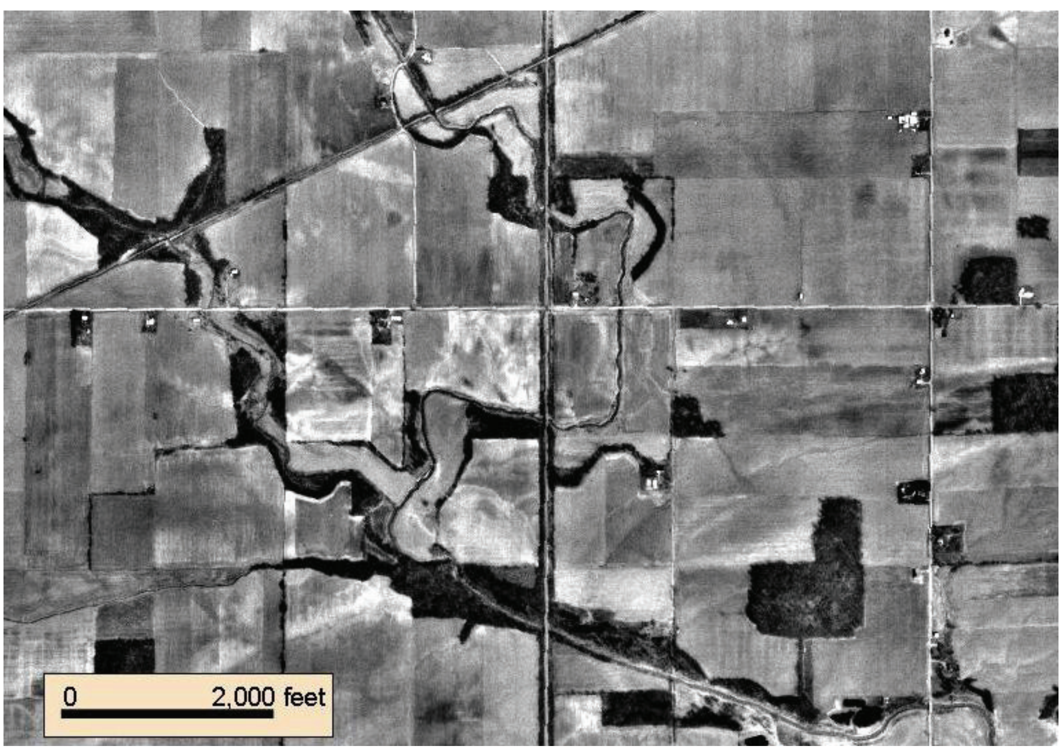


Figure 11. Example of aerial photography at field scale in Digital Watershed.

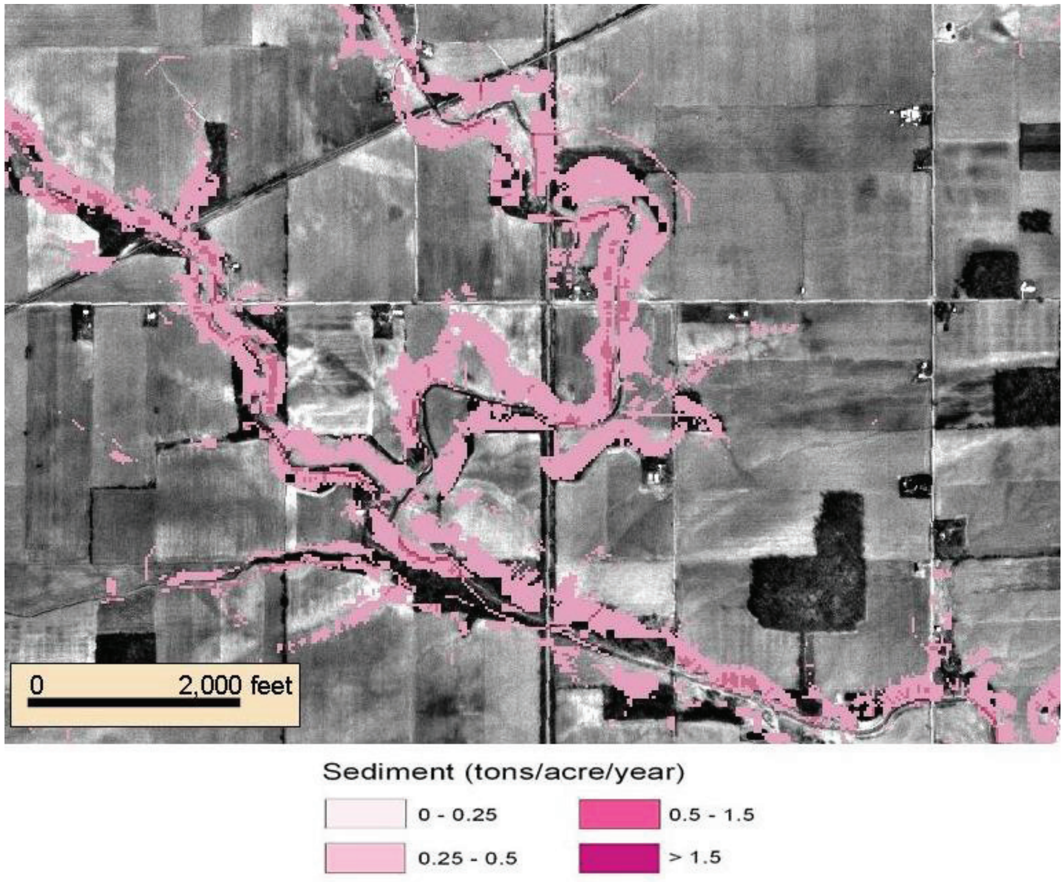


Figure 12. High risk sediment-generating areas highlighted in pink applied to same image as seen in Figure 11.

Land cover data are also required for other simulation models accessed through the Digital Watershed mapper including the Long-Term Hydrologic Impact Assessment (L-THIA) model; Sediment and Erosion Control Planning, Design and SPECification Information and Guidance Tool (SEDSPEC); and others. These models are activated by first clicking on “Delineate Watershed” on the toolbar (Figure 13), and then clicking on the point at which the user wants to delineate a watershed for analysis. Then input information needed for the Purdue University L-THIA model is seamlessly displayed (see Figure 14) in the Digital Watershed screen. The L-THIA model uses long term (30+ years) daily weather, hydric soil group, and land use data to simulate runoff volumes and loadings of 13 nonpoint source pollutants, including phosphorus, nitrates, heavy metals, and fecal coliform bacteria. Long-term annual outputs include loadings for each land use type and the probability of exceedance curves where loadings exceed applicable water quality standards.

The SEDSPEC model estimates small watershed peak runoff that can be used to provide preliminary information on the design, cost, and maintenance of hydraulic and erosion control structures. To estimate peak runoff, two standard hydrologic models (the Rational Method and TR-55) are used to simulate short-term peak runoff based on site-specific land uses and hydrologic soil groups. SEDSPEC can be used to recommend the structural dimensions of channels; culverts; riprap-lined, concrete-lined, and open channels; level terraces; low water crossings; runoff diversions; sediment basins; and storm water detention basins (Tang *et al.* 2004).

THE IMPORTANCE OF UNDERSTANDING TEMPORAL LAND COVER CHANGE

Accurate and consistent information about temporal changes in land cover is critically important for discerning trends and drivers and understanding the impacts of those trends and drivers on the landscape. Figures 15 shows land cover change for the 8-digit Upper Grand Watershed and the state of Michigan in 1980, 2020, and 2040, respectively (http://www.cevl.msu.edu/pages/lulc/peopleland.htm). Rather startling changes in terms of the extent of future conversion of agricultural and rural areas to build-out areas are clearly evident from merely viewing these maps. These maps were developed from Land Transformation Model outputs as part of a 2001 state land resource study (Public Sector Consultants 2001). An increase of 178% in build-out was projected by 2040 for the state as a whole. These maps illustrate the temporal distribution of the areas that will be converted from agriculture, forestry, and wetlands to build-out areas (Public Sector Consultants 2001).

Direct economic impacts of these changes include substantial revenue losses to the agricultural and forestry sectors. Grow-out map presentation (Figure 15) can have a powerful impact on citizens and units of government by motivating good land use resource planning coupled with economic development. Indirect economic impacts include expected increases in agricultural and rural land values from development pressures and corresponding escalation of crop and food prices. In addition to those indirect economic impacts, losses are also expected to result from the impairment of ecosystem

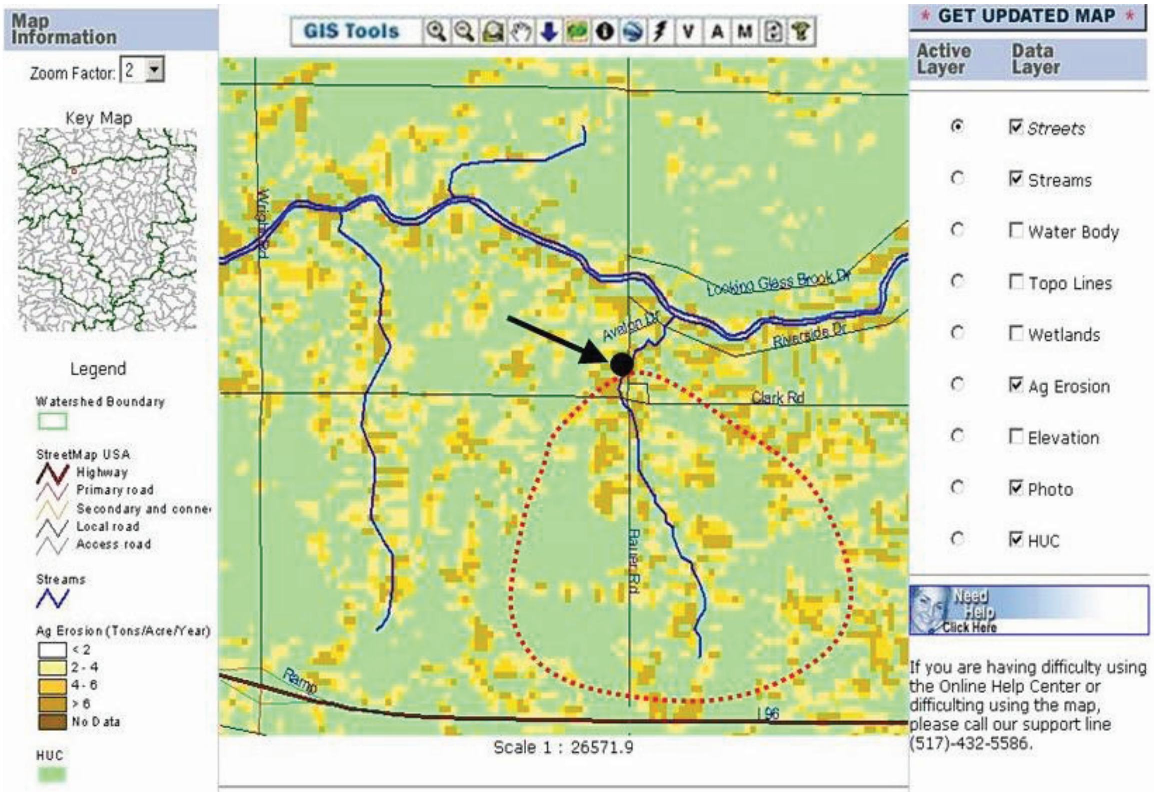
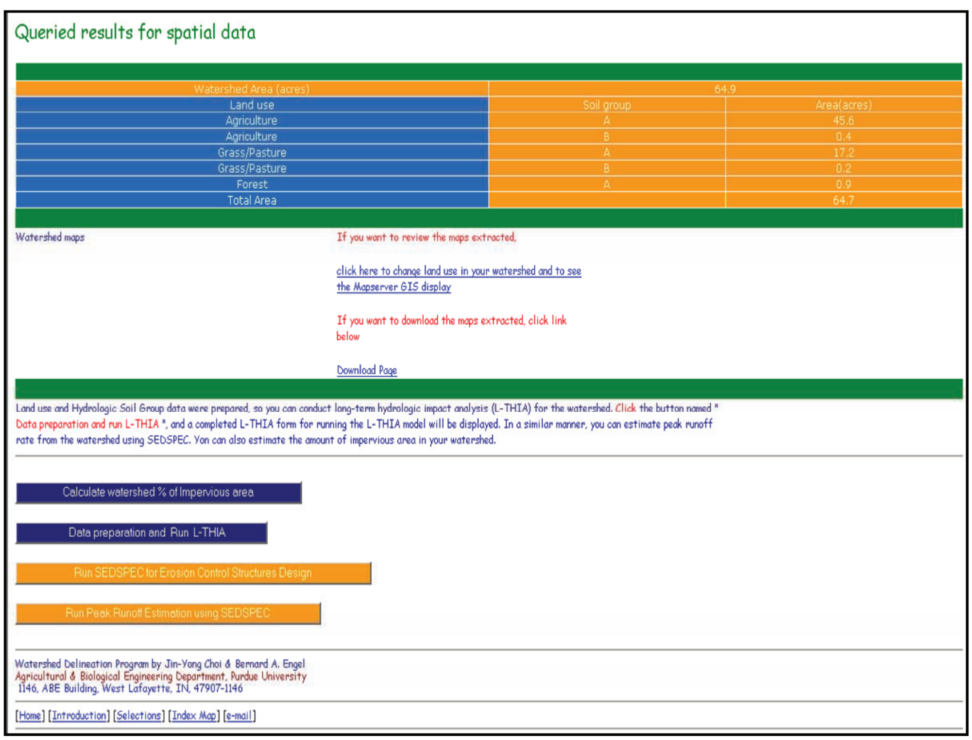


Figure 13. Delineated watershed (shown in dashed-red line here for demonstration purposes only) based on the user's selected location (arrow pointed at black point) that s/he wants to analyze.



Queried results for spatial data

Watershed Area (acres)	64.9	
Land use	Soil group	Area(acres)
Agriculture	A	45.6
Agriculture	B	0.4
Grass/Pasture	A	17.2
Grass/Pasture	B	0.2
Forest	A	0.9
Total Area		64.7

Watershed maps

If you want to review the maps extracted,

click here to change land use in your watershed and to see the Mapserver GIS display

If you want to download the maps extracted, click link below

Download Page

Land use and Hydrologic Soil Group data were prepared, so you can conduct long-term hydrologic impact analysis (L-THIA) for the watershed. Click the button named " Data preparation and run L-THIA ", and a completed L-THIA form for running the L-THIA model will be displayed. In a similar manner, you can estimate peak runoff rate from the watershed using SEDSPEC. Yon can also estimate the amount of impervious area in your watershed.

Calculate watershed % of Impervious area

Data preparation and Run L-THIA

Run SEDSPEC for Erosion Control Structures Design

Run Peak Runoff Estimation using SEDSPEC

Watershed Delineation Program by Jin-Yong Choi & Bernard A. Engel
Agricultural & Biological Engineering Department, Purdue University
1146, ABE Building, West Lafayette, IN, 47907-1146

[Home] [Introduction] [Selections] [Index Map] [e-mail]

Figure 14. L-THIA Modeling Function providing land and soil summary information for the user-selected delineated watershed in Figure 13.

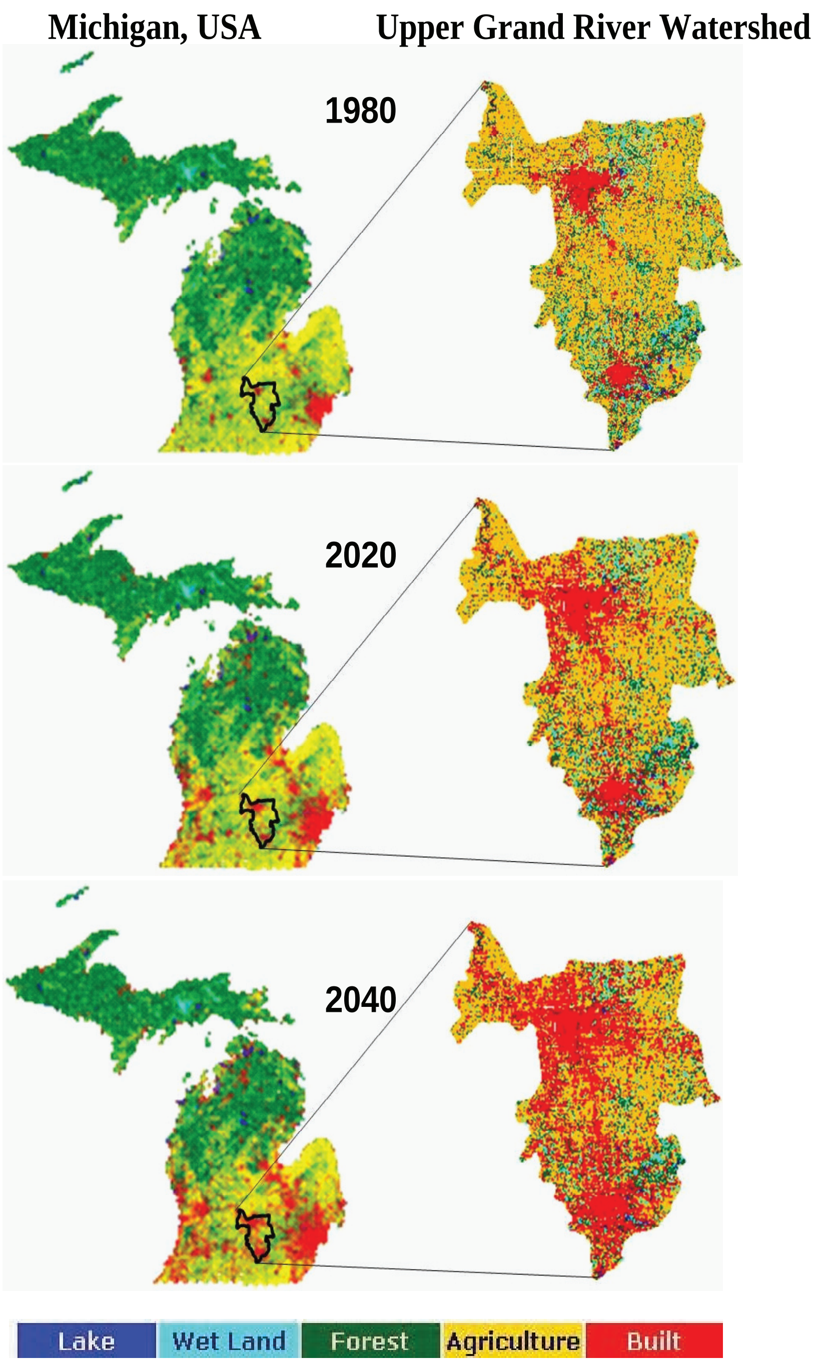


Figure 15. Land use for the State of Michigan and the Upper Grand River watershed for years 1980 (actual), 2020 (projected) and 2040 (projected), respectively (Public Sector Consultants 2001).

services and could jeopardize the state's natural resource-based economic sectors, primarily tourism and agriculture (Public Sector Consultants 2001). These impairments are closely associated with the increased fragmentation of natural areas that are best measured by changes in land cover (and land use) (Jones *et al.*, 1997, Jones *et al*,. 2001), preferably at 10-m resolution or finer. Finally, the impacts of urbanization on water quality and aquatic habitat from increases in water temperatures, stream flashiness, and riparian development (Wang *et al*., 2001, Franklin 1992) may impair those riverine resources that support cold water fisheries in those watersheds (Seelbach *et al*., 1997).

Clearly, the trends and impacts of urbanization and the potential loss of ecosystem services are critical concerns at multiple scales: local, state, basin-wide, national, and global. The multiple characteristics of changes in land cover and their multiple impacts at multiple scales on climate change, ecosystem services, and the ambient environment (Wang *et al.*, 2001, Ourso and Frenzel 2003, Weigel *et al.* 2003, Allan 2004) dictate the need to accelerate and expand the use of scalable GIS-based decision support systems. Using this system, decision makers will be able to better manage data and understand trends, perform comparative scenario analyses, understand both specific and aggregate impacts of trends and decision options, and integrate the value of ecosystem services with more traditional economic measures of value.

The capacity to visualize, quantify, and analyze the extent and impacts of land use change, specifically the conversion of agriculture and other open areas to urban build-out, has a distinct relevance and important value to local decision makers. The use of geospatial depictions of past, current, and predicted future conditions can be extremely powerful in providing planners and communities with a more sensitive understanding and comprehensive knowledge of the conditions of their watersheds (Conway and Lathrop 2005). With this expanded understanding and knowledge, decision makers will more likely use a range of Midwest Partnership decision support system tools, and consequently will be able to better anticipate and understand the full extent of the impacts of land cover changes on the conditions of their watersheds. The greater the capacity to use land cover data to identify relevant trends, drivers, and impacts at multiple scales, the more likely effective resource and watershed management can be implemented (National Fish Habitat Science and Data Committee 2006). Ideally, the application of this knowledge and understanding to myriad planning, zoning, resource management, and economic development decisions can instigate and guide greater coordination of the numerous actions taken by local units of government and traction for collaborative sustainable management of natural resources at multiple scales. Local decision makers can act as intelligent stewards of natural resources, supported by their Web access to a transparent, user-friendly GIS framework provided by the Midwest Partnership System and/or other systems.

FUTURE CAPABILITIES OF THE MIDWEST PARTNERSHIP SYSTEM

The future capabilities of the Partnership include expanded development and refinement of an advanced Web portal/user interface that provides user-friendly access to ever more extensive data and sophisticated modeling tools applicable to various types of landscapes at multiple scales. This portal/system will better serve the multiplicity of federal, state, and local government agency needs and enhance the capabilities of these agencies, non-governmental organizations, and local communities to make sustainable natural resource and environmental decisions. System functionality will also be expanded to address critical ecological perspectives and issues associated with the impacts of resource decisions on ecosystem services. These impacts include changes in both the ecological and economic value of ecosystem services. That is, the impairment of ecological functions is also reflected in a decline of the economic value of that ecosystem service. Economic valuation of ecosystem services needs to be investigated and the Midwest System can be an important tool in that line of inquiry.

The Web-accessible Midwest System will be expanded to deliver innovative GIS analysis tools at statewide, Great Lakes basin-wide, and ultimately nationwide scales. The multiple functionality of the system relies on land cover and numerous other data layers connected seamlessly to Digital Watershed from multiple sources and modeling functions (hosted by either MSU or Purdue University) that are integrated in the Digital Watershed mapper. Figure 16 demonstrates the multiple functions of the future Digital Watershed gateway and how local decision-makers can acquire information about watershed trends and drivers to assess both specific and aggregate impacts of land change on the landscape. As illustrated, Digital Watershed provides access to a wide array of multiple models and databases including

Analytical Tools Interface for Landscape Assessments (ATtILA; Ebert and Wade, 2001; http://www.epa.gov/nerlesd1/land-sci/attila/index.htm), Regional Vulnerability Assessment (ReVA; Smith 2000; http://www.epa.gov/reva/), Automated Geospatial Watershed Assessment (AGWA; Semmens *et al.*, 2004; http://www.tucson.ars.ag.gov/agwa/), and Long Term Hydrologic Impact Assessment (L-THIA; Bhaduri *et al.*, 2001; http://www.ecn.purdue.edu/runoff/lthianew/).

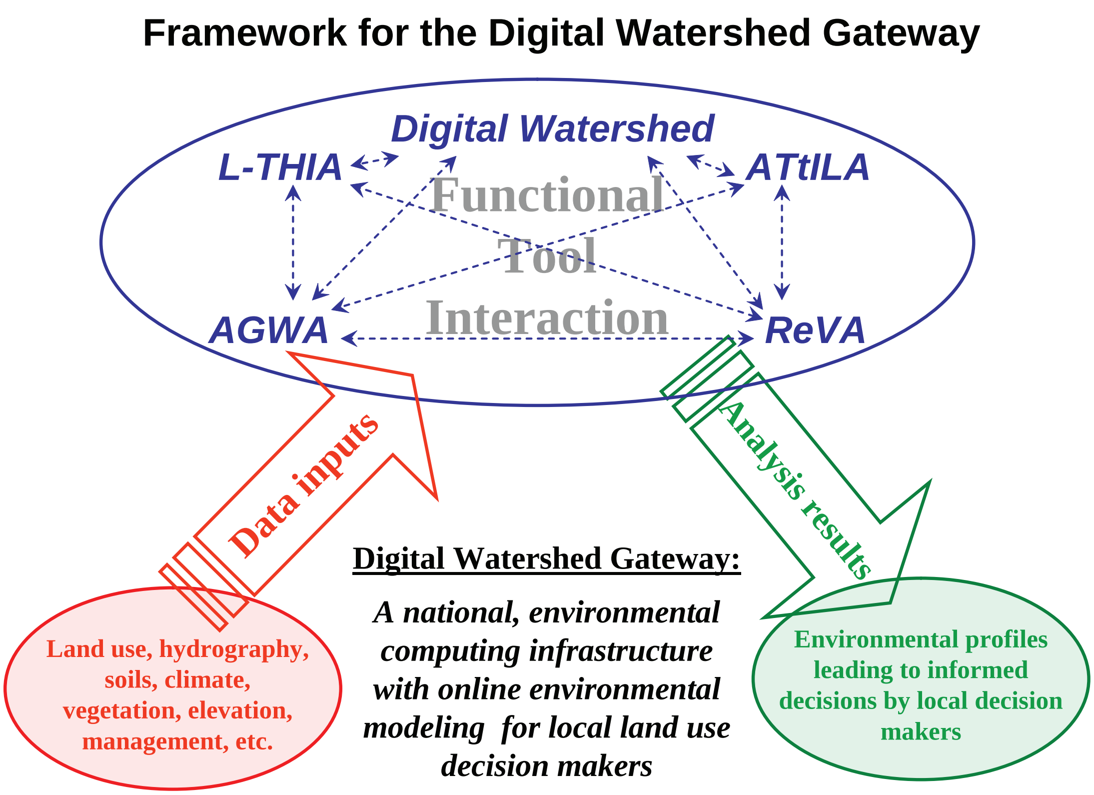


Figure 16. Local decision makers can select from a menu of functions in accessing the Digital Watershed Gateway.

The MDSSP's innovative use of interoperable Web services represents the cutting edge of environmental computing technology and the environmental sciences. Robust technical capacity and equally dynamic cooperative partnerships are shaping a new Web-based, GIS infrastructure to deliver data, analysis, and modeling functions to natural resource decision makers across the Great Lakes Basin, the nation, and the world.

The development of a global environmental management platform is clearly feasible in the near term as the Midwest Partnership and other organizations transform how systems collect and distribute information, and share and perform analyses. The integrative functionality of the system expands the scope and depth of geospatial information dependent on land cover data that can be employed in resource decision making at multiple scales. As environmental problems become increasingly understood and demanding of solutions on a global scale—climate change, invasive species, land use dynamics, and access to clean water, as examples—a flexible global platform for effective management and sustainability of natural resources is not only desirable but also imperative.

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CHAPTER 15

EVALUATING HYDROLOGICAL RESPONSE TO FORECASTED LAND-USE CHANGE

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ABSTRACT

It is currently possible to measure landscape change over large areas and determine trends in environmental condition using advanced space-based technologies accompanied by geospatial analyses of the remotely sensed data. There are numerous earth-observing satellite platforms for mapping and monitoring land cover and land-cover change; however, the traditional workhorses have been the Landsat Multi-Spectral Scanner (MSS) and Thematic Mapper (TM) sensors. Landsat has had a long history of commercial availability (first launch July 1972), a well developed global archive, and has been widely used for land-cover change detection and monitoring. During the past two decades, important advances in the integration of remote imagery, computer processing, and spatial-analysis technologies have been used to develop landscape information that can be integrated within hydrologic models to determine long-term change and make predictive inferences about the future. This article presents two studies in which future land-use scenarios were examined relative to their impact on surface-water conditions, e.g. sediment yield and surface runoff, using hydrologic models associated with the Automated Geospatial Watershed Assessment (AGWA) tool. The base reference grid for land cover was modified in both study locations to reflect stakeholder preferences twenty to sixty years into the future and the consequences of landscape change were evaluated relative to the selected future scenarios. A third study utilized historical land-cover data to validate the approach and explore the uncertainty associated with scenario analysis. These studies provide examples of integrating modeling with advanced Earth-observing technology to produce information on trends and make plausible forecasts for the future from which to understand the impact of landscape change on ecological services.

Key words: *landscape characterization, hydrological process models, alternative futures, scenario analysis, watershed assessment, ecosystem services, San Pedro River, Willamette River.*

INTRODUCTION

Inferring biophysical processes on the Earth's surface by measuring reflected electromagnetic spectra at the edge of the troposphere and organizing the information into meaningful representations that relate to vegetative composition, extent, and distribution seems like a difficult if not impossible task. Nevertheless, Earth-observing satellites and algorithm technology represent two of the most important scientific achievements of our time for observing and characterizing the Earth's surface in regard to natural phenomena, environmental hazards, and the direct effects of human-induced impacts on natural resources and the ecological goods and services they provide.

Over the last decades, numerous advances have been made in the development of remote sensors and geographic information systems (GIS) and their linkage with land-use change models to assess the influence of land cover on biophysical processes and conditions, e.g. land degradation, ecosystem vulnerability, watershed condition, and biodiversity (Guisan and Zimmermann 2000; Kepner et al. 2005; Petrosillo et al. 2008).

GIS is a widely accepted tool for ecosystem management and has provided an enhanced capability for research scientists to develop and apply land-use models because of the capacity to work with and organize large datasets in addition to the ability to integrate with most image analysis and processing systems. Today, remotely sensed data in the form of classified land cover are used to derive input variables for a wide variety of environmental models, e.g. hydrologic-response and habitat models (Scott et al. 1993; Edwards et al. 1996; Miller et al. 2007).

This is especially important because of the current attention provided to sustaining ecosystem goods and services and the changes in ecosystem state or condition that are perceived throughout the world (Millennium Ecosystem Assessment 2005b; Farber et al. 2006). Space-based sensor data provide multi-temporal and multi-spectral datasets that support monitoring ecosystem change and testing our understanding of key processes in land-use change, irrespective of their causal agents (Lunetta and Sturdevant 1993; National Science and Technology Council Committee on Environment and Natural Resources Research 1996; Homer et al. 2004). Additionally, it is possible to examine ecosystem state at a variety of scales and these data especially support working at regional, continental, and global scales and the contemporary interest in large-area processes.

The ability to assess, report, and forecast the life-support functions of ecosystems is absolutely critical to our capacity to make informed decisions that will maintain the sustainable nature of our ecosystem services and secure these resources into the future (Liu et al. 2008; SCEP 1970). This chapter explores the emerging field of scenario analysis that allows users to project alternative pathways into the future and test the sensitivity of selected variables to land-cover conversion and changes in land-use pattern. In the following case studies, the alternative future courses of action relate to two urbanizing watersheds and the assessment of the subsequent impacts of land-cover change on watershed response, i.e. surface runoff, erosion, channel discharge, and percolation.

SCENARIO ANALYSIS

Scenarios, as defined by the Intergovernmental Panel on Climate Change (IPCC 2001), are "plausible and often simplified descriptions of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships." Thus scenario analysis is an approach for evaluating various rational choices and the respective trajectories that lead to alternative future events. In the realm of natural sciences this is typically accomplished by using a combination of land-use change and process models to develop an artificial representation of the physical manifestations of scenario characteristics, and to establish a multi-disciplinary framework within which scenario characteristics may be analyzed (Turner et al. 1995; Clayton and Radcliffe 1996; Millenium Ecosystem Assessment 2005a). Scenarios are also usually conducted over long time periods (20-50 years) and develop a range of stakeholder-driven perspectives (scenarios), which are analyzed in detail for the consequences or benefits of their selection.

Scenario analysis is gaining widespread acceptance among decision-makers as a practical tool for addressing uncertainty about the future. The process provides the ability to explore the potential impacts, risks, benefits, and management opportunities that stem from a variety of plausible future conditions. The first step in this process, i.e., scenario definition, is a critical part of scientific and social decision-making with the purpose of creating a shared vision for both desirable and sustainable future outcomes. Scenario studies require experts and models from widely different disciplines and involve substantial interaction among scientists and stakeholders, as well as expert judgment. The information is combined in an iterative process of scenario definition, construction, analysis, assessment, translating model outputs to forms relevant to stakeholders, quantification and communication of scenario uncertainty, linking scenario outcomes to decision-making strategies or operational monitoring, and response, i.e. risk management (Liu et al. 2008). Scenario analysis, combined with landscape sciences, can be used to 1) test possible impacts, 2) assist strategic planning and policy information, and 3) structure current knowledge to scope the range of potential future conditions. In particular, it helps us address the key contemporary question of how ecological systems are affected by changes in land use and climate across a range of spatial and temporal scales.

This chapter summarizes the results from two studies that examined the impact of urban development relative to the sustainability of water resources, a crucial asset of the western U.S. Specifically, it examines extreme positions related to future urbanization in the Willamette River Basin (Oregon) and the San Pedro River (U.S./Mexico borderland of Arizona) with the intent of providing answers and a process for determining whether urban/agricultural growth patterns can be managed to minimize hydrologic and ecologic impacts. Results from a third study are also presented to provide a means of gauging the utility of hydrologic analysis of future scenarios by looking back at past land-use change.

HYDROLOGICAL PROCESS MODELING

Typically, scenario analysis uses a model-based approach to identify the key variables that reflect environmental change and to examine landscape change relative to specific issues or endpoints. This involves first modeling land-use change that is consistent with scenario definitions and then using it as input to hydrologic process models to examine hydrologic change. Generally models are selected with the idea of using available contemporary datasets such as digital land cover to construct the reference or baseline condition and the various alternative future options. It is the combined model output information for each scenario definition that is utilized for comparison of the options and represents the core of the actual scenario assessment (Liu et al. 2008).

In the two example case studies, the focus was directed at examining surface hydrological features associated with each watershed. Consequently, we chose to employ the Automated Geospatial Watershed Assessment (AGWA) tool, a GIS interface jointly developed by the U.S. Environmental Protection Agency, U.S. Department of Agriculture (USDA) Agricultural Research Service, and the University of Arizona to automate the parameterization and execution of the Soil Water Assessment Tool (SWAT) (Arnold and Fohrer 2005), and KINEmatic Runoff and EROSion (KINEROS2) (Smith et al. 1995; Semmens et al. 2007) hydrologic models (Miller et al. 2007). The application of these two models allows AGWA to conduct hydrologic modeling and watershed assessments at multiple temporal and spatial scales; for large river basins typically SWAT is employed. AGWA's current outputs are runoff (volumes and peaks) and sediment yield, plus nitrogen and phosphorus with the SWAT model.

AGWA uses commonly available GIS data layers to fully parameterize, execute, and spatially visualize results from both SWAT and KINEROS2. Through an intuitive interface the users select an outlet from which AGWA delineates and discretizes the watershed using a Digital Elevation Model (DEM) based on the individual model requirements. The watershed model elements are then intersected with soils and land cover data layers to derive the requisite model input parameters. AGWA can currently use STATSGO, SSURGO, and FAO soils and nationally available land-cover/use data such as the National Land Cover Data (NLCD) datasets (Homer et al. 2004). Users are also provided the functionality to easily customize AGWA for use with any classified land-cover/use data. The chosen hydrologic model is then executed, and the results are imported back into AGWA for visualization. This allows decision-makers to identify potential problem areas where additional monitoring can be undertaken or mitigation activities can be focused. AGWA can difference results from multiple simulations to examine and compare changes predicted for each alternative input scenario (e.g. climate/storm change, land-cover change, present conditions, and alternative futures). In addition, a variety of new capabilities have been incorporated into AGWA including pre- and post-fire watershed assessment, watershed group simulations, implementation of stream buffer zones, and installation of retention and detention structures. A land-cover modification tool is provided for the development of prescribed land-cover change scenarios, with a number of options for uniform, spatially random, and patchy change to single or multiple land-cover classes. There are currently two versions of AGWA available: AGWA 1.5 for users with Environmental Systems Research Institute (ESRI) ArcView 3.x GIS software (ESRI 2005), and AGWA 2.0 for users with ESRI ArcGIS 9.x (ESRI 2006).

The required input data for AGWA include a DEM, polygon soil map, e.g. STATSGO, and classified digital land-cover/use grid. Landsat Thematic Mapper (TM) has routinely been used as the classified imagery source for these analyses. Landsat has a reasonably long acquisition history, covers a large aerial extent of the Earth's surface, and has a well developed data archive for easy access at nominal cost. Most importantly it is provided at a spatial resolution (30-meter pixel ground resolution) that is appropriate for many of the common biophysical process models, e.g. wildlife habitat and hydrological response, which are currently applied to establish current condition or to assess the impact of land-cover change.

CASE STUDIES

In this chapter, potential impacts from three wide-ranging scenarios are compared to current conditions in two different watersheds in the western U.S. in terms of a set of processes that are modeled in a GIS. Alternative futures landscape analysis involves 1) describing development patterns and significant human and natural processes that affect a particular geographic area of concern; 2) constructing GIS models to simulate these processes and patterns; 3) creating changes in the landscape by forecasting and by design; and 4) evaluating how the changes affect pattern and process using models (USEPA 2000). This study presents an integrated approach to identify areas with potential water-quality problems as a result of land-cover change projected by stakeholders within the two river basins. The information is summarized from two separate studies (Kepner et al. 2004; Kepner et al. 2008) for the San Pedro and Willamette, respectively (Figure 1). The approach was largely similar for both locations. In the case of the San Pedro, the reference condition was the baseline year of 2000 that was established from a geospatial database developed specifically for the San Pedro (Kepner et al. 2003). In the case of the Willamette the reference condition was circa 1990 (Vogelmann et al. 2001). The land-cover/

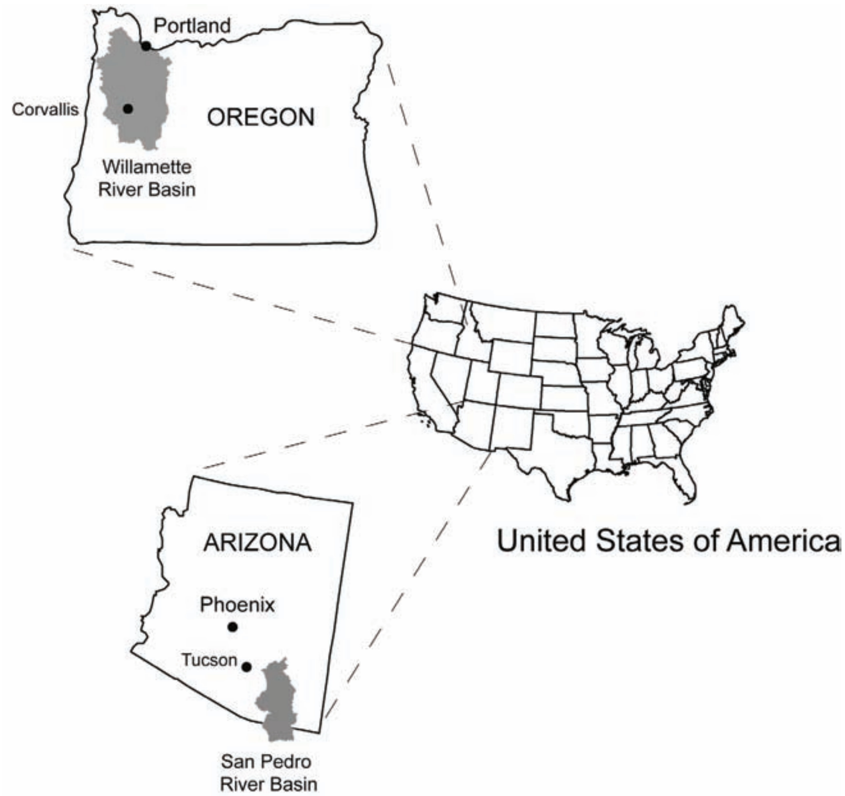

Figure 1. Location of the San Pedro and Willamette River Basins.

use scenarios were provided from separate studies (Steinitz 2003; Baker 2004) in which alternative courses of action were developed in consultation with local stakeholders for three basic options which reflected important contradictions in desired future policy based on stakeholder input. The scenarios are listed in Table 1 for both watersheds and reflect changes in population, patterns of growth, and development practices and constraints. The Conservation Scenario is characterized as the most ecosystem protection/restoration-oriented option, the Plan Trend Scenario reflects the most likely census predictions with zoning options designed to accommodate growth, and the Development Scenario is the least conservation and most market-economy positioned option. The future conditions for the San Pedro were projected to the year 2020 and to the year 2050 for the Willamette.

In both cases the AGWA tool was used to model each basin using SWAT and to evaluate the relative hydrologic consequences of anticipated future urban and suburban development. In the San Pedro case study (a preliminary demonstration of the method), SWAT was not calibrated to baseline conditions and the results were presented qualitatively. For the follow-on Willamette study SWAT was calibrated for base flow, surface runoff, and water yield. Results from the automated base flow separation program (Arnold et al., 1994) were used to identify the groundwater contribution to the total water yield. Both studies were designed to evaluate hydrologic conditions at distinct points in the future, which were represented as land-cover grids, and compare them to the present. Since future rainfall is unknown, 10-year observed, distributed baseline rainfall records were used in all simulations. By holding rainfall constant the analyses isolated the impacts of land-use change, but did not account for the sensitivity of those impacts to variable climatic conditions. Readers are referred to Kepner et al. (2004, 2008) for more details on the study areas and their respective approaches.

A third study (Semmens et al. 2006) utilized historic land-use/cover observations to validate the general scenario-assessment approach that was employed in the San Pedro and Willamette Basins. This retrospective analysis used repeat land-use/cover maps as proxies for future scenarios, with the earliest representing the baseline conditions. By working with known conditions it was possible to evaluate the effects of calibration on model performance and predicted hydrologic change. The ability to forecast land-use change associated with specific alternative future scenarios was not evaluated in this analysis. Instead, it endeavored to identify the strengths and weaknesses of utilizing hydrologic models to compare and contrast land-use/cover scenarios as was done in the San Pedro and Willamette Basins.

Scenario	**Description**
Conservation (Constrained)	Places greater priority on ecosystem protection and restoration, although still reflecting a plausible balance between ecological, social, and economic considerations as defined by citizen stakeholders.
Plan Trend	Assumes existing comprehensive land-use plans are implemented as written, with few exceptions, and recent trends continue.
Development (Open)	Assumes current land-use policies are relaxed and greater reliance on market-oriented approaches to land and water use.

Table 1. Alternative-future scenarios in the San Pedro River (U.S./Mexico) and the Willamette River (Oregon) basins.

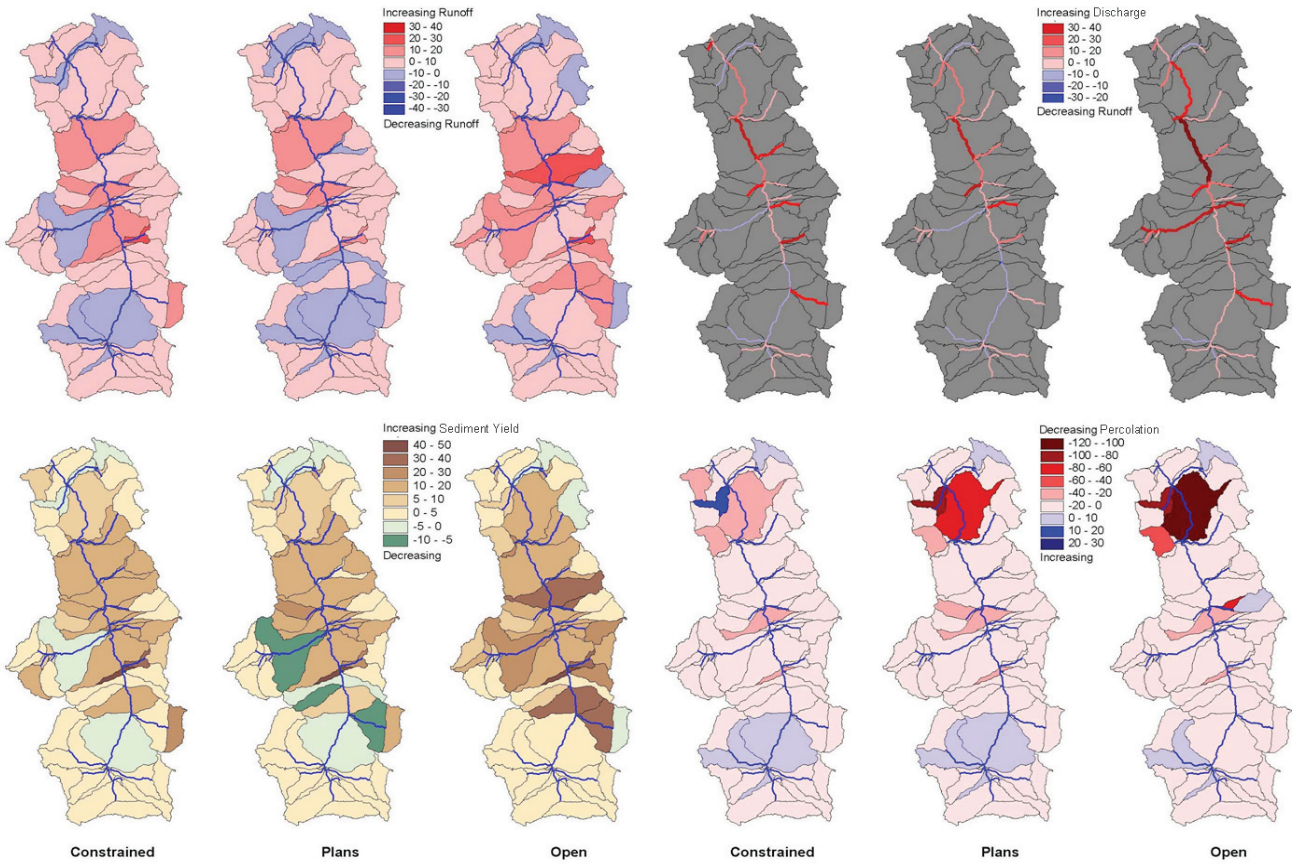

Figure 2. Maps showing modeled percent change in average annual surface runoff (upper left), channel discharge (upper right), sediment yield (lower left), and percolation (lower right) for each of the three alternative future (2020) scenarios for the San Pedro River Basin. Modified after Kepner et al. (2004).

SAN PEDRO CASE STUDY

The San Pedro River represents an area that has undergone remarkable land-cover change. This change has been quantified by satellite sensors (Kepner et al. 2000; Kepner, Edmonds, and Watts 2002) during the last quarter of the twentieth century. Surface runoff, channel discharge, percolation, and sediment yield were simulated using the SWAT model with AGWA for the three 2020 scenarios listed in Table 1. Results from the simulation runs are displayed in Figure 2. For the purpose of these studies, negative impacts are considered to be increases in surface runoff, streamflow discharge, sediment yield, and decline of percolation volume. The figures show the relative departure from the 2000 baseline year and illustrate the spatial variability of changes to the surface-water hydrology. In general, the simulation results indicate that land-cover changes associated with future development will alter the hydrology of the watershed. Changes are primarily associated with increasing urbanization and the associated replacement of vegetated surfaces with impervious ones. The most notable changes are likely to be increases in the amount of runoff, channel scour, and sediment discharge, and a loss of surface-water access to the groundwater table in the northern reaches of the watershed near Benson, Arizona.

In addition to providing a means of looking to the future, land-use/cover observations in the form of classified satellite imagery have also provided a means of using past observations to retrospectively evaluate the validity of scenario-analysis methodologies and predictions. In the southern portion of the San Pedro, historic observations for a series of dates over a period of 24 years (1973, 1986, 1992, and 1997) were used to evaluate methods and quantify error associated with forecasting future hydrologic response from baseline conditions. In this example, 1973 was taken to be the baseline condition and subsequent dates were treated as future scenarios. Simulations were conducted with and without calibrating the model to baseline conditions, and utilizing both observed and historic (baseline) rainfall. Some of the results from this analysis are presented in Figures 3 and 4, which illustrate two important points. First, climate has a profound influence over the magnitude of predicted changes in water yield. Neither specific modeled values, nor the modeled change in those values should be used for quantitative estimation of future conditions when baseline rainfall is used (Figure 3). However, by holding rainfall constant in such an analysis it is possible to see just the impacts of land-use change, which is a useful means of comparing alternative land-use scenarios. Second, while calibration greatly improved quantitative predictions of water yield for any given scenario, it had no consistent impact on the predicted change in water yield relative to baseline conditions (Figure 4). If this observation holds true for other geographies and models it suggests that calibration may not be necessary for scenario assessment if model results are only to be used for scenario comparison. This would make simple better/worse model-based scenario assessment faster, less expensive, and possible even when observed hydrologic data are unavailable.

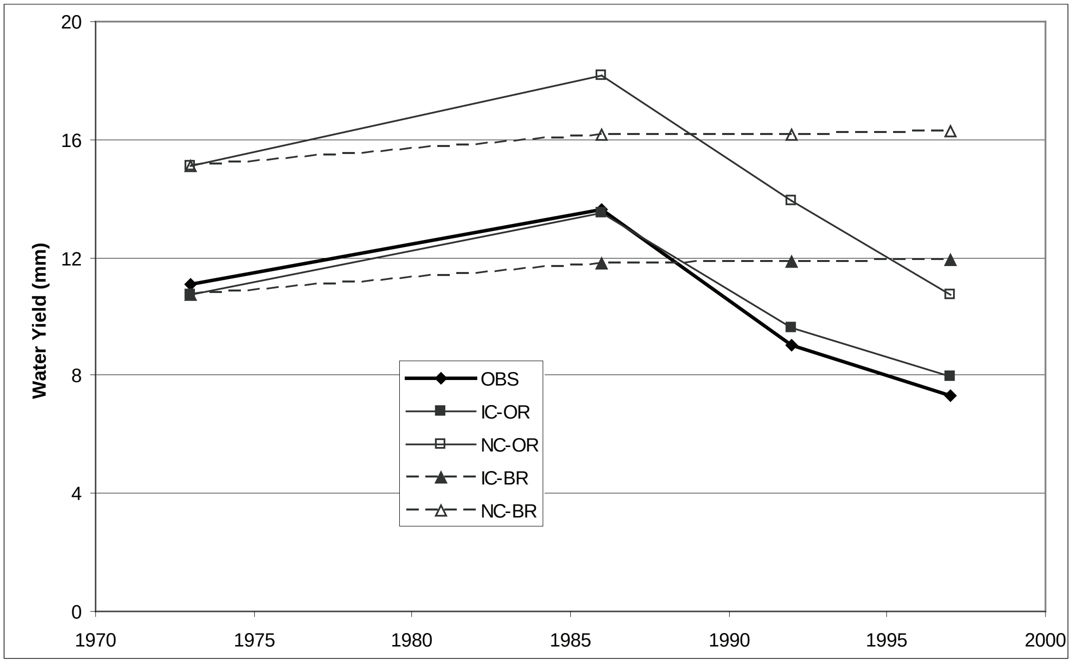

Figure 3. Graph showing modeled and observed (OBS) water yield for each simulation period. Initially calibrated (IC) simulation results are shown with solid symbols and uncalibrated (NC) results are shown with open symbols. Simulation results based on observed rainfall (OR) are shown with square symbols, and those based on baseline rainfall (BR) and shown with triangles.

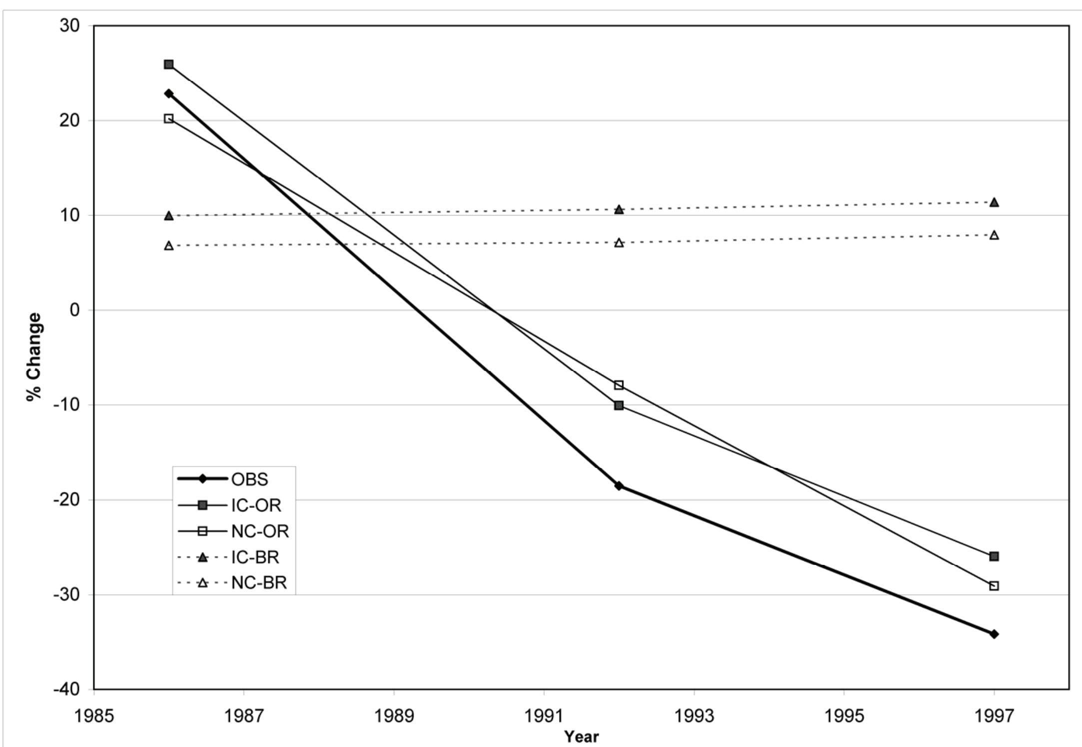

Figure 4. Graph showing modeled and observed (OBS) percent change in basin water yield relative to 1973 baseline land-use conditions for simulations that were initially calibrated (IC) to baseline conditions, and those that were not calibrated (NC). All simulations were repeated with both observed rainfall (OR) and baseline rainfall (BR) inputs.

WILLAMETTE CASE STUDY

The Willamette River demonstrated considerable spatial variability for simulated hydrologic response, similar in nature to the San Pedro, for the three scenarios. As might be expected, surface runoff simulations showed average increases commensurate with increases in urbanization. Although some watershed elements exhibited an increase in surface runoff, other areas showed improvement or decreasing runoff (Figure 4A). The greatest change was simulated for the Development 2050 scenario over the 1990 baseline. Simulated increases in surface runoff predominantly occur within subwatersheds distributed in the northern reaches of the watershed and along the Willamette Valley near Portland, Oregon City, and Eugene. Percent change in simulated channel discharge agreed closely with results from surface runoff. As in the previous example, patterns were variable, however channel discharge increased most under the Development scenario and appears to be concentrated in subwatersheds in the northern portion of the basin and along the Willamette Valley where most new development is anticipated (Figure 4B). Sediment-yield patterns were also quite variable across the subwatersheds; however sediment concentration was greatest under the Development and Plan Trend scenarios (Figure 4C). Lastly, simulated changes for percolation in the three future scenarios is expected to decrease in all options as urban impervious surfaces are expanded, especially under the Development 2050 scenario (Figure 4D).

SUMMARY AND CONCLUSIONS

The hydrologic responses resulting from three development scenarios for both the San Pedro and Willamette River Basins were evaluated using AGWA, a GIS tool developed to integrate landscape information with hydrological process models to assess watershed impacts. Baseline conditions were established for each watershed using map products derived from Landsat TM data. Through a stakeholder/scientist involvement process various plausible future scenarios were defined and constructed from which to evaluate anticipated impacts in a spatially explicit manner.

The environmental endpoints related to surface hydrology were selected because they represent fundamental ecosystem services that are important to maintaining sustainable societies in these geog-

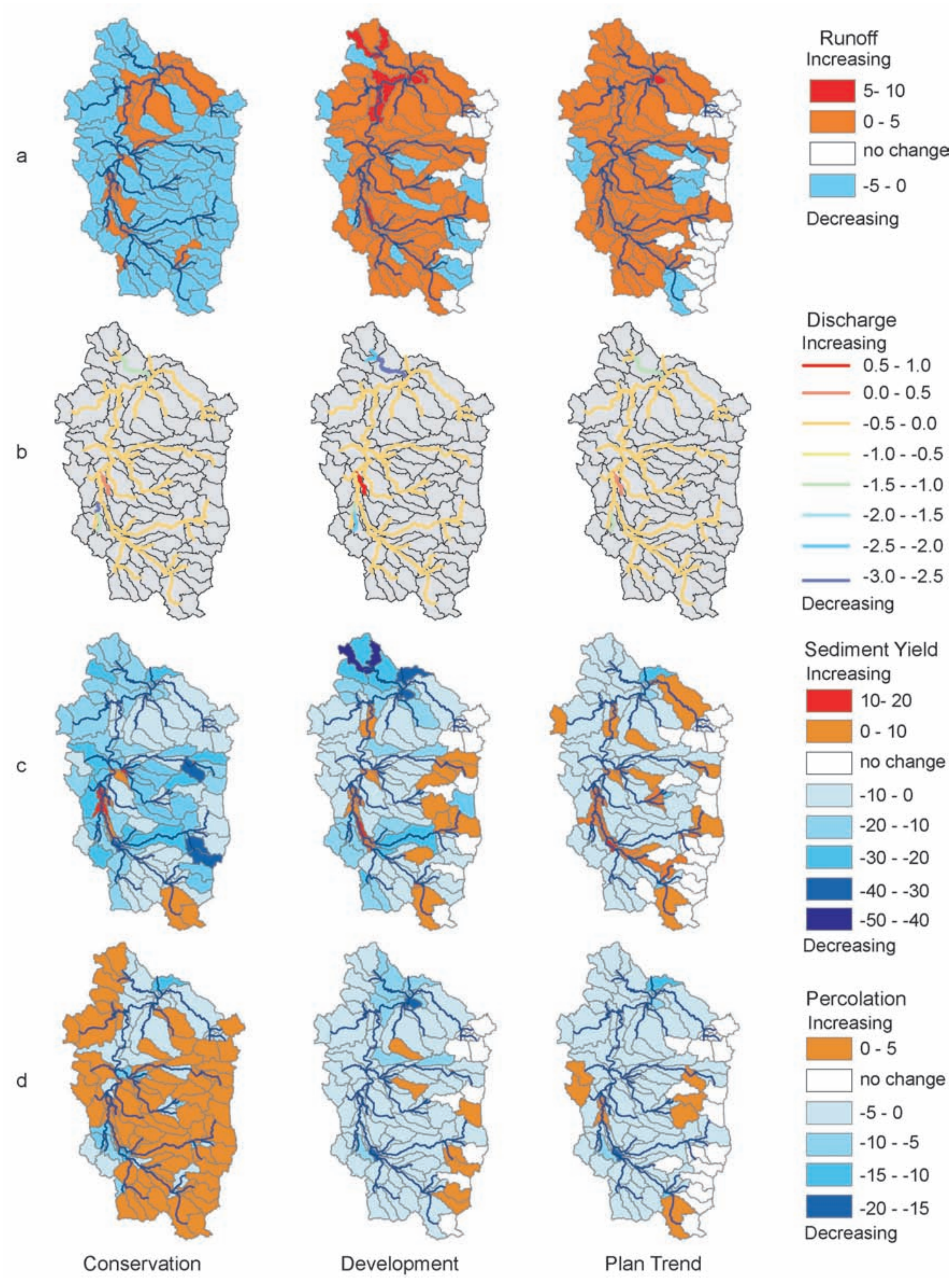

Figure 4. Maps showing modeled percent change in average annual surface runoff, channel discharge, sediment yield, and percolation for each of the three alternative future (2050) scenarios for the Willamette River Basin. Modified after Kepner et al. (2008).

raphies as well as throughout the world (Brauman et al. 2007). Available input datasets (e.g. digital land cover), stakeholder partnerships, and advances in GIS technology relative to representing important biophysical processes all contributed to the success of these projects.

In general, the simulation results for the alternative future scenarios indicate that land-cover changes associated with potential future development will alter the hydrology of each basin. The most significant hydrologic change was associated with urbanization and increasing coverage of impervious surfaces. Although the Development scenario had the greatest negative impact in both locations, it should be noted the results were spatially variable and that negative impacts are likely under all three of the future scenarios as a result of predicted urbanization. Comparative analyses are facilitated by summarizing simulation results graphically in terms of percent change relative to the baseline conditions for each of the scenarios, using subwatersheds as the comparative unit. Additionally, the changes can be quantified and statistically tabulated.

Remotely sensed observations of past land-use conditions were utilized to validate this approach to land-use scenario assessment. Although the magnitude of hydrologic change cannot be predicted with certainty at any point in the future, the results of this analysis suggest that rapid and inexpensive assessments, such as those presented for the San Pedro and Willamette Basins, represent a reliable means of comparing and contrasting a number of plausible future land-use scenarios.

These studies demonstrate the importance of integrating digital land-cover information typically derived from satellite sensors with hydrological process models within an alternative-futures framework to explore and evaluate our options for the future. They provide a scientific underpinning for analyzing one set of endpoints related to surface hydrology, and undoubtedly the approach and technologies may apply to others. This combination of tools provides one of the most powerful approaches to quantify and forecast the relative impacts to ecosystem services, and thus improve our collective decision-making for the future (Millenium Ecosystem Assessment 2005a). The approach is transferable to other landscapes, watersheds, and geographies throughout the world providing the datasets are available and the interest in examining the potential for future environments exists.

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CHAPTER 16

LAND COVER DATA AND TOOLS FOR ANALYZING ALTERNATIVE FUTURES: ONE STATE'S LESSONS LEARNED

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ABSTRACT

Recent work by the Wisconsin Department of Natural Resources and Midwest Spatial Decision-Support Systems Partnership has identified the types of GIS and Internet tools that local stakeholders want and enumerated the characteristics that make particular tools useful to a range of local government decision makers. Users need a range of tools—data discovery, data access, interactive mapping, analytical and predictive modeling, and decision-support. These decision makers find web-based, public domain tools that access needed data automatically, are scalable and customizable through "plug ins" or inherent features, and have relatively intuitive interfaces to be the most useful. The current state of information technology infrastructure, nature and characteristics of land cover data, lack of interoperability between existing tools, and limited commitment to effective capacity building approaches pose challenges for the development and widespread application of comprehensive land cover information. These needs and gaps can, however, be readily addressed if researchers, policy makers, and others take a more comprehensive view of where and how these challenges arise and develop clear strategies for coordinated solutions. The identified challenges present opportunities for cooperation among federal agencies, state and local governments, nonprofit organizations, and private sector businesses. Based on our experiences, we suggest six broad actions that can be taken to foster interagency, intergovernmental, and public-private sector cooperation to address the barriers: overcome the infrastructure challenges, coordinate and link federal data collection efforts, promote data sharing, make existing tools interoperable, validate existing models and create ability to calibrate them with local data, and support effective capacity building on a broader scale.

Key words: *Land cover data, land cover applications, predictive models, decision-support tools, web-based tools, data challenges*

INTRODUCTION

The 2006 North America Land Cover Summit provided institutions and government agencies with opportunities to pursue collaboration to advance the development and application of comprehensive land cover information. The summit sponsors asked participants to assess critical issues for improving land cover applications, identify institutional needs and gaps in technical capabilities, point out opportunities for interagency and international collaboration, and review innovative uses of land cover information. Recent work conducted by the Wisconsin Department of Natural Resources (Wisconsin DNR) and the Midwest Spatial Decision-Support Systems Partnership[1] provides insights pertinent to these discussions, particularly those related to the development of modeling and forecasting tools that rely on digital land cover data.

Over the past two decades, many people have recognized that land-use decisions fundamentally affect the ability of environmental and natural resource agencies to carry out their missions to preserve, protect, enhance, and manage natural resources (e.g., Watermolen and Fenner 1995; MPCA 2000). While many environmental agency programs affect land-use decision making, private entities own the vast majority of land in most states and local units of government retain the primary responsibility for regulating land uses through their planning and zoning authorities. Despite a recent convergence in ecological interests between the land use planning community and the conservation science community, most land use decisions only incorporate ecological principles and biodiversity considerations in a cursory way (Stein 2007). In order to be successful in addressing environmental concerns, state and federal environmental agencies must work with others to help guide development patterns to minimize negative environmental impacts, consider long-term consequences, make efficient use of existing and planned infrastructure and services, and account for community costs. Computer-based modeling and forecasting tools that use land cover data can help environmental agencies accomplish these objectives by offering choices, illuminating alternatives, and validating decisions. The assessment of land cover issues, needs, gaps, and opportunities presented in this article stems from our efforts to support

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1 The Midwest Spatial Decision-Support Systems Partnership, founded in 2002, is a U.S. EPA-led federal-state-local government partnership to develop, promote, and disseminate web-based, spatial decision-support tools for watershed management and land-use decision making (see http://www.epa.gov/waterspace/).

environmentally sound plans and decisions by building capacity to use such modern technologies in local processes.

CRITICAL ISSUES FOR IMPROVING LAND COVER APPLICATIONS

The ultimate value of a technology lies in the extent to which it is transferred and adopted and used by individuals and groups who can apply it to their particular needs. And yet the developers of land cover-based computer applications built for the explicit purpose of assisting land-use decision makers and interested publics have rarely considered two key aspects of such development: 1) the actual types of tools that specific stakeholders need and 2) the characteristics that make particular tools useful. Understanding these interrelated factors should be an ongoing requisite when investing in emerging technologies and developing new tools; we can capitalize on such investments most effectively when we fully understand the business needs the data and technology are intended to support. Failure to consider the needs and preferences of end users can result in data and tools that do not adequately address organizations' goals and processes, resulting in tools that largely go unused. Over the past few decades, federal government agencies have spent millions of dollars developing environmental modeling tools. These simulation models may be used widely in research settings, but we have found that local officials rarely incorporate these tools into their decision-making processes. These tools often lack the type of cross-community translation and outreach functions needed to meet the needs of the planning community's constituencies (Stein 2007).

Nonetheless, recent work in Wisconsin has begun to address these questions. In an effort to understand how geographic information systems (GIS) and Internet technologies might aid local decision making, the Wisconsin DNR assembled representatives from diverse agencies and organizations that make or influence land use decisions for two workshops in 2003 and 2004. These workshops, "Changing Landscapes: Anticipating the Effects of Local Land Use Decisions" and "Changing Landscapes 2," each introduced over one hundred participants to a wide range of technologies, with an emphasis on web-based, decision-support tools (most of which rely on land cover data). We demonstrated the tools, asked for feedback regarding the tools' utility and accessibility, and discussed strategies for promoting their use. We also asked the participants to evaluate the tools against a number of measures to help us understand how useful these tools would be to the participants' work as well as to the public at large. We wanted to identify the factors that make tools particularly useful. Lucero (2003, 2004) summarized results from these workshops and I highlight key points below.

What tools do people need?

To maximize their return on investment in data and technology, government agencies need to look beyond the technologies and examine the actual tasks or business processes the tools are capable of addressing. Not surprisingly, we learned from our workshops that different users have different needs and as a result need/want a range of GIS and Internet tools—data discovery, data access, interactive mapping, analytical and predictive modeling, and decision-support (Figure 1). For example, citizen planners generally lack access to GIS hardware, software, and data, and as a consequence rely on Internet mapping applications to aid their involvement in planning and decision-making (e.g., see Welch 2005). Professional planners, however, often have access to GIS resources and therefore find data discovery and data access tools more useful. University extension educators consider tools for modeling decision impacts as critical to their work (Wisconsin DNR 2004a). From work elsewhere, we also know that carefully constructed spatial models can be particularly useful for integrating ecological information and communicating assumptions, potential uncertainties, and the complexity of feedbacks to various local stakeholders and can enhance public participation in local processes (Convis 2001; Dale 2003; Conroy and Gordon 2004).

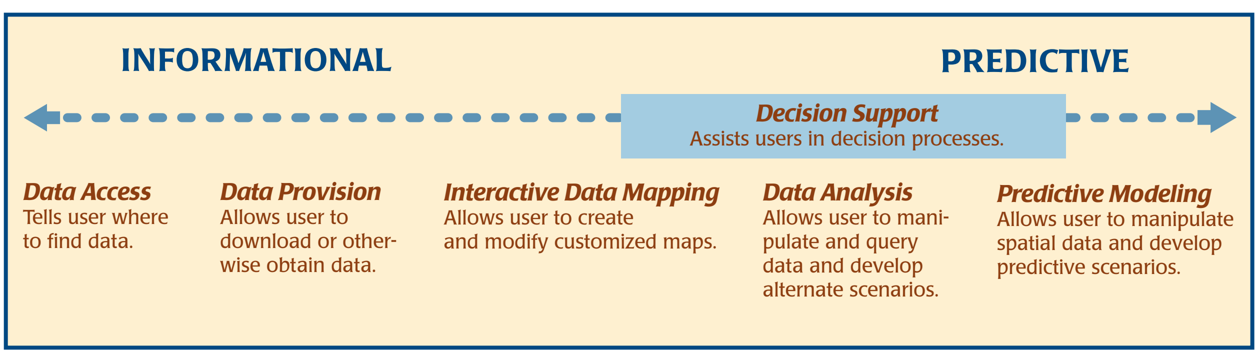

Figure 1. Functional range of tools desired by end users working at local and state levels (modified from Lucero, Watermolen, and Murrell, 2004).

Based on feedback received at our workshops, we suggest that national land cover efforts include the development, maintenance, and promotion of a wide range of data products and tools (Figure 1). Different users will need to discover conveniently the land cover data that are available, easily access those data, generate useful map products derived from the available data, and manipulate those data to predict outcomes and impacts of various types of decisions. Rather than setting up competing interests from these users, government agencies and their private sector partners must find ways to support and leverage technology investments and efforts in all these areas.

What makes a tool useful?

Our analysis of participant evaluations of the various tools demonstrated during the "Changing Landscapes" workshops yields a list of criteria (Table 1) that characterize tools identified as being most useful to a range of local government decision makers. For example, Purdue University's Long-

Characteristic	Comments
Web-based	Accessible via the Internet; only required software or hardware is an Internet browser.
Cost-free	Housed within the public domain; no purchase cost. Our research indicates that tools that perform basic functions like data access, interactive mapping, and routine modeling increasingly will be made available in the public domain.
Data included	Data required for the tool to function is implicit to the tool. For example, all mapping tools contain spatial data sets that can be customized and displayed to illustrate local conditions. For modeling tools, only the most basic inputs are required. Thus, there is no cost to create unique scenarios when using the tools.
Scalable	Data are accessible at various spatial scales. Tool allows user to assess local conditions within a regional context.
Customizable	Users can address specific needs through features inherent in the tool or through "plug-in" components.
Relatively intuitive	With a user friendly interface. As users and tool developers increasingly rely on Internet-based services for their daily activities (e.g., travel arrangements, news sources, search engines, etc.), consistent, intuitive navigation features are becoming increasingly common.

Table 1. What makes a tool useful? Characteristics derived from Wisconsin DNR's evaluative workshops.

term Hydrologic Impact Assessment (L-THIA; see http://www.ecn.purdue.edu/runoff/lthianew/) tool, which participants considered very useful, can help regional planning commissions quantify nonpoint source water pollution impacts from alternative land management decisions, but citizen watershed groups also can use it effectively to document the water quality benefits of their land protection efforts (Welch 2005).

Considering the characteristics in Table 1 *early* in the research and development process can help maximize investments in land cover applications that not only address federal agency business needs, but also prove useful to a wider range of end users. Along these lines, the Wisconsin DNR has been working with planners, extension educators, and others to integrate tools fitting these criteria into local land use planning and decision-making processes (Lucero 2006). As a result of this work, we have identified data access, interactive mapping, and predictive modeling tools that can be used in

Plan Element*	Example Web-based Tools
Issues and Opportunities	Window to My Environment Developer: U.S. Environmental Protection Agency URL: http://www.epa.gov/enviro/wme/
Housing	HUD Locator Services Developer: U.S. Department of Housing and Urban Development URL: http://egis.hud.gov/egis/
Transportation	Wisconsin Information System for Local Roads (WISLR) Developer: Wisconsin Department of Transportation URL: http://www.dot.state.wi.us/localgov/wislr/index.htm
Agricultural, Natural, and Cultural Resources	Web Soil Survey Developer: Natural Resources Conservation Service URL: http://websoilsurvey.nrcs.usda.gov/app/ Digital Watershed Developer: Michigan State University URL: http://www.iwr.msu.edu/dw/
Economic Development	RR Sites Map Developer: Wisconsin DNR URL: http://dnr.wi.gov/org/aw/rr/gis/ UrbanSim Developer: University of Washington URL: http://www.urbansim.org/
Land Use	Long-term Hydrologic Impact Assessment (L-THIA) model Developer: Purdue University URL: http://www.ecn.purdue.edu/runoff/lthianew/ Social Cost of Alternative Land Development Scenarios (SCALDS) model Developer: Federal Highway Administration URL: http://www.fhwa.dot.gov/scalds/scalds.html
Implementation	Habplan Developer: National Council for Air and Stream Improvement URL: http://ncasi.uml.edu/projects/habplan/habplan/

* These plan elements are defined in s. 66.1001, *Wisconsin Statutes*. The basic comprehensive plan structure, however, is not unique to Wisconsin (Meck 2002). Plans in Wisconsin also include “intergovernmental cooperation” and “utilities and community facilities” elements.

Table 2. Examples of web-based data discovery, interactive mapping, and predictive modeling tools that can be used to prepare and implement various elements of a community’s comprehensive plan.

developing and implementing specific elements of a community's comprehensive plan (Table 2).

Similarly, we identified tools that can be applied in the various steps of a planning process. For example, Figure 2 identifies web-based tools that a community might consider using when developing a storm water management plan. Not surprisingly, land cover and related data are central to several of these applications.

INSTITUTIONAL NEEDS AND GAPS IN TECHNICAL CAPABILITIES

The current state of information technology (IT) infrastructure, the nature and characteristics of land cover data, the lack of interoperability between existing data, mapping, and modeling tools, and limited commitment to effective technical assistance and capacity building approaches pose challenges for the development and application of comprehensive land cover information. These needs and gaps can, however, be readily addressed if researchers, data collectors, technology managers, policy makers, and others take a more comprehensive view of where and how these challenges arise and develop clear

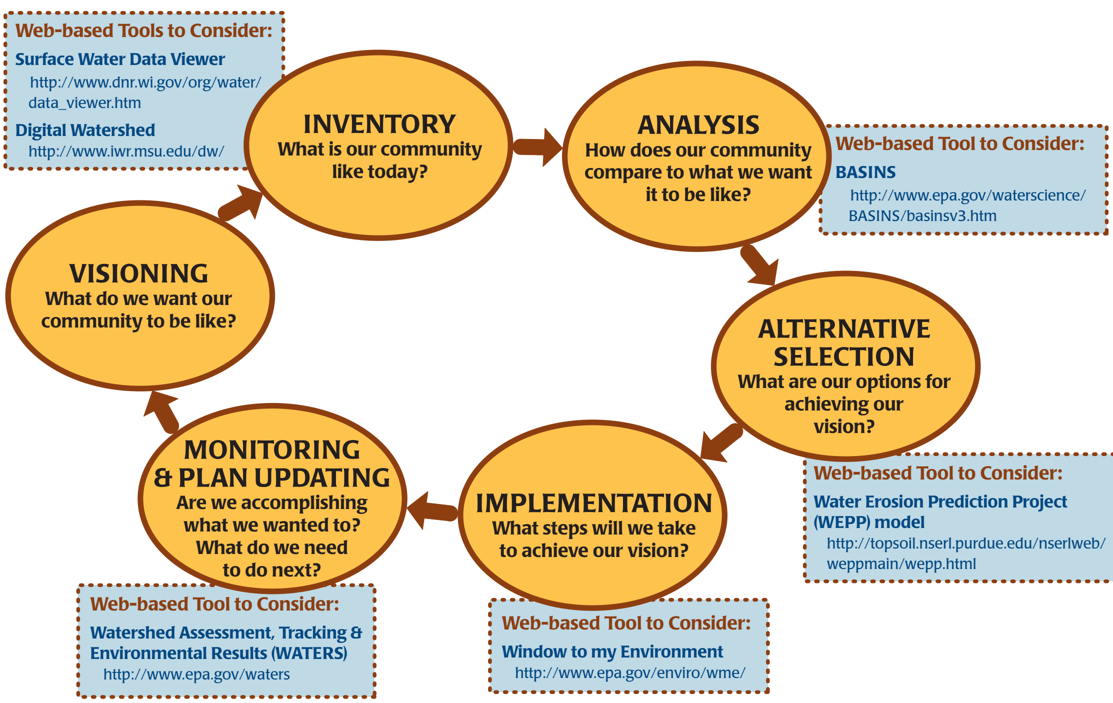

Figure 2. Examples of web-based tools that a community might consider integrating into the various steps of a storm water management planning processes.

strategies for coordinated solutions.

***IT Infrastructure Challenges*:**

In 2001, an estimated 54 percent of the U.S. population used the Internet (U.S. Department of Commerce 2002). By March 2006, 84 million Americans had broadband connections in their homes (Horrigan 2006). Businesses now widely recognize that technology adoption increasingly drives growth, with many professionals turning to the Internet to boost efficiency and meet regulatory requirements. At the same time, emerging technologies have simplified the development of sophisticated web sites, allowing the integration of GIS with complicated modeling processes and interactive user interfaces. Many local government, nonprofit organization, and citizen users, however, remain unable to access the full technological capabilities of many of these new sites, especially end users in rural areas (Samson 1998; Malecki and Boush 2000; Rao 2000; Hartell 2001). To the extent that conflicts between land use development and natural resources protection become more pronounced in rural/exurban "fringe" areas, these infrastructure limitations are especially problematic.

Many rural users lack access to high-speed connections and rely on older technologies (U.S. Department of Commerce 2002; Malecki 2003). For example, although broadband adoption in rural areas has been brisk (39 percent growth between 2005 and 2006), it has not been any different from the growth rate in suburban and urban America, where broadband penetration is already more extensive. Thus, broadband penetration rates in rural areas continue to lag behind those in suburban and urban areas (Horringan 2006). Firmware and hardware associated with security, switching, and routing functions also affect access speed, again with rural areas typically managed with the oldest and slowest equipment.

Land cover data files can be extremely large (>2 Gb) and require considerable bandwidth to move the data over the Internet. While advances in fiber optics, data storage systems, and related technologies have fostered innovative data sharing approaches and applications, these emerging technologies continue to use infrastructure developed in the late 1970s and early 1980s. Voice band modems, the current dominant technology, cannot deliver sufficient bandwidth to meet existing levels of data flow over the web (Hartell 2001). In addition, the lack of bandwidth slows the response times of many web-based applications making these tools less than useful for many potential users. Given that we have experienced this problem in rural areas of Wisconsin, a state that ranks in the middle among the fifty states in broadband penetration (Fleissner 2006; Vanden Plas 2006), as well as in northern Indiana and Michigan, these limitations are likely a common problem throughout much of rural America.

To "get on" the Internet, a user must work with an Internet service provider that provides physical access to the Internet. Unfortunately, many rural users lack choices of service providers (Malecki 2003). Rural users often have to pay toll calls, in addition to the same monthly fees their urban counterparts pay, in order to access online services. This makes access to advanced telecommunications extremely costly in some areas; market competition has simply not lowered prices for these users. For example, monthly costs of having a T-1 leased line to a rural school can be much higher than costs for the same service in urban areas (ITC 2006).

Finally, while the nature of land cover data makes GIS an appropriate technology for viewing and analysis, many small towns and rural counties lack GIS staff and resources necessary to construct and maintain a local GIS (personal observation; DeLozier, Yarbrough, and Easson 2004; Stein 2007). Even where GIS resources are available, many planning agencies are not yet fully using the Internet to provide access to digital information (Knapp and Holler 2003; Conroy and Evans-Cowley 2006).

***Land Cover Data Challenges*:**

Human-environment interactions happen within spatial and temporal contexts. As such, natural resources and conservation planning are best served by broad-scale information that is detailed, spatially complete, and consistent across ownerships and time periods. Many public domain land cover data sets, however, remain incomplete, dated, or of an insufficient spatial resolution to be useful to certain stakeholders or decision processes, particularly at the local level. This is in part because the data are acquired for specific purposes and may not be collectively rational when viewed across jurisdictions and scales.

Until recently, the most current National Land Cover Dataset (NLCD) for the conterminous U.S.

was derived from early 1990's era Landsat-5 images (Sohl et al 1999) and was thus considerably dated. More recently, the U.S. Geological Survey completed efforts to map the U.S. using circa 2000 Landsat-7 imagery (NLCD 2001; Homer et al 2002, 2004). While potentially useful for many applications, these data are already too dated for others. Landscapes, particularly in urbanizing areas, can be extremely dynamic and a 10-15 year update cycle for the data provides insufficient information for accurate or precise modeling. In addition, the classification schemes for the two rounds of classification (1992, 2001) are similar, but not identical, making comparisons over time more difficult; direct comparison of NLCD 1992 and NLCD 2001 can be used to estimate only land-cover change at a simplistic classification level (e.g., water, urban, forest, etc.).

The scale at which remote sensing data are collected and analyzed directly impacts the relevance of analytical results. Most broad scale, public domain land cover data were collected to meet national needs (i.e. federal agency business processes). As a result, national land cover data sets lack the detailed functional data needed for much regional and local planning and decision making. For example, ecologists often desire land cover/land use projections at spatial scales relevant to the ecological processes they work with (Kline 2003). While national land cover databases may be suitable for identifying biodiversity hotspots within a large area (e.g., >1000 ha.), these data usually are unsuitable to identify whether or not a particular property (e.g., 10 ha.) has critical habitat (Theobald et al. 2005). Additionally, local and regional environmental applications often require data of various spatial scales; single scale remote sensing data are insufficient to appropriately sample the hierarchical scales encountered in nature (Treitz and Howarth 1996).

Mapping land use (as opposed to land cover) remains a challenge, particularly when trying to map residential development in rural areas where the land-use changes often cause only small footprints that are difficult to detect in land cover images (Theobald 2001). Land use, however, can be inferred from parcel scale data (e.g., Kline 2003), but only limited efforts have used GIS to link parcel scale data with remotely sensed land cover data to generate the more complete picture.

As a result of these temporal and spatial considerations, many satellite-derived land cover data remain insufficient to meet many local stakeholders' needs. These decision makers call the accuracy of land cover data into question, become less inclined to use imagery for their applications, and instead invest in aerial photography, LIDAR, or other data collection programs believing these locally generated data will be more accurate and reliable for their uses. As with parcel data, these other types of land cover data can be linked to satellite derived data through a GIS.

Complicating the development of a comprehensive view of land cover/land use is the fact that a variety of federal agencies collect natural resources data on a broad scale (Table 3). Most of these census efforts rely, at least in part, on accurate classification and interpretation of land cover data. Yet there appears to be little coordination between these various data collection and analysis efforts and many of the spatial data remain relatively inaccessible (e.g., many of the data remain unavailable through the Geospatial One-Stop website [http://gos2.geodata.gov/wps/portal/gos], identifying the appropriate data custodian can take considerable time, etc.).

Finally, the Landsat 5 and Landsat 7 satellites, the sources of much public domain, satellite-derived land cover imagery, are extremely over-aged and need replacement. The replacement Landsat Data Continuity Mission (LDCM) satellite, however, has no announced launch date[2]. National land cover efforts must consider the potential problems that collapses in public domain remote sensing capabilities could cause. While some higher resolution data may be available from private sources, the costs for a national coverage are considerable and it is unlikely private sector vendors will make such high resolution data freely available via the Internet.

***Interoperability Challenges*:**

A remarkable number of mapping, modeling, and decision-support tools have been developed over the last decade. Using the criteria from our "Changing Landscapes" workshops (Table 1), the Wisconsin DNR compiled an inventory of over 100 web-based data clearinghouses, information portals, interactive mapping sites, and predictive modeling tools now available to support local planning, conservation, and environmental protection efforts (e.g., see Figure 3). Similarly, PlaceMatters' tools

2 Following the North American Land Cover Summit, the U.S.G.S. held the first LDCM-era Landsat Science Team Meeting in January 2007, where a 2011 targeted launch readiness date was discussed. The meeting agenda and links to key presentations can be found on the LDCM website: http://ldcm.usgs.gov/meeting.php. See also the report by the Future of Land Imaging Interagency Working Group (2007).

Data Collection Effort	Responsible Agency	Primary Purpose	Source(s) of Data	Timeframe	Key References
National Land Cover Dataset	U.S. Geological Survey	A database approach to land cover (multiple interlinked data layers that are useful either as individual components or in synergistic groupings) to meet the vision of the *The National Map.*	Remote sensing materials (Landsat 5 and Landsat 7 imagery)	1992, 2002	Loveland et al. 1991; Sohl et al. 1999; Vogelmann and Wickham 2000; Vogelmann et al. 2001; Wickham et al. 2002; Homer et al. 2004
National Resources Inventory	Natural Resources Conservation Service	Longitudinal survey of soil, water, and related resources to assess condition and trends on non-federal U.S. lands.	Photography, remote sensing materials, county office records, field visits	Recurring 5-year basis (1977, 1982, 1987, 1992, 1997, 2002) See Nusser and Goebel 1997 for overview of historical NRCS surveys.	Nusser and Goebel 1997; Goebel 1998; Nusser, Breidt, and Fuller 1998; U.S.D.A. 2000
Forest Inventory and Analysis	U.S. Forest Service	Comprehensive inventory and analysis of the present and prospective conditions of and requirements for the renewable resources of U.S. forest and rangelands.	Remote sensing materials, field and logging operation visits, forestland owner and wood processor surveys	Recurring annual basis, with individual state reports every 5 years (1930-present)	Gillespie 1999; American Forest and Paper Assoc. 2001; U.S.D.A. 2005a; U.S.D.A. 2005b; U.S.D.A. 2006;
Census of Agriculture	National Agricultural Statistics Service	Source of statistics on American agriculture showing comparable data at the county, state, and national levels and classifying farms in various ways.	Mailed census questionnaires	Recurring 5-year basis (1992, 1997, 2002) See U.S.D.A. 2002 for overview of historical census activities.	U.S.D.A. 2002
National Wetland Inventory	U.S. Fish and Wildlife Service	Geospatially referenced information on the status, extent, characteristics and functions of wetland, riparian, deepwater and related aquatic habitats.	Remote sensing materials, aerial imagery, field visits	Recurring annual basis (1974 – present)	Wilen and Bates 1995; U.S.F.W.S. 2002; U.S.F.W.S. 2004a, U.S.F.W.S. 2004b

Table 3. Examples of significant federal natural resources data collection efforts.

database (see www.placematters.org) includes several web-based tools in its comprehensive inventory. This proliferation of planning and decision-support applications makes selecting a tool appropriate for one's needs difficult and suggests to some users that if they want to apply technology solutions, they will have to use many different incompatible tools.

We recognize that no single tool can address all possible questions/problems, but participants in Wisconsin DNR's technical assistance program regularly note that the "tools do not 'talk' to each other." This lack of interoperability seems to run counter to the requirements for and basic tenets of both comprehensive planning and the "systems approach" that is often touted as a means for making more sustainable decisions. The users we interact with repeatedly ask for the ability of two or more tools to exchange information and have the meaning of that information accurately and automatically

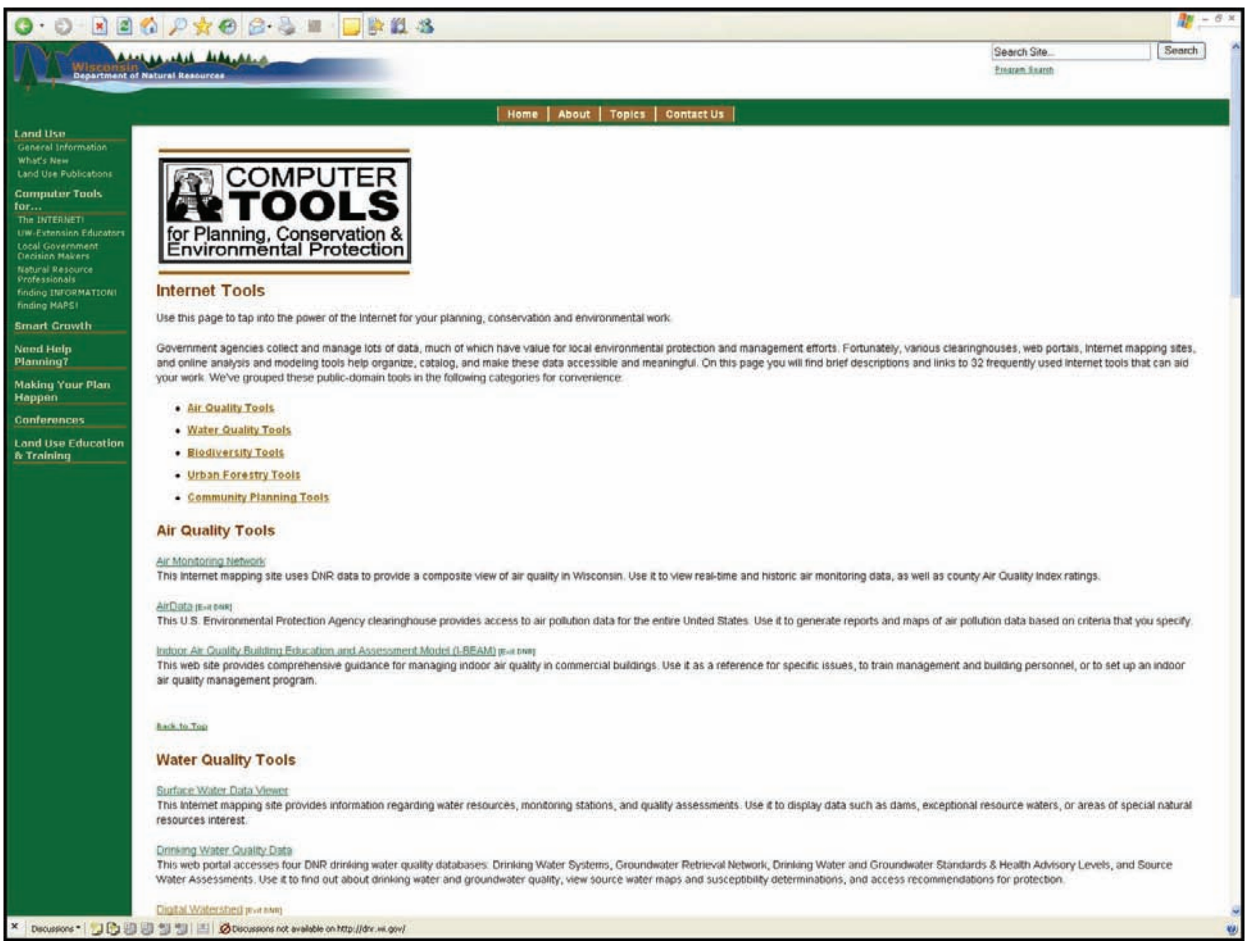

Figure 3. The Wisconsin DNR website (http://dnr.wi.gov/org/es/science/landuse/CompTools/internet.htm) provides descriptions of and links to thirty-two commonly used data access, interactive mapping, and predictive modeling tools.

interpreted by the receiving systems (i.e. semantic interoperability). Such interoperability would help narrow the choice of tools and create integrated decision-support systems that would allow users to answer questions in a more comprehensive manner.

Our ongoing discussions with tool developers suggest several key factors have hindered interoperability among existing tools: impediments to data sharing, a lack of standards and protocols, a preference by tool developers for developing new tools, and products that are simply not engineered to work together.

***Capacity Building Challenges*:**

A policy study by the International Telecomputing Consortium (ITC 2006) recently concluded that without support for training and professional development, Internet connectivity "remains useless." Similarly, the Space Studies Board (2003) identified a "gap in communication and understanding between those with technical experience and training and the potential new end users of [remote sensing] technology." These conclusions mirror Wisconsin DNR's findings (2004a) and underscore the importance of capacity building and technical assistance efforts. Not everyone is technologically inclined or completely comfortable with electronic processes (Garretson 2006). This appears to be the case even with professionals who routinely incorporate computers into their daily work. For example, Milla et al. (2005) describe how the rapid development and integration of spatial technologies have created many new tools for university extension educators, but "have also widened the 'digital divide,' leaving many with little understanding of the technology and potential applications." These authors further observe that "to the uninitiated Extension specialist, the complexity and vast array of potential applications can be confusing and intimidating" and that "as a result of the relatively fast evolution of geospatial technologies, many professionals may either be unaware of their capabilities or may have an obsolete understanding of their potential and current implementation." We have observed this "digital divide" phenomenon in several of the target audiences that we work with in the Upper Midwest, raising concern by tool developers that some tools could be used improperly if the end users do not understand them well enough.

There appears to be relatively little commitment from federal agencies to effectively build capacity to use the data or tools that their programs develop. Budgets for outreach, technical assistance, and similar support dwarf those for data acquisition and tool development (NSF 2002; OMB 2006) and often appear to be afterthoughts in the budget planning process. Agencies that do support these types of programs rarely coordinate their efforts with each other and tend to apply generic technical assistance approaches (e.g., they mass produce fact sheets, brochures, etc.) that may not be fully effective in transferring technology to the wide range of potential target audiences.

Finally, case studies can be an effective way of realistically contextualizing theoretical land cover applications, particularly for local government decision makers and citizen activists. The International City-County Management Association and National Association of Counties employ this approach in much of their technology transfer work (e.g., Fleming 2005; NACo 2006). Finding useful examples of truly outstanding or successful land cover projects or applications that have informed land-use planning or other local decision processes, however, remains challenging (personal observation; Theobald et al. 2005). Tool developers rarely have time or interest to develop these. Their efforts focus elsewhere (e.g., several tool developers have shared with us that their performance often is measured by the number of tools developed, papers published, etc. rather than by the ultimate adoption/value of their products).

OPPORTUNITIES FOR INTERAGENCY COOPERATION

The challenges identified above present significant opportunities for cooperation among federal agencies, state and local governments, nonprofit organizations, and private sector businesses. Based on our work with the Midwest Spatial Decision-Support Systems Partnership, we suggest the following six broad actions can be taken to foster interagency, intergovernmental, and public-private sector cooperation to overcome the identified challenges.

1) *Overcome the IT Infrastructure Challenges*

Government agencies and their private-sector partners must find ways to overcome the infrastructure challenges identified above in order for local governments, nonprofit organizations, and average citizens to be able to access and use applications relying on land cover data. While our experience in Wisconsin does not point to any particular solutions, we do believe that if these issues remain unaddressed, the opportunity to maximize returns on data and technology investments greatly diminishes. The preliminary policy recommendations developed by the International Telecomputing Consortium in support of the National Science Foundation's Networking Infrastructure for Education program (ITC 2006) could provide one valuable starting point for a national dialog on these issues. Similarly, ideas generated in response to the New Millennium Research Council's white papers (e.g., Litan 2005; New Millennium Research Council 2005) could foster creative solutions. Policy initiatives should consider both the role market forces will play in improving IT infrastructure (e.g., see Insight Research Corporation 2006) and the role emerging technologies (e.g., satellite telecom) can play in bringing higher band widths to rural areas.

2) *Coordinate and Link Federal Data Collection Efforts*

The U.S. Department of Agriculture's National Agricultural Statistics Service recently assumed responsibility for the Census of Agriculture (previously, the Bureau of the Census conducted this effort). Since the U.S.D.A. also has responsibility for the National Resources Inventory (NRI) and Forest Inventory and Analysis (FIA) programs, there is an unprecedented opportunity to coordinate these efforts more closely. Coordination of data elements collected, timing of data collection, and data collection methodologies are some areas that we believe merit further discussion.

The U.S. Forest Service has significantly enhanced the FIA program by changing from a periodic survey to an annual survey, by increasing its capacity to analyze and publish data, and by expanding the scope of its data collection to include soil, under story vegetation, coarse woody debris, and lichen community composition on a subsample of plots (U.S.D.A. 2005b). Similar enhancements to the NRI and Census of Agriculture would allow for more directly comparable data. The additional FIA data also could be coupled with the National Wetlands Inventory to provide a more comprehensive view of wetlands and related habitats in forested systems.

The Multi-Resolution Land Characteristics (MRLC) Consortium, a group of federal agencies that joined together in 1993 and again in 1999 to purchase Landsat imagery and develop the National Land Cover Database, provides one example of coordinated data collection and processing and might be looked to as a model for coordination and collaboration. Because the consortium also provides imagery and land cover data as public domain information, all of which can be accessed via the web, local and regional decision makers have been able to benefit from this federal investment. The MRLC consortium, however, is specifically designed to meet the current needs of federal agencies. Should the MRLC be looked to as a model, the approach will need to be broadened to include additional stakeholders (i.e. state and local governments, nonprofit conservation organizations, etc.). Concerted efforts should be made to provide for meaningful participation by a full range of potential end users.

In addition, federal land cover data collection initiatives can and should be integrated with the FGDC's standards for orthoimagery and related National Spatial Data Infrastructure (NSDI) framework themes. The National States Geographic Information Council's "Imagery for the Nation" initiative (Koch 2006; NSGIC 2007) provides yet another opportunity to eliminate duplication of effort, reduce costs, achieve consistent quality, accuracy and currency of data, and enhance access to and use of imagery data.

3) ***Promote Data Sharing and Data Exchange***

The ability to share data across agency and jurisdictional lines makes service delivery more efficient and effective. While sharing data among departments is a top priority in many regions, state and local governments have also realized benefits from making data available to residents and private-sector businesses (Perlman 2006). As computing technologies evolve, the web is becoming the core medium for distributed geo-processing (Hecht 2002a). In other words, GISystems that once focused on data and tools implemented with client-server architecture now are evolving to a web services model (Dangermond 2002). This evolution necessitates a commitment to data sharing.

The Office of Management and Budget (OMB) and Federal Geographic Data Committee (FGDC) have laid considerable groundwork for the coordinated development, use, sharing, and dissemination of geospatial data through the National Spatial Data Infrastructure (NSDI; FGDC 2004, 2005a). The NSDI Clearinghouse provides access to digital spatial data and related online services for data access, visualization, or order. As of August 2005, however, only fifty-two percent of federal agencies were metadata publishers (FGDC 2005b). Additional agencies should embrace the direction outline in OMB's *Circular* A-16 (OMB 2002). While it is promising that several federal agencies have successfully established metadata policies, others have made lesser progress and unless significant efforts are made, it will be a considerable time before we near 100 percent participation. In addition, a little over half of the metadata records currently in the Geospatial One-Stop are from federal agencies (FGDC 2005b). This means that the nation's extensive state, regional, and local data holdings are not yet fully represented in the Geospatial One-Stop. State and local entities should more seriously consider full participation in this portal, particularly because their participation would greatly enhance homeland security and disaster relief efforts across the country.

The National Environmental Information Exchange Network (NEIEN; http://exchangenetwork.net/index.htm) provides another model. This partnership among states, tribes, and the U.S. Environmental Protection Agency is revolutionizing the exchange of environmental information by providing real-time access to higher quality data while saving time, resources, and money for states, tribes, and territories.

The NEIEN partners share data via the Internet. The partners establish and maintain servers ("network nodes") that are securely connected to the Internet. These nodes provide partners with a single point of presence on the network and serve as the exchange point for all data requests and submissions. The nodes automatically listen for and submit requests for data from other information trading partners and then deliver or publish the data based upon pre-described methods. Extensible markup language (XML) provides the standards base for exchanging data and overcomes system incompatibility by translating information into a common data structure and format. With XML, the partners' existing data management systems remain in place and the data are transformed as they enter and exit each system without changing the meaning or appearance of the data. While most of the data exchanges to date have focused on tabular data, the Wisconsin DNR has undertaken a pilot project focused on the exchange of spatial data using geographic markup language (GML), a standardized means of storing geographic information in XML encoded files.

On a regional scale, the Illinois Data Exchange Affiliates (IDEA), a voluntary group of government agencies and not-for-profit organizations working to improve data sharing in Illinois, provides a model. IDEA's work includes the creation of a web-based, real-time data sharing network. These partners are establishing technical standards for organizing and sharing data, ensuring organizations' security, confidentiality, and proprietary needs, and simplifying intergovernmental and cross organizational data sharing.

IDEA's exchange and use of local data builds on a foundation established by the Chicago Open Data Exchange Collaborative, a MacArthur Foundation project through which local entities currently share demographic, economic, and property data via XML web services. A Wisconsin DNR project recently funded by the U.S. EPA through the NEIEN will build on these efforts and link locally generated data with Michigan State University's Digital Watershed portal (see http://www.iwr.msu.edu/dw/) to allow those data to be placed into a broader context and enable more informed decision making throughout the Great Lakes region.

We believe more and more local governments will use the web to make data available. For example, more than 88 percent of Wisconsin county governments and a large number of Wisconsin municipalities have undertaken the development of web mapping sites (Hart 2004a, 2004b). Similar trends have been observed in other states (Perlman 2004; ESRI 2006a, 2006b). These local data can be linked to the NSDI through the Geospatial One-Stop, making them available for a variety of decision-support applications.

Finally, the National Biological Information Infrastructure (NBII) initiative could be more closely coordinated with the other federal data exchange efforts. Initiated in 1993, the NBII is a U.S.G.S.-led effort to provide increased access to data and information on biological resources (U.S.G.S. 2002, 2006). Like the Geospatial One-Stop, the NBII provides a web portal that links data and analytical tools in government agencies, academic institutions, nongovernmental organizations, and private industry. NBII partners and collaborators also develop new standards, tools, and technologies to make it easier to find, integrate, and apply biological resources information to answer a wide range of questions. Similar to the EPA's NEIEN, the NBII relies on a series of nodes as focal points for the flow and exchange of data. Yet, in spite of these similarities (redundancies?), there appears to be very little coordination of efforts.

4) ***Make Existing Tools and Models Interoperable***

Interoperability can be achieved in several ways: through product engineering, industry/community partnerships, access to IT infrastructure and technology, and implementation of standards.

Some participants in the "Changing Landscapes" workshops commented that tool developers have been more than willing to develop new tools, leading to the proliferation of tools that we now see. It is clear that decision makers want tools that match their needs. This desire often leads to new development efforts, but we have found that many times there is an existing tool sufficient for the identified purpose. When these tools are identified, many local users suggest using what is available rather than pursing something new. To get the maximum return on investment, agencies should encourage developers to consider how their existing tools might be able to be used in new ways. For example, some times outputs from an existing tool can readily serve as inputs for another existing tool (Figure 4).

Increasingly, land use models have been linked to other models in order to extend the power of both types of models (Alig 2005). For example, the U.S. Forest Service has fed projections of market conditions from supply and demand models into land-use change models (Haynes 2003; Alig and Butler 2004). Such efforts can provide models for interoperability. Unfortunately, much of this interoperability has failed to employ current Internet technologies or markup languages (e.g., XML and GML) and the newly interoperable tools remain inaccessible to local stakeholders.

Recent work by the Midwest Spatial Decision-Support Systems Partnership has demonstrated the technical feasibility of linking existing modeling tools over the web. These partners have linked the watershed delineation capabilities of Michigan State University's Digital Watershed with the water quality modeling capabilities of Purdue University's Long-term Hydrologic Impact Assessment (L-THIA) tool (Figure 4). Future efforts by the Midwest Partnership will link U.S. EPA's Analytical

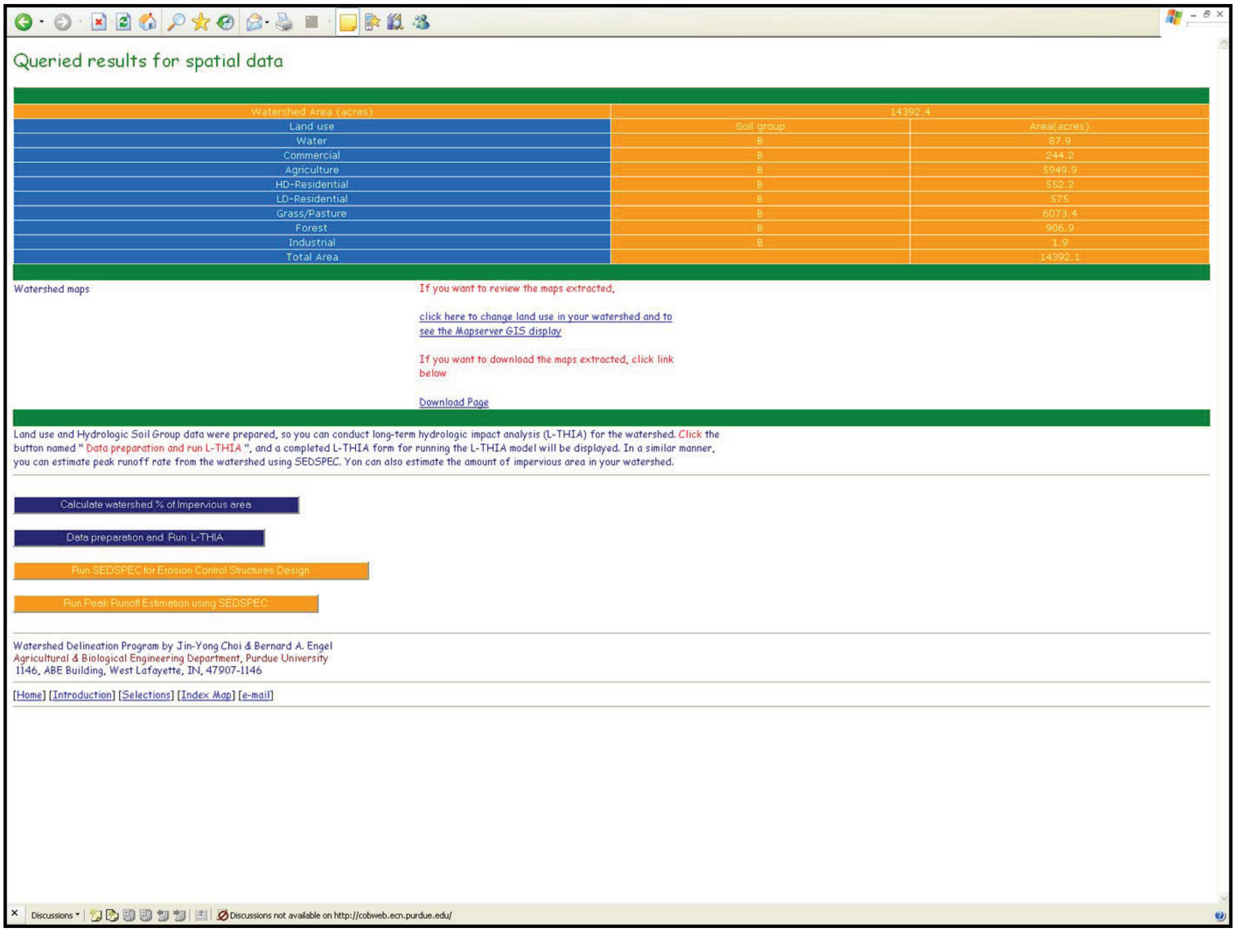

Figure 4. Output from Michigan State University's Digital Watershed. This output supplies the input needed for the water quality modeling capabilities of Purdue University's Long-term Hydrologic Impact Assessment (L-THIA) tool demonstrating interoperability via web services.

Tools Interface for Landscape Assessments (ATtILA; U.S. EPA 2004) and pollutant loading model (PLOAD; U.S. EPA 2001) with these tools.

It is quite clear that the next wave of interoperable models will rely on web services that allow integration of heterogeneous applications. In this new architecture, the web will be used for delivering not just data, but geo-processing functionality. Using web services will allow developers to implement application integration projects, consolidate development efforts, reduce redundant applications, and make it easier for partners to do business based on similar solutions and more comprehensive services and/or applications (Hecht 2002b; Füstös 2006; Moreno-Sanchez 2006).

As with data exchanges, we can only achieve effective interoperability if tool developers comply with agreed upon standards (i.e. open specifications) that eliminate the need to write individualized proprietary interfaces for many different products. U.S.G.S. researchers have made considerable efforts to collectively establish standards for predictive models, computer simulations, and scientific visualizations so that the components of decision support will be interoperable and interchangeable (Buchanan, Acevedo, and Zirbes, no date). Such standards ultimately result in lower development costs and increase the size of the potential market for the tools. Just as application design benefits from inclusion of diverse expertise, however, it remains important to have multiple active participants in any standards development process, including implementers (proprietary and open source; traditional as well as web-based), end-users, accessibility and consumer advocates, etc. Involvement of these interests must move beyond token representation and provide for full engagement in the specification, validation, standardization, and adoption processes to ensure adopted standards will become institutionalized.

5) *Validate Existing Models and Create Ability to Calibrate with Local Data*

While many forecasting models have been used to predict probable impacts or outcomes, we are aware of very few validation studies that have measured the actual impacts of decisions following use of models in a decision process to determine if the model predictions were accurate. Such a feedback loop will be necessary if we expect broad scale adoption of such tools to take place.

Local decision makers and interested publics must be confident that the results of forecasting models are plausible and valid. To this end, processing outputs as probabilities (stochastic modeling and uncertainty analyses) rather than deterministic responses can make results more meaningful to these decision makers.

It will also be necessary to examine how much outputs change when inputs are altered (sensitivity analyses) whenever possible. These analyses can help us understand model results and identify if there are crucial points where minor changes in input parameters have a major change in outputs. People with extensive local knowledge can help validate tool results to make sure the results make sense. If model results do not make sense to such experts, the logical next step is to figure out why: data and tool analyses could be flawed or the data and outputs could be revealing new trends.

Customizing regional models using “local knowledge” can improve the quality of information produced and honor the contributions of all stakeholders (Theobald et al. 2005). Where possible, models also should include the measured variation in data or some assumptions about variation (Theobald et al. 2005). For example, Purdue University’s L-THIA tool does this by providing graphic depictions of annual variation in runoff and percent probability of exceedence for each of the modeled pollutants based on local rainfall data.

6) ***Support Capacity Building on a Broader Scale***

It is not enough to simply provide decision makers with data and tools. To be effective, land cover information must be carefully incorporated into local planning and decision-making processes through effective communication (Space Studies Board 2003; Theobald et al. 2005).

Several recent efforts have addressed technical assistance, outreach, and capacity building on a broad scale. The Space Studies Board’s Steering Committee on Space Applications and Commercialization organized a workshop on “Facilitating Public Sector Uses of Remote Sensing Data.” Representatives of state, local, regional, and federal governments, the private sector, and universities attended the workshop. These participants examined factors that have led to the development of successful applications of remote sensing data in state and local governments and identified common problems encountered in this process. A report (Space Studies Board 2003) drawing on the workshop provides several broad policy recommendations related to education, training, and outreach. More recently, municipal, county, regional, and state officials from fourteen northeastern states convened for a 3-day workshop focused on outreach strategies for remote sensing and related geospatial information technologies (GIT). The intent was to identify ways of improving and maximizing the outcomes of outreach strategies and programs. The workshop findings (Warnecke, et al. 2005) provide a foundation for developing and implementing action plans that advocate improved GIT outreach and intergovernmental collaboration. Lessons learned during our capacity building efforts in Wisconsin resonate with these earlier efforts.

Capacity building must be audience-focused. As such, land cover programs must seek to understand the many and varying players and needs at local, regional, and state levels if they wish to maximize use of their data and applications. These efforts must recognize the complexities of federalism and opportunities to create customized, multifaceted approaches to address the "have-nots" as well as the "have mores." In taking this approach, it will be essential to recognize and understand that local, regional, and state entities have differing sizes, roles, responsibilities, structures, needs, and business processes. Similarly, staff working in local, regional, and state agencies hail from a variety of professional backgrounds. Our work in Wisconsin (Wisconsin DNR 2004a) demonstrates that planners, engineers, land conservationists, elected officials, etc. have very different technical assistance needs and preferences for receiving assistance.

Capacity building will need to use a variety of approaches and techniques. Current learning theories suggest curricula will need to be based on learners' experiences and interests (Wilson and Hayes 2000; Caffarella 2002; Wisconsin DNR 2004b). Every target audience contains a configuration of idiosyncratic personalities, differing past experiences, current orientations, levels of learning readiness, and individual learning styles. Thus policy makers should be wary of prescribing any standardized approach to facilitating learning (Brookfield 1986; Ota et al. 2006).

Capacity building must be an on-going, sustained effort. Politics and turnover are regular aspects of government, particularly at the local level, that impact the effectiveness of capacity building efforts. One-time approaches will not likely result in institutionalized learning outcomes. Lessons learned from federally funded pilot projects and demonstrations, like the Wisconsin DNR's current efforts, should be shared and applied on a broader scale.

Capacity building should be a priority for planning and funding in the *earliest* stages of land cover program development. Agencies should dedicate and sustain financial resources for GIT outreach with meaningful incentives for participation. For example, needs assessment work undertaken in Wisconsin as part of a coastal GIS applications project (Rink, Hart, and Miller 1998) uncovered a need for GIS training directed at the local government level. County staff indicated that while resources were generally available for GIS hardware and software acquisition and database development, training funds were scarce in most county budgets. The Space Studies Board (2003) identified several federal agencies that should provide funding for remote sensing (i.e. land cover) training and educational materials.

Capacity building programs can be better coordinated. Federal agencies will be more effective if they synchronize their outreach efforts, both within and across agencies—particularly in deployment at regional and field levels—and with similar state and nongovernmental programs targeted toward local and regional organizations. Thoughtfully planned and well coordinated outreach and assistance efforts can help foster data sharing and tool interoperability.

Capacity building efforts should leverage existing outreach organizations, structures, programs, and events to create economies of scale. A number of nongovernmental organizations are already providing effective outreach and technical assistance. For example, the International City-County Management Association assisted Purdue University in developing a user friendly interface for the L-THIA (Figure 5) and hosts the tool at its Local Government Environmental Assistance Network.

One area meriting further exploration is the use of the Internet itself to teach about web-based data, tools, and technologies. Our experience in Wisconsin (Bellrichard and Watermolen 2006) suggests

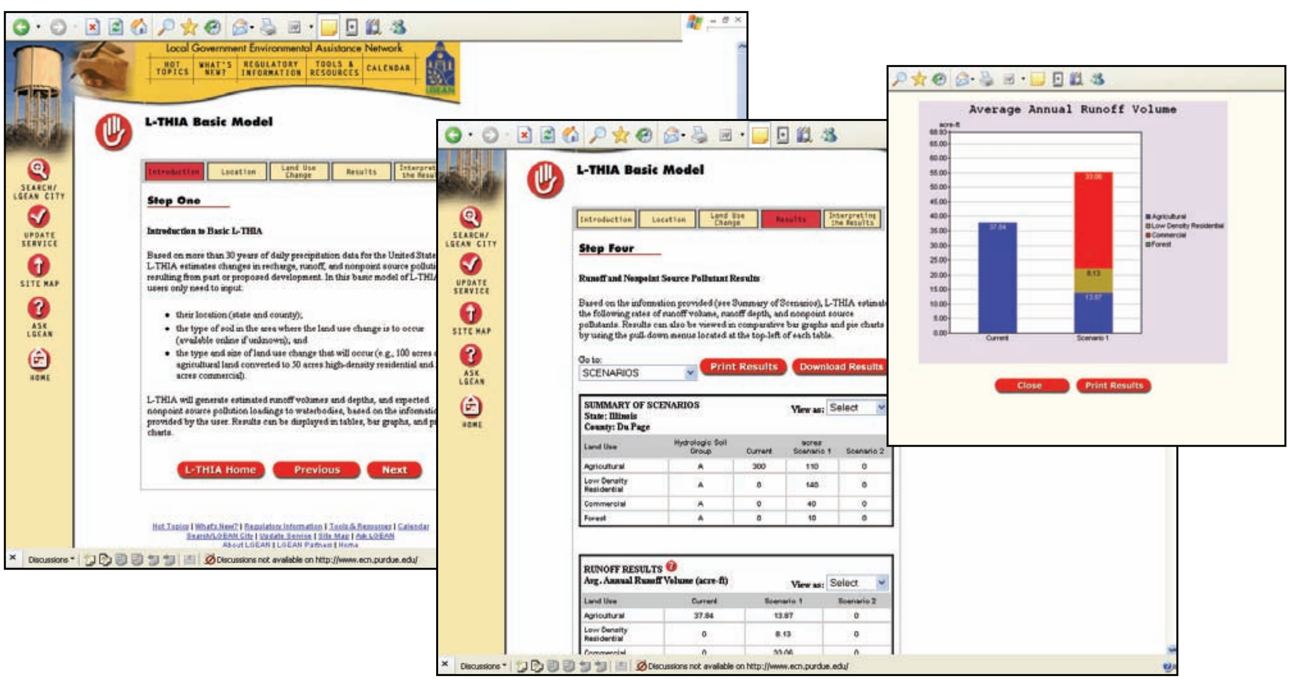

Figure 5. The user-friendly interface of Purdue University's Long-term Hydrologic Impact Assessment (L-THIA) tool. The International City-County Management Association (ICMA) assisted Purdue in developing an interface accessible to municipal and county officials. ICMA hosts L-THIA on its Local Government Environmental Assistance Network site.

webconferencing and webcasting may be effective means of teaching local officials how to access and use land cover data and applications. The U.S. EPA's Watershed Academy Distance Learning Program (http://www.epa.gov/watertrain/) provides another model of web-based learning that should be considered.

Finally, capacity building approaches and programs should be evaluated. Government agencies responsible for developing land cover data and tools should develop an organized and systematic means to evaluate and learn from their projects. The U.S. EPA-supported approach applied in Wisconsin DNR's capacity building and technical assistance program can serve as one model for such efforts.

We have found through our work with the Midwest Spatial Decision-Support Systems Partnership that there is considerable value in creating a feedback loop that connects end users with tool developers. Our experience resonates with the Space Studies Board (2003), which found that many remote sensing applications have "specific requirements, including continuity in data collection, consistency in format, frequency of observations, and access to comparable data over time." Further, they concluded that it is important that end user requirements be communicated to data producers and tool developers throughout the process of designing new technologies and producing and disseminating remote sensing data.

SUMMARY: THE BENEFITS OF INNOVATIVE APPLICATIONS

Many modern environmental issues (e.g., nonpoint source water pollution, greenhouse gas emissions, habitat fragmentation and loss, etc.) result from the cumulative actions of numerous individuals and the land use decisions we collectively make. As such, dealing with these concerns requires new ways of looking at their causes, effects, and possible solutions. Comprehensive land cover data and applications that use those data can aid agencies and interested publics in more fully understanding and addressing these issues. We believe the lessons learned by the Midwest Spatial Decision-Support Systems Partnership and outlined in this paper can inform current and future North American land cover initiatives.

When we consider the needs of local, regional, and state decision makers *early* in the planning and development of land cover initiatives, we can create tools that meet their business needs. Local stakeholders view web-based, public domain tools that access needed data automatically, are scalable and customizable through "plug ins" or inherent features, have relatively intuitive interfaces, and function interoperably with other tools as being most useful to addressing their needs. When we validate models and calibrate them with local data, we increase their predictive power and enhance their believability for these decision makers. Collectively, these steps lead to land cover data and applications that are meaningful to people who make day-to-day, on-the-ground decisions. Providing a feedback loop that allows these end users opportunities to provide evaluative comments to the data collectors and tool developers can further enhance tool usability.

If we hope to bring land cover data to bear on our most pressing environmental issues, it will be necessary to find creative ways to transfer the technologies and help local, state, and regional decision makers use land cover-based tools. When we do so, we empower those decision makers to make more environmentally responsible decisions (e.g., see Welch 2005). Since private landowners and local governmental units will remain the primary land-use decision makers and their decisions will continue to impact the environment profoundly, it is especially important that outreach and assistance efforts consider the diverse needs and preferences of these stakeholders. In doing so, we create countless allies for environmental protection and resource stewardship, achieve a significantly greater return on our investments, and build a solid base of support for land cover programs and initiatives.

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CHAPTER 17

LAND COVER AND INDICATORS OF ENVIRONMENTAL QUALITY BREAKOUT SESSION REPORT

Moderator: E. Terrence Slonecker, U.S. Environmental Protection Agency

Recorded by:
K. Bruce Jones, U.S. Geological Survey
Peter R. Claggett, U.S. Geological Survey

In exploring the connection between land cover and indicators of environmental quality, the first and most obvious point is that land cover data is, in itself, an indicator of environmental condition. The status and changes in the areal extent of *any* land cover class is an important measure of some underlying environmental activity or ecological condition. However, beyond this basic connection between land cover data and environmental indicators, the charge to the environmental indicators workgroup was to explore the common ground of environmental indicators in North America and to facilitate collaboration across institutions, governments, information technology systems, and borders.

The discussion was initiated with the following questions posed to the breakout group:

1. What are the environmental indicators related to land cover data that we currently utilize in North America?
2. What are the ecological indicators related to land cover data that we would use if comprehensive land cover information were available for North America?
3. What environmental border issues are, or could be, addressed with land cover data and derivative environmental indicators?

4. In what areas are we likely to develop new or improved environmental indicators based on emerging remote sensing, GIS, statistical or other analytical methods?
5. What would be the value of developing historical land cover data and indicators in a consistent spatial and thematic framework?

Although the initial exchanges centered on the above questions, the discussion rapidly moved into specific technical areas. There was general consensus on the value of regularly-produced land cover data and on the value of a continental program. Many participants also expressed the belief that processing of historical imagery to complete a temporal series would have great benefit.

ENVIRONMENTAL ENDPOINTS

Much of the initial discussion revolved around the importance of utilizing land cover data not just to provide an index of some environmental condition, but rather as a vehicle to assess, correlate, and articulate one or more critical environmental endpoints - explicit, actual, measurable, or observable effects in the environment that are relevant and meaningful to significant environmental issues. Much emphasis was placed on the need to ensure that indicators utilize quantitative measures and are statistically validated.

Similarly, an almost unanimous opinion among the workgroup members was that land cover data serves a critical information need in helping to assess and explain many environmental issues that naturally transcend national boundaries. Further, the development of a consistent continental scale land cover program would serve the science and regulatory communities of all North American countries. Examples include bird habitat, endangered species, sedimentation, runoff, and numerous air quality issues.

METADATA, TRAINING, AND OUTREACH

A common theme noted among the participants was the need for better documentation, training and outreach for land cover data, the processes utilized in its development, and the technical issues relevant to technical interpretations of indicator values. Several members felt that many indicators did not have a sufficient level of background or explanatory detail and that standard metadata and were often inadequate. What results is often misinterpretation or ambiguity of a key indicator because of this lack of documentation and outreach.

DATA SCALE AND RESOLUTION

Another common discussion area was the "scale" of indicator metrics and the appropriate interpretation of indicator values, especially as related to the spatial resolution, and the limitations of the source remote sensing data. Similarly, many breakout group members expressed the desire to have land cover data available at finer scales of spatial resolution, with a tiered classification schema and strong quantitative ties to biological indicators and data derived from *in situ* sampling of biological resources.

LAND USE AND LAND COVER

A unanimous theme voiced by the group was the strong desire to have a Land Use component developed coincident with Land Cover. The anthropogenic utilization of a landscape is often just as important as the biological cover and often the two are inseparable. Although certainly an additional expense, the value-added and integrative nature of land use and land cover data together would be tremendously important for understanding and reporting on environmental quality.

LANDSAT, SENSOR FUSION, AND DATA CONTINUITY

Remote sensing data themes were a major component. There was much discussion about the future of the Landsat program, the status of the existing Landsat systems, and the need for strategic planning for data continuity in the interim period. Several members of the discussion group stated that it was also desirable and appropriate that data fusion with other sensors, such as lidar and radar, be considered as part of a new land cover program. The availability of these sensor technologies and the value that the data would bring to some of the classic land cover classification issues would be worth the investment in some preliminary remote sensing research.

TIES WITH INTERNATIONAL PROGRAMS

On a more programmatic note, group members articulated the belief that any proposed North American Land Cover program should build synergistic relationships with existing cross-border programs such as the Great Lakes Program, the Gulf of Mexico Program, the Border 2010 Air Quality Monitoring Program and many others. Connections with these programs would serve to foster immediate alliances, give the program a firm legal foundation, and build an immediate clientele for land cover data products.

OTHER TECHNICAL ISSUES

Validation of indicators, trends, and forecasting models is critically important and should be treated as an inherent part of a land cover mapping program.

Backwards development of a spatially and thematically consistent land cover data for the 1970s, 1980s and even earlier, is now feasible and would present an very valuable dataset for trends analysis and forecasting models.

Improvement in the accurate classification of agricultural land uses was identified as a critical information requirement. Especially important is the difference between cropland and pasture land because they both are important to landscape models of nutrient and sediment dynamics.

Finally, many participants applauded the land cover derivative products, such as the impervious surface and canopy closure data layers that are currently being produced by the NLCD program and expressed the hope that more of these types of specialized land cover data products, developed on a continuous rather than categorical basis, would be incorporated into any new land cover mapping approaches.

CHAPTER 18

LAND COVER AND ECOSYSTEM CONDITION BREAKOUT SESSION REPORT

Moderator: Roger Sayre, U.S. Geological Survey

Ecosystems are frequently defined as integrated systems of organisms interacting with their physical environment. They are also frequently characterized as scaleless, ranging in size from a particle of dirt (or smaller) to a boreal forest biome (or larger). Ecosystems provide goods (food, fuel, fiber, forage, etc.) and services (flood control, soil fertility, etc.) that are critical to human welfare. To ensure that these goods and services continue to benefit humankind, ecosystems must be managed so that they persist on the landscape and in the seascape. Ecosystem-based management has emerged as an increasingly important paradigm for sustainable development and is increasingly practiced in many government agencies throughout the world. Ecosystem-based management requires a knowledge of the types and distributions of ecosystems within the management area. It further requires a fundamental understanding of how these ecosystems are affected by changes in land cover and land use.

The Land Cover and Ecosystem Condition breakout group discussed the relationship between land cover and ecosystem condition. This discussion necessarily began with an attempt to distinguish between ecosystems, land cover, and vegetation, and an exploration of the spatial scale and classification resolution dimensions associated with defining ecosystems. The group reviewed a process for developing abiotic ecosystem footprints and combining these with land cover to develop unique physical environments and associated land cover as ecosystem occurrences. From this discussion, the group developed a multi-tiered conceptual framework which characterizes the vegetation/land cover/ecosystems continuum at different spatial scales.

The group then discussed land cover monitoring as an indicator of ecosystem condition, and concluded with an assessment of the potential for developing a tri-national ecosystems and land cover assessment and monitoring initiative. The major conclusions from this working group effort are summarized, and subsequently elaborated, as follows:

1. Standardization of ecosystem concepts, e.g. ecosystem condition, is necessary.
2. A multi-tiered classification approach would best describe and distinguish differing levels of ecological classification.
3. A tri-national ecosystem classification and mapping initiative is needed and recommended.
4. Moreover, a tri-national initiative aimed at assessing these ecosystems, once mapped, is important from a monitoring perspective.
5. Ecosystem goods and services values are a societal priority, and should be developed as attributes of the ecosystem occurrences.

1. Clarification of key ecosystems concepts is necessary for both ecosystem science and ecosystem management.

There is a strong need to come to a common understanding about what is meant by ecosystems, ecosystem condition, ecosystem processes, and ecosystem goods and services. Ecosystems are increasingly advocated as a holistic approach to sustainable development, and are increasingly described in the popular press. Ecosystems, and threats to ecosystems in particular, are rapidly becoming a mainstream societal concern. As such, there is a strong need for the scientific and resource management communities to come to a clear, shared understanding of key ecosystem concepts. Moreover, there is a need for standardized, robust, practical ecosystem classifications and maps.

2. Ecosystems are appropriately conceptualized as meso-scale landscape and seascape entities, intermediate between relatively macro-scaled land cover types, and relatively micro-scaled vegetation units.

Land cover, the (bio)physical cover of the earth's surface, is commonly identified from remotely-sensed imagery, and is generally described globally with fewer than 20 classes. These classes describe biome-level entities such as tropical moist forests, dry grasslands, deserts and xeric shrublands, etc. Vegetation, on the other hand, is often defined at a much finer spatial and classification resolution, using knowledge of the structure and composition of plant communities, usually at local (site) scales. Ecosystem scientists have been historically reluctant to classify and map ecosystems at intermediate scales, primarily because ecosystems are widely recognized as "scaleless" (multi-scaled). We propose that ecosystems be classified and mapped at an intermediate, meso-scale, and placed in a multi-tiered conceptual framework between coarse scale land cover, and fine scale vegetation:

Coarse scales: Land Cover, Ecoregions

Medium scales: Ecosystems

Fine scales: Vegetation

3. We propose a collaboration between Mexican, Canadian, and US federal agencies, NGOs and scientific communities to develop a tri-national, standardized classification and map of meso-scale ecosystems.

The lack of standardized, consistent, management-appropriate scale ecosystem classifications and maps for any of the three countries is problematic. We recognize that there are several ecoregionalizations of North America, and that these all subdivide the continent into very-large, ecologically meaningful planning areas. These ecoregions tend to be very useful for regional-scale planning and assessments, but are generally too coarse for local management applications. We advocate the development of a robust, standardized, practical, meso-scale North American

Ecosystems Classification and Map, seamless and consistent across borders.

4. We propose that this tri-national map of ecosystems be used as the basis for a standardized, continental ecosystem monitoring effort.

Once mapped, we advocate the use of this standardized North America Ecosystems product as the basis for a continental effort to regularly assess ecosystem condition. Many of the physical features that define ecosystems on-the-ground (lithology, elevation, and landform) are enduring physical features of the environment which are not expected to change dramatically. The components of ecosystems that are likely to change are the biota (vegetation and species), and the climate. Changes in vegetation can be characterized using remotely-sensed imagery, highlighting an important monitoring relationship between land cover and ecosystem condition. A tri-national land cover and ecosystems monitoring effort, using standardized classifications, maps, source imagery, and methodological approaches, would represent a highly advanced and societally relevant collaboration between the three nations.

5. Ecosystem goods and services values are a societal priority, and should be developed as attributes of the ecosystem occurrences.

Finally, ecosystems are critical to maintaining human societies because of the value of the ecosystem goods and services they produce. While the science and practice of economic and societal valuation of ecosystem goods and services is still in its infancy, there is little question that these values should be attributed to the ecosystem polygon occurrences in a spatially explicit framework. This level of detail will permit assessments of ecosystem goods and services for any geography of interest at scales ranging from local areas to the entire continent.

Participants

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CHAPTER 19

HAZARD IDENTIFICATION AND FORECASTING BREAKOUT SESSION REPORT

Moderator: Carl Shapiro, U.S. Geological Survey

The breakout group discussed issues relating to the use of land cover data and hazard identification and forecasting. The discussion focused on the importance of land cover to this issue and ways that the data could be used and produced more effectively. The breakout group developed seven specific conclusions. The conclusions are summarized below:

1. **Common definitions are needed for hazards, vulnerability, and risk across disciplines, organizations, and nations.** Planning new applications across organizations will be facilitated though improved communications with terms that have commonly understood meanings. Hazards were defined as the potential for an event that could cause harm to people or property. Understanding and predicting the hazard requires physical and biological science information. Vulnerability was defined as the susceptibility to loss of people, property, or resources if a hazardous event occurs. Risk combines the hazard and the vulnerability and represents the expected hazard-related losses which includes the likelihood of a hazard occurring.
2. **Clear definitions and boundaries are needed for land use and land cover.** Both types of data are essential for improved hazard identification and forecasting. Land cover relates to the physical features on the earth. Land use addresses the human interactions with cover. It

deals with how land cover is used and managed by humans. The two types of data should be viewed as complementary rather than as substitutes. It is important that the distinctions between land cover and land use data be understood and that the potential for applications for both types of data be developed. Limiting the discussion to land cover or land use limits the scope of analysis.

3. **Multi-scale, multi-temporal land cover data based on land characteristics are needed to inform decisions for land use and mitigation decisions on multiple hazards.** It is important that the need for multi-scale land cover data be developed and understood and that trends data be used to not only record the past, but more importantly to develop predictions and scenarios for the future. This will support improved linkages between the data and its use to inform decision making.
4. **The use and development of land over data needs to move from a reactionary descriptive emphasis to an enhanced focus on prediction, mitigation, and decision support.** It is important that applications be explicitly considered and understood even by data providers.
5. **Common or harmonized classifications are needed across the borders between Canada, Mexico, and the United States.** Currently, classification systems are different among the North American nations. The difficulty in changing definitions is recognized. However, where the need is great such as in reducing the risk from natural and environmental hazards, consistent classifications are important. Consistency should address issues associated with granularity, definitions, standards, interoperability, and names. Common classifications will facilitate increased cooperation and collaboration across borders. This is important because land characteristics do not stop at borders.
6. **Communications channels should be developed and improved in advance of potential disasters. Cross-boundary disaster response rehearsals should include development of plans for using relevant land cover, land use, and other spatial data.** An emergency geospatial kit should be developed documenting data sources and availability, tools, and

methods to be used during emergency situations. These should be developed through existing international groups so that duplication among organizations is minimized.

7. **Planning should be expedited to develop priorities across borders for multiple hazards.** Joint data needs and availability should be identified and agreement should be developed on the types of decisions and issues that will be faced across borders.

The breakout group suggests that addressing these seven issues is important to improving effective land cover and land use data application and production. Existing international groups should provide leadership on these issues so that additional bureaucracy is not unnecessarily developed and duplicative activities do not result. However, it is urgent that action be taken on these issues expeditiously so that Canada, Mexico, and the United States can more effectively benefit from land cover data.

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CHAPTER 20

LAND COVER AND GLOBAL CHANGE
BREAKOUT SESSION REPORT
SEPTEMBER 22, 2006

Moderator: Patricia Jellison, U.S. Geological Survey

Like many key issues in climate change, land cover is both a driver and an indicator. The National Research Council has identified land use dynamics as one of the grand challenges for environmental research. No other global change parameter is so tightly intertwined with the issues of past, present and future land use practices; weather patterns; soil and carbon dynamics; ecosystem health and diversity; human population size and distribution; economic development and policy; technology and human health.

The importance of land cover interactions is further recognized in the stated goal of the International Geosphere-Biosphere Programme (IGBP) Global Land Project: "to measure, model and understand the coupled socioenvironmental terrestrial system." However, a lack of quantitative understanding of the timing and magnitudes of the response of ecological, social and economic systems to the combined effects of climate change and **land cover/land use** change are cited in the IPCC's Third Assessment Report as key uncertainties in understanding vulnerabilities and predicting both regional and global impacts of climate change.

The Land Cover and Global Change breakout group discussed issues that ranged from the use, development and preservation of land cover data to reach a better understanding of climate change locally, regionally, and worldwide, to practical issues like cross-boundary access to data and decision support tools. The group identified six critical land cover needs and issues of importance for climate change research: 1) the need to develop and work to international standards; 2) the importance of distinguishing between land cover and land use; 3) the need for quick turnaround in data collection and dissemination; 4) the need to identify and preserve at-risk archives of historical data; 5) the need for continuity and consistency; and 6) issues related to national data policies. These are summarized below.

1. Cross-walking classifications to international standards

"What is a tree?" Breakout participants acknowledged that different organizations use different classification standards, terminology, and ground truth frequencies and scales depending upon the type of analysis at hand. Classification systems vary depending upon the objectives and needs of the country, agency, or research entity that developed them. In most cases these are well-established systems that serve their users' needs well so the likelihood of any agency or group changing their classification to accommodate international standards is therefore small. However, the lack of a consistent system across jurisdictional boundaries makes global interpretation and synthesis difficult.

How can we put datasets together that are compatible globally, nationally, and regionally, to assemble a common baseline and consistent measures of change? The Food and Agriculture Organization's Land Cover Classification System (LCCS) represents a major attempt to develop a unified land cover classification protocol. While it is unlikely that major national efforts will be in a position to change their well-functioning internal classification schemes, breakout participants agreed that it should be feasible, without compromising agency requirements, to crosswalk those classification schemes to an international standard like the LCCS.

Similarly but at a higher level, there is a need for standardization or the development of methodologies for crosswalking in satellite and airborne sensors, delivery systems, and tools. The Landsat and Landsat Data Continuity Mission (LDCM) communities have been working hard to have both consistent metadata and data collection standards and product exchange from any station around the world. However, since many sensor systems and protocols are used worldwide, there is a clear need for the development of methods to make data and analyses compatible with one another for global change studies.

2. Land Cover Data vs. Land Use Data

While the terms *land cover* and *land use* are often used interchangeably, they are very different concepts. Which one is used usually depends upon the discipline doing the study and the desired goal of the study. In general terms, land cover is what is on the ground; land use is the effect of human activity on the landscape. Delineation of land cover classes can vary depending upon the discipline in which a study is conducted. Even the choice of *land cover* versus *land use* is dependent upon the intended application of the data (agriculture studies, for example, may use either). There are also studies in which the two are blended with varying degrees of consistency and accuracy (water, for instance, can be either a land cover class or a land use class). In some landscapes (e.g. African savannas), human activity has been so persistent over so long a time that it becomes problematic to tease land cover apart from land use.

In Australia, the paradigm often used is that *land cover* is what can be seen from photo or satellite interpretation, i.e. the characteristics of the land that can affect albedo, while *land use* is what is actually done to the land by people. Taking the analysis further, the Australian approach looks at *land use* along a continuum that identifies level of intervention and delineates five major carbon classes – national parks (where there is very little intervention), followed by natural environments, forestry areas, dryland activities, and finally irrigated activities (where intervention is very high). After *land cover* and *land use*, the next important tier of data to collect is *land use practices* and *land disturbance*. All of these quantities are important as inputs for climate change modeling.

Another aspect of land cover and land use information for climate change studies is the need for consistent and comparable time series data. Understanding climate change at regional scales requires high accuracy data (3% error is very large for climate change), and in some cases high resolution data products. Producing data of this type and quality is intensive, requiring substantial efforts to align and correct the data.

Ultimately, climate change studies need time series, plus high resolution, high-accuracy information on surface dynamics - not just land use classes, but disturbances. Breakout participants agreed that more research and different perspectives are needed to understand what data are needed for understanding climate change.

3. Quicker Turnaround on Global Dataset Generation

Participants agreed that quicker turnaround than that presently available is needed if global datasets are to be useful in more than academic exercises. Decadal datasets take so long to be released that they are obsolete before they become available, and their utility is therefore limited to retrospective studies. There is such a great need for rapid-turnaround mid-decadal data series for global climate modeling and analyses that participants felt that sacrificing some aspects of data quality (e.g. accepting some spatial data gaps, higher cloud cover) would be appropriate if it brought the datasets into the hands of scientists in time to be of use.

4. Preservation and Accessibility of Archival Data

Part of understanding global change is understanding how things have changed in the past. Landsat data provide a window on more than 30 years of change, but satellite data are not generally available for dates prior to the early 1970's. However, much information can be gained from historical aerial photography and ground-based images, providing those data are made available. Participants noted the existence of large collections of aerial photography acquired before, during and after World War II, as well as images acquired for soil surveys and other purposes over many decades. Historical map information can also provide insights and details on land use and change.

While some of these images are in public archives, a great many remain in private hands. Many public and private archives are at risk of data loss due to the ageing of photographic films, paper, and ancillary data and the lack of resources for preservation. The information these sources can contribute to understanding landscape change through time is immense. Breakout participants agreed that resources are needed and should be found to (at a minimum) catalog, store, and make metadata available for these archival materials, and to scan and georeference materials of high importance.

5. Continuity and Consistency of Data

Touched upon in the sections above are the overarching issues of data continuity and data consistency, in both the spatial and temporal domains. Global change research and especially climate change modeling are dependent upon the continued availability of consistent time series data from comparable sensors and sources, with consistent metadata and ground truth information that has been collected with uniform or at least comparable terminology, granularity, and parameterization.

Some of the difficulties in assembling global or even regional and transnational datasets have been addressed in the sections above. There is a great need for standardization of units, definitions, and ground truth. Otherwise, crosswalking to a common classification rubric becomes an exercise in futility. The need for consistency ranges from such fundamental observations as the minimum height that woody vegetation must attain to be called a tree; to the consistent description and definition of each land cover or land use class (e.g. exactly how is *mixed forest* defined?); to the total number, independence, and character of classes used.

At another level entirely is the need for eventual consistency across climate models and coupled models themselves, so that model results are comparable and that the results of one model can serve as inputs to the next. Modeling of this type is still maturing and is strongly dependent upon what question(s) the model is intended to answer. Providing the correct input data at the correct spatial and temporal scales is crucial to the success and validity of the results. This goal can best be achieved through joint and cooperative efforts between the modeling and land cover communities.

6. Fundamental Differences in Data Policies

Breakout session participants generally agreed that differences in data policies hinder transboundary and regional monitoring, research, and modeling. At the national level, data policy and access to land use and land cover data varies: U.S. land use-land cover data are available to everyone at no cost, while Mexico and Canada each have particular copyright issues that are often compounded by legislative requirements for cost recovery. In addition, though these data would be of inestimable value as ground truth and as model inputs, there are privacy issues associated with land use and land cover data at the parcel or individual landowner level. Taken together, these issues hamper transboundary efforts.

Participants offered suggestions on ways to address these issues. There was consensus that while sweeping changes to national policy are hard to achieve, it is very possible to be successful in developing agreements to address specific problems in specific locations. Furthermore, it is important to elucidate what the most important data are and to work towards cooperation with those specific data needs in mind. These interactions take place at the human rather than governmental scale, beginning with dialogue and inclusion of stakeholders. Effective international cooperation requires patience, persistence, and good will not only to achieve the immediate objectives of a project, but to nurture the likelihood of adoption of mutually accepted standards and policies that will benefit all parties.

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NORTH AMERICAN LAND COVER SUMMIT: SUMMARY

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INTRODUCTION

The North American Land Cover Summit brought together scientists and practitioners who develop land cover products at national, continental, and global scales. It provided a forum for end-users of land cover data on applications and issues and offered an opportunity for scientists from Mexico, Canada, and the United States to initiate discussions on development of a North American Land Cover Change program.

A number of crucial applications and issues related to the generation and use of land cover data were discussed during the three-day conference. Details of these applications, issues, and opportunities are addressed in the 16 papers and four breakout group summaries included in this special issue. The following summary is intended to condense and categorize the applications of land cover described in those papers and breakout sessions and to identify broad issues that need to be resolved in order for land cover data to be more effectively generated and used by scientists, decision makers, and stakeholders.

MULTI-SCALE LAND COVER PRODUCTS AND CHANGE DETECTION

A number of papers dealt with the development of land cover products and databases at broad spatial scales, including efforts across Canada (Wulder *et al*.), the U.S. (Homer *et al*), Mexico (Jiménez), Europe (Kleeschulte and Büttner), Australia (Barson), and the entire globe (Latham). Many of these programs have nested land cover classifications, but each of the programs use different approaches which makes cross-country and cross-continental comparisons difficult. Latham presented a nested classification approach that would facilitate comparisons among different regions of the world.

Monitoring land cover change is a primary objective of several of the programs discussed in this special issue. Wall-to-wall land cover change products have been developed for the lower 48-United States, large parts of Europe, and Mexico. For example, two-date land cover products from Landsat Thematic Mapper (TM) data have been generated for the U.S. (at 30-meters) and for Europe (at 100 and 250 meters) for the early 1990s and the early 2000s. Land cover change products have been developed for both of these geographies between these periods of time. Australia also has used Landsat TM data as the foundation for its change program as well (Barson), and similar to the FAO program, uses a nested sampling design to evaluate status and change at multiple scales. The FAO uses coarser-scale spatial data from the Advanced Very High Resolution Radiometer (AVHRR, 1-km), Spot 4 (1-km), and the Medium Resolution Imaging Spectrometer (MERIS, 300 m) to generate global land cover, and Landsat and other finer spatial resolution imagery to generate more detailed land cover on sub-continental scales.

Some of these broad geographic programs have developed sets of derivative products. For example, the National Land Cover Database (NLCD) includes databases on impervious surfaces and canopy density (Homer *et al*). Additionally, some of these programs are working with in-situ monitoring programs to develop spatially explicit estimates of certain types of land use. Latifovic and Pouliot used a combination of remote sensing imagery and agricultural census data to develop a spatial database of crop type. Similarly, the U.S. Department of Agriculture's National Agricultural Statistical Service has developed a cropland data layer by using the NLCD and survey-based, agricultural statistics (http://www.nass.usda.gov/research/Cropland/ SARS1a.htm).

Some variation exists in the way these programs have been designed and implemented. In Australia, land cover databases are generated through the States and Territories. The U.S. implements its NLCD program through a consortium of ten Federal agencies. Similarly, land cover mapping of forested areas in Canada is accomplished through collaboration among Federal agencies. The European Corine land cover database involves close coordination with a number of European Union member countries. Finally, Mexico land cover databases are generated through partnerships with universities and Federal and State agencies. Common to the success of all of these programs has been development of strong partnerships - partnerships that are essential in securing the resources to acquire and process imagery and to provide land cover products. Strong partnerships also have been critical in ensuring that the land cover products meet the needs of a wide range of potential users, including those in the science community, governments, conservation organizations, communities, private companies, and citizens

APPLICATIONS

Australia's land cover change program is used to track changes in carbon stocks, and fluxes and flows across landscapes. The EEA's Corine Land Cover program provides important information on habitat and watershed modeling and across large areas of Europe. The NLCD program provides data that are crucial to habitat modeling, wildfire modeling and restoration, watershed modeling, and natural hazard risk analysis. Mexico's land cover products help protect the country's exceptionally rich biological diversity, and Canada's land cover programs help protect and restore its important forested landscapes. FAO's land cover program helps evaluate status and changes in food security, and provides for early warning and climate change analysis, disaster preparation and response, and analysis of populations and areas at risk. It also uses a set of indicators and models derived from land cover and other biophysical data to conduct these analyses.

Several papers in this volume discussed the use of land cover data in environmental monitoring, assessment, and management applications. Although many authors felt that land cover played a critical role in these applications, they also concluded that land cover by itself was insufficient to address some of the specific environmental issues of concern.

Land cover is an important element of ecosystem and landscape characterization programs. Sayre *et al*. described how land cover can be used in combination with other biophysical data to map ecosystems across entire continents. Spatially extensive and consistently mapped ecosystem maps are important in establishing priorities for ecosystem conservation and protection. Wickham and Norton

(1994) developed a landscape composition and pattern classification (Landscape Pattern Types or LPTs) using land cover data and this approach has been used in several national-scale environmental assessments in the U.S., including the State of the Nation's Ecosystems report (Heinz Center 2002).

Availability of digital land cover data at regional to continental scales has led to development of a number of spatial or landscape metrics, indicators, and models. Riitters and Reams described how the NLCD was used to assess forest fragmentation across the U.S. at different spatial scales. The wall-to-wall nature of the NLCD makes it possible to apply a "sliding window" approach to assess forest fragmentation at a range of scales. This approach has been used to assess fragmentation in Europe (applied to the Corine land cover data), as well as to assess global forest fragmentation using 1-km AVHRR land cover data (Riitters *et al*. 2000). Jones provided a summary of the different types of land cover-based indicators and their applications. Although some of these indicators are based entirely on land cover composition and pattern, many are based on the spatial intersection of land cover with other biophysical data. For example, land cover is intersected with digital data on slopes to provide an indicator of potential soil and nutrient loss. Land cover is intersected with stream network data to evaluate riparian habitat conditions. Intersection of land cover data with other biophysical data, such as soil texture (derived from soil databases), slopes, precipitation, often form the basis for spatial explicit landscape models. Land cover change is also being used to track carbon stocks and flows across landscapes in Australia (Barson).

Wiens *et al.* emphasized the importance of land cover in conservation planning. Land cover data are critical in assessing environmental conditions both inside and outside of conservation areas, but especially in putting individual conservation areas into a regional landscape context. Connectivity and conditions of landscapes adjacent to and outside of conservation areas will be important factors in determining the long-term viability of habitats and populations in the face of global climate change. Wiens *et al.* also emphasized the importance of monitoring land cover and land use change.

Land cover-based metrics have been used extensively in environmental vulnerability assessments. White *et al.* used land cover to generated metrics of ecosystem condition, environmental stressors (anthropogenic influences), and rarity (land cover and diversity). Indices of each of these three categories were combined into a spatially explicit measure of vulnerability. The U.S. Environmental Protection Agency's Regional Vulnerability Assessment Program (ReVA) uses a set of land cover and landscape-based metrics to evaluate environmental vulnerability at multiple scales across broad regions (Bradley and Smith 2004). Wood (this volume) used the NLCD to map the vulnerability of coastal communities to tsunami waves. Additionally, land cover change information can be used to help forecast future landscape change and to assess potential environmental consequences and outcomes (Wickham *et al.* 2002, Claggett *et al.* 2004).

Land cover data play important roles in environmental decision support tools and web-based systems. The Automated Geospatial Watershed Assessment tool uses land cover and other biophysical data to model important hydrologic changes associated with different alternative future landscape scenarios (Kepner). As such, it provides decision makers with a power tool to develop environmental management strategies. Shi *et al*. described a web-based decision support system that uses land cover in several of its applications, including modeling tools and on-line data searches and inquires by watershed. This web-based system is used by a wide range of stakeholders, including communities, counties, state and federal agencies, universities, NGOs, and citizens. Watermolen emphasized the importance of land cover and spatial decision support tools for natural resource agencies, but raised a number of issues that prevent decision makers from using these data and tools in an effective manner. These and other issues are summarized in the following section.

ISSUES, NEEDS, OPPORTUNITIES

Certain issues, needs, and opportunities that were raised during the Summit are reflected in the papers found to this volume.

(1) Standards and Data Policies. With perhaps the exception of Europe, the lack of classification and data policy standards has reduced our ability to map land cover across country boundaries at moderate spatial resolution (e.g., 30 m). Lack of standardized classifications also precludes cross-country land cover change analyses and environmental assessments, especially those

that utilize indicators generated in part from land cover data. Moreover, the lack of consistent national policies on land cover data access and distribution prevents the acquisition of satellite and other imagery needed to develop cross-country land cover maps. One solution is to develop a nested classification framework similar to that proposed by Latham (this volume). Additionally, the USGS Earth Resources Observation and Science (EROS) Center is in the process of making the entire Landsat archive (Landsat 1 -7) available via its website for free.

(2) *Continuity of Landsat and other Moderate Resolution Data*. Land cover change detection and change analysis of indicators generated from land cover data require acquisition of data that are similar in spatial resolution and spectral properties from one period to the next. Landsat sensors have been the primary source of data for land cover change analysis, but there is concern that both Landsat 5 and 7 may fail before Landsat 8 is launched (projected for October 2011). Additionally, problems with Landsat 7 have lead organizations to use other moderate resolution imagery, including but not limited to the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), the Advanced Wide-field Sensor (AWiFS), the China-Brazil Earth Resources Satellite (CBERS), and SPOT. Although land cover data can be produced from these and other sensors, cost and limitations in historical spatial and temporal coverage make land cover change and trend analysis problematic.

(3) *Methods to Assess the Accuracy of Land Cover Change Estimates.* Most of the published literature on accuracy assessment methodologies have focused on individual land cover maps (see for example Stehman *et al.* 2003). However, land cover change detection introduces additional complexity into accuracy assessments and requires development of new methodologies.

(4) *Derivative Data Important to Environmental Studies*. Several participants at the Land Cover Summit emphasized the need to develop digital databases that are derivatives of land cover data, but especially land use. Additionally, derivative products, such as canopy height and structure provide a third dimension of land cover and vegetation important in a wide range of models, including watershed and hydrologic models, carbon storage and balance models, and habitat models. These derivative data offer great potential to improve environmental decision

making. The most significant advances in mapping these types of derivative data have been achieved by linking land cover programs with in-situ and census-based monitoring programs. Examples include crop-type (Latifovic and Pouliot) and vegetation height (Zhu *et al.* 2006). Another approach is to implement a nested, multi-tiered monitoring design similar to that being used in the United Kingdom (Haines-Young *et al.* 2006). Finer-scale landscape features are derived through random samples involving higher resolution imagery and/or in-situ field sampling.

(5) *Downscale Land Cover Data.* Many of the decisions affecting land cover and land use changes occur at the local and community scales. Watermolen concluded that existing land cover data, such as that provided from the NLCD, were marginally useful for environmental planning at local and community scales. He indicated that there was a need for finer-scale land cover data (spatial resolution and number of land cover classes) to increase the use of land cover data in local-scale planning. Spatial data exist for many places at relatively fine spatial scales (one to a few meters), but the cost of their acquisition and labelling (into land cover, vegetation, or land use types) limits creation of detailed land cover maps. However, increased access to inexpensive land cover labelling tools (http://edcintl.cr.usgs.gov/rlcm/index/php) and high resolution data may increase the generation and use of detailed land cover at local and community scales.

(6) *Time to Delivery of Land Cover Data.* Many participants raised the issue that it takes too long for land cover data to be produced and made available. For example, some NLCD data were 5 or more years old before they were made available. Similar problems exist for the Corine program. Improvements in image processing and reduced costs of image acquisition may decrease the time between data collection and delivery of land cover products, but national-scale land cover programs will continue to be challenged with this issue. One solution is for regional organizations to update (refresh) land cover databases using newer imagery as it becomes available. Each regional organization would be responsible for updating land cover within their region.

(7) *Validate Land Cover-Based Indicators*. Land cover-based metrics and indicators offer great potential to assess status and trends in environmental conditions at multiple scales based on land cover databases. They also hold great promise to assist in formulating alternatives to restore and maintain environmental quality. However, quantitative linkages between landscape metrics and indicators and ecological and hydrological processes are mostly lacking. Studies are needed to establish quantitative associations.

(8) *Identify and Preserve At-Risk Archives of Spatial and Land Cover Data.* Historical data are critical in establishing baseline conditions and trends in key environmental attributes and indicators. They also are critical in conducting retrospective studies or "back-casts" to develop predictive models of potential future changes. Therefore, there is a need to identify and protect spatial data archives, especially those that are a risk of being lost due to poor maintenance and/or the age of the materials.

(9) *Increase Involvement of Stakeholders in Development of Land Cover Data and Decision Support Tools.* Over the last 15 years, local communities and organizations have gained consider interest and capability in analyzing spatial data and applying the results to community and environmental planning. However, as pointed out Watermolen, dialogue between local communities, state agencies, and large land cover programs such as NLCD, have been limited. Partnerships involving stakeholders and agencies at multiple scales (Shi *et al.*) are one way to improve stakeholder input into the development and improvement of land cover programs.

(10) *Cost-Benefit Accounting for Land Cover.* Free, Internet-based access to land cover data has lead to an explosion in the use of land cover data for a variety of purposes. Despite great increase in use and demand, we lack an accounting of cost-benefit of comprehensive land cover products. Kleeschulte and Büttner reported that users of the Corine land cover database generated about 20 times more revenue than the cost of developing the database. Similar cost-benefit accounting systems need to be developed for other land cover programs in order to maintain their support.

CONCLUSION

The North American Land Cover Summit brought together a unique combination of scientists, practitioners, and stake holders who work at scales ranging from communities to the entire globe. The papers included in this volume identify a number of important uses of land cover data. They also identify limitations and needs related to the generation, distribution, and use of land cover data.

Developing and maintaining comprehensive land cover programs presents significant challenges that include acquiring imagery that is of sufficient spatial and temporal resolution to be relevant to a wide range of clients. At the same time, the producers of land cover data have resource constraints that limit the spatial scale and temporal frequency of the land cover data that can be delivered to the public. Maintaining a productive balance between relevancy to stake holders and resource constraints is the daily hard work of land cover programs. Despite limited resources, the demand and use of land cover data are increasing exponentially.

Finally, a substantive result of the Summit was the exchange of ideas and development of collaborative projects among participants. One specific outcome has been a shared project between Mexico, Canada, and the U.S. to monitor landscape change across North America. The hope is to develop similar collaborative projects through initiatives such as the Global Earth Observation System of Systems (GEOSS 2005).

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