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 Partnership1 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-

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Web-based</td>
<td>Accessible via the Internet; only required software or hardware is an Internet browser.</td>
</tr>
<tr>
<td>Cost-free</td>
<td>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.</td>
</tr>
<tr>
<td>Data included</td>
<td>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.</td>
</tr>
<tr>
<td>Scalable</td>
<td>Data are accessible at various spatial scales. Tool allows user to assess local conditions within a regional context.</td>
</tr>
<tr>
<td>Customizable</td>
<td>Users can address specific needs through features inherent in the tool or through “plug-in” components.</td>
</tr>
<tr>
<td>Relatively intuitive</td>
<td>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.</td>
</tr>
</tbody>
</table>

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

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

* 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
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 (Horrigan 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. 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

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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).
<table>
<thead>
<tr>
<th>Data Collection Effort</th>
<th>Responsible Agency</th>
<th>Primary Purpose</th>
<th>Source(s) of Data</th>
<th>Timeframe</th>
<th>Key References</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Land Cover Dataset</td>
<td>U.S. Geological Survey</td>
<td>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 <em>The National Map.</em></td>
<td>Remote sensing materials (Landsat 5 and Landsat 7 imagery)</td>
<td>1992, 2002</td>
<td>Loveland et al. 1991; Sohl et al. 1999; Vogelmann and Wickham 2000; Vogelmann et al. 2001; Wickham et al. 2002; Homer et al. 2004</td>
</tr>
<tr>
<td>Forest Inventory and Analysis</td>
<td>U.S. Forest Service</td>
<td>Comprehensive inventory and analysis of the present and prospective conditions of and requirements for the renewable resources of U.S. forest and rangelands.</td>
<td>Remote sensing materials, field and logging operation visits, forestland owner and wood processor surveys</td>
<td>Recurring annual basis, with individual state reports every 5 years (1930-present)</td>
<td>Gillespie 1999; American Forest and Paper Assoc. 2001; U.S.D.A. 2005a; U.S.D.A. 2005b; U.S.D.A. 2006;</td>
</tr>
</tbody>
</table>

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 outlined 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 pursuing 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
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
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...
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.

REFERENCES


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