

Mapping the ever-changing landscape

Lessons from the Arkansas land-use/land-cover mapping project

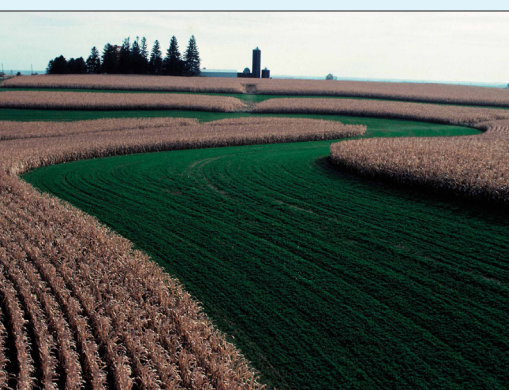
Land-use maps are an essential component of land- and natural-resource planning efforts. However, because these maps are infrequently updated, dynamic landscape changes such as urban expansion may not be adequately represented. The Arkansas Land-use/Land-cover (LULC) Project is working to provide up-to-date land-use information in a scale and format that has wide applicability to many end users. Here, we discuss the practical and technical considerations for producing a more-frequent, consistent digital land-use database that is relevant for many stakeholders.

All landscapes change over time. With the exception of catastrophic change caused by such events as earthquakes and hurricanes, natural changes on the earth's surface occur slowly through geologic and hydrologic processes. Human-induced changes to the landscape, on the other hand, are often rapid. They are a complex, often unpredictable, integration of natural, sociological, and economic forces. We refer to these human alterations to the natural landscape as "land use."

The importance of land-use data

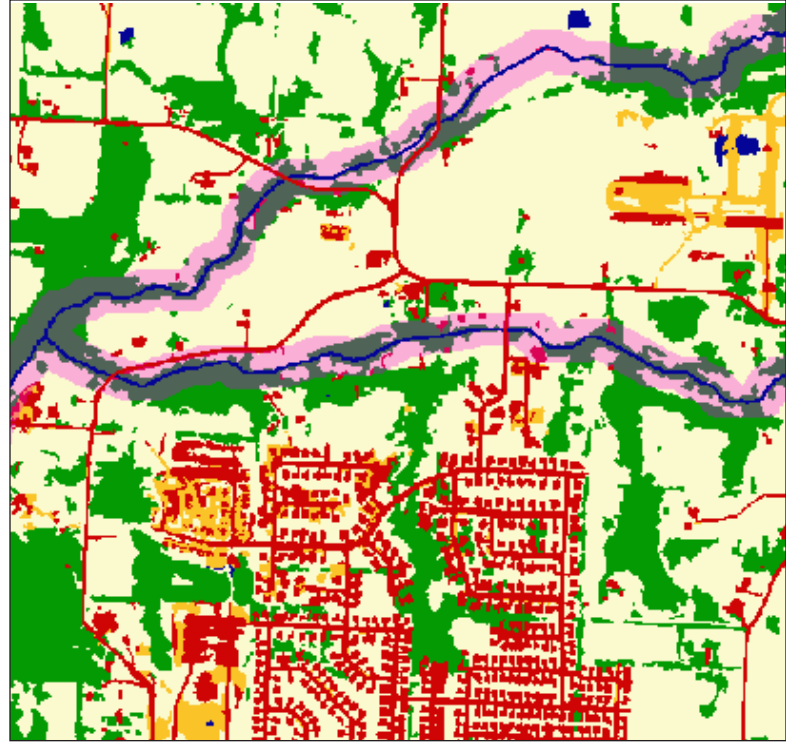
Understanding long-term land-use trends and how they will impact America's economy and environment in the 21st century is the goal of land planners, natural resource managers, and others. To be effective, planning efforts require land-use information that is accurate, consistent, and up-to-date.

While often thought of as mundane by many GIS professionals, baseline data such as roads, elevations, and land use are the "bread and butter" for land-use analysis, planning, and critical decision-making. Land-use maps are also employed in many traditional GIS research and planning fields such as habitat modeling and urban planning. (See "Weighing Land-use Planning Decisions," *RGIS Innovator*, January 2007 for an example of how land-use data are being used for comprehensive planning.)

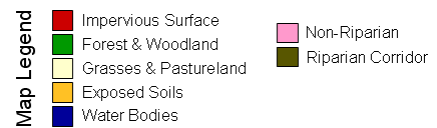


With an understanding of how land is being used, regional planners can more easily develop long-range strategies to best manage our natural resources.

Using basic GIS tools, up-to-date land-cover maps allow planners to see where certain types of action are needed. This riparian buffer map, shows the presence/absence of vegetation along stream channels and indicates where vegetation could be added to reduce pollution from urban stormwater runoff.



Riparian Corridor Map



Land-use data are also integrated into many leading-edge arenas of global research, from mapping endangered habitats to monitoring international food-security issues.

While tax dollars are often readily available for regular updates to various spatial datasets deemed essential, such as road centerlines and political boundaries, land-use maps are updated much less frequently. That's because they are perceived as being more costly and difficult to produce. The only categorically and spatially consistent, land-use/land-cover map for the United States is the National Land Cover Dataset (NLCD). First produced by the U.S. Geological Survey in 1992, and again in 2001, this national "wall-to-wall" effort is a worthy accomplishment. For some regions and ecosystems, the anticipated 10-year frequency may suffice; however, for rapidly growing and/or dynamic landscapes, more frequent updates may be needed.

The big picture

Like many states and regions of the U.S., Arkansas has experienced rapid and dynamic land-use changes over the last few decades. Urbanization is the most obvious conversion in Arkansas, but there are other ongoing, significant landscape changes taking place as well. The Arkansas Land-use/Land-cover (LULC) Project was conceived in 2000 to provide an up-to-date spatial database of land-use information for the entire state.

A project of this scope generates much interest, but not all users of land-use/land-cover data are interested in the same things. Soil scientists have different data needs than urban planners. With advance planning, it is possible to create a single dataset that addresses the special requirements of

many users. For the Arkansas LULC, producing information that is useful to as many end-users as possible is an overriding goal. There is, of course, always a push to satisfy the particular agency or agencies that are funding data development. But it is often feasible to meet the special requirements of funding agencies while creating a database that has wide applicability. Before beginning a project of this magnitude, the Arkansas project team had to set mapping parameters that were both useful and economical.

Land use or land cover?

Simply stated, land cover is the observed physical/biological cover of the earth's surface: grasslands, forestlands, water, and bare rock are examples of land-cover types. Land use, on the other hand, is the human "footprint" on the land—activities, and inputs that people undertake on land to produce, change, or maintain certain characteristics. Grasslands, for example, would be considered a land-cover type, but a pasture or lawn

Land cover is the observed physical/biological cover of the earth's surface.

Land use is the human "footprint" on the land.

would refer to a land use. Likewise, forestland refers to a land-cover type, but the term “tree farm” indicates land use. Reservoirs—a land use—are water bodies, but not all water bodies are reservoirs.

Collecting land-cover data is fairly straightforward using satellite remote sensing and other traditional data-gathering tools. Many land-use categories, however, are difficult, if not impossible, to map using traditional, automated extraction methodologies without ancillary data and labor-intensive analysis. For example, the size and shape of two buildings may be identical, but one building may be a shopping center and the other a factory or warehouse. Where relevant zoning information is available and additional time is budgeted, these different categories can be identified. However, this example illustrates the difficulties faced in defining neat land-use categories.

Landscapes of change

Once stakeholders have a clear understanding of how remote sensing methods can be employed to map the landscape, they must then determine what types of land use they want to map. Landscapes can be progressive or cyclical in nature. If a general land-use/land-cover map is desired, both progressive and cyclical landscapes must be mapped, but sometimes only a specialized map, such as an urban change map may be required. Before proceeding we must distinguish between progressive and cyclical landscape dynamics.

Progressive landscapes

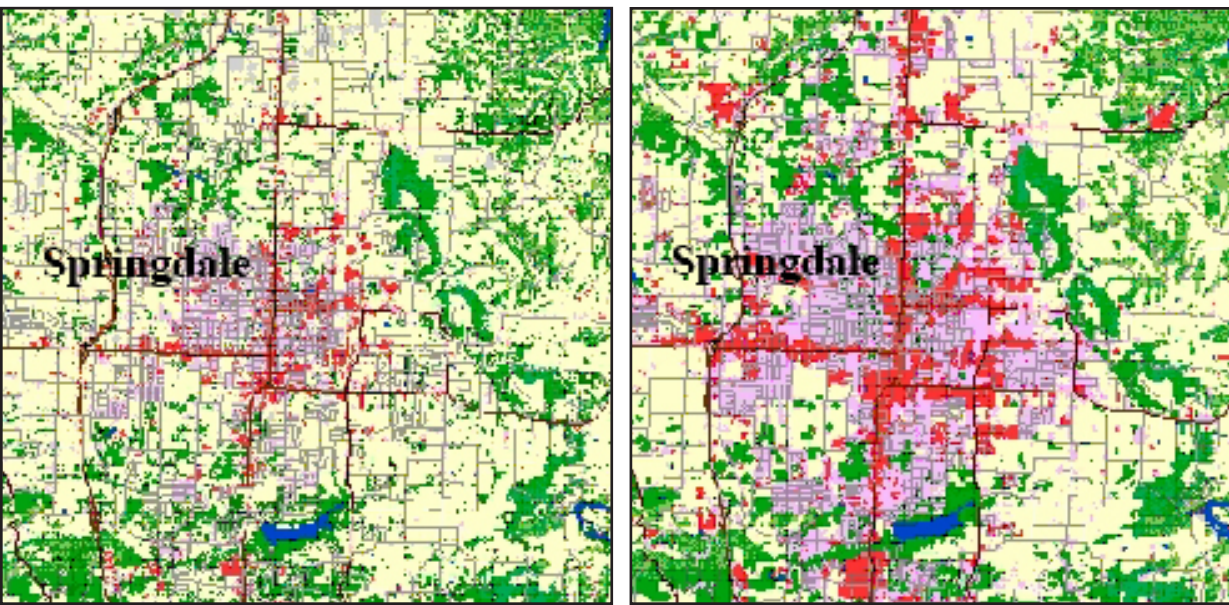
Progressive processes refer to long-term modifications to the landscape that are generally irreversible. Urban sprawl and forest-to-agricultural land conversion are examples of progressive landscape processes. Since the change occurs in one direction,

progressive processes are easy to monitor and map. Once land is urbanized it rarely goes back to a natural setting, so there is little need for frequent updates and monitoring of commercial and industrial areas. When mapping progressive landscapes, it is only necessary to map changes over time, so urban areas may not need to be reconsidered every time a new land-cover map is developed.

Basic image processing algorithms, available in remote-sensing and GIS software packages, can be effectively used to map most types of progressive change. As a general rule, development follows roads, so mapping changes to roads is a key indicator of where change mapping should be focused. This is not only true for urbanization, but also for areas of natural-resource extraction. New roads precede change; similarly, new irrigation canals precede increased intensities of agriculture. Therefore, baseline road and water vector datasets can delineate where there is a potential for change.

Cyclical landscapes

Cyclical processes can occur seasonally (agricultural crop rotations) or periodically (flooding patterns related to climate). They can also fluctuate according to market-driven forces. Market-driven changes can be short or long-term; the choices a farmer makes each year on what crops to plant, and how much of each, is a short-term market-driven change. Long-term market-driven changes often relate to the interplay of land productivity and expected rates of return on investment. The proliferation of aquaculture ponds for catfish farming during the 1990s in Arkansas’ lower Mississippi river valley illustrates this long-term, market-driven dynamic.



Growing urban landscapes are an example of progressive change in the landscape. Land-use maps are useful for seeing historic trends and for projecting future spatial patterns.



Landscapes are dynamic and satellite imagery is useful for detecting within-year changes. From left: fall, spring, and summer.

Unlike progressive change, cyclical landscape processes must be mapped in total every time a new version of the map is to be produced, or until that landscape becomes a progressive landscape. When mapping cyclical change, it is especially useful to know as much information as possible about the phenomenon to be mapped. When mapping crops from satellite imagery, for example, it is useful to know about the life cycle (phenology) of the crops. Each crop to be mapped will have some unique phenomenal/temporal characteristics. Various crops may be planted and harvested at different times, and this information can be used to select the calendar date of the imagery to be purchased for the mapping project.

Nuts and bolts: Technical considerations

Having a firm understanding of the type(s) of landscapes to be mapped will allow stakeholders to develop an appropriate classification scheme. Generally speaking, for every increase in category, there is a proportional increase in the amounts of data and labor required to extract the desired information. A classification scheme that looks at cyclical land uses such as crop rotations, or that differentiates between various crop types (soybean, cotton, rice, etc.), requires more data and more labor than a scheme with a single cropland category. Likewise, differentiating specific tree species in forest habitats requires much more time and effort than a unified forest category. All classification systems are an abstraction of reality, and you will discover that all pixels in an image can never be placed into a limited classification scheme. The map can never

depict the totality of the whole, so it is best to adopt and stick to a prearranged classification system before all work begins. You can always improve your map on the next iteration. For an excellent discussion of land-cover classification schemes, see the “Land Cover Classification System” developed by the U.N. Food and Agriculture Organization at: <http://www.fao.org/docrep/008/y7220e/y7220e00.htm>.

Once you have established your needs and a mapping scheme, it’s time to look at the specifics of the project. Project particulars are both practical and technical in nature. The technical aspects of a remote-sensing based land-cover mapping project include such things as the selection of remote-sensing data, the collection of GPS-based ground-truth information/accuracy-assessment points, project software and hardware requirements, etc.

Most technical issues involved in land-use mapping from remote sensing data such as aerial or satellite images deal with matters of resolution. For our concerns we can identify three types of resolution: spatial, spectral, and temporal.

- **Spatial resolution**, simply stated, is the ability to distinguish between two closely spaced objects on an image. In a purely computer-digital sense, this is the two-dimensional size (in ground units) represented by a single pixel in an image. Higher spatial resolution means greater spatial detail. Street level land-use mapping requires a very high level of spatial resolution, while mapping North American soybean production would require only a moderate or low level of spatial resolution. Often, people assume that high-resolution data is always better, but this is not always the case. From a technical point of view,

For every increase in category, there is a proportional increase in the amounts of data and labor required to extract the desired information.

high-resolution data requires more “pre-processing” time and disk storage capacity. In cases where timeliness of the land-use data is of greater importance than spatial detail, it may be better to map from a lower-resolution source. Increasingly, improved technology and automation will allow faster image-to-map turnaround. For the present, a good rule of thumb for determining spatial data needs is to make your choice scale dependant: the larger the study area, the lower the resolution.

- **Spectral resolution** refers to camera or sensor sensitivity to various “kinds” of light. The human eye sees light in the visible spectrum only—a continuum from blue to green to red. Cameras and sensors can be designed to see more spectral information, including ultraviolet and infrared light as well as heat. Spectral information from the infrared portion of the light spectrum is very useful, even critical, to digital land-use/land-cover mapping. Increased spectral resolution (data from more portions of the light spectrum) allows the image analyst to distinguish very subtle differences in landscape types. The classic example is the ability to differentiate, with 100 percent accuracy, between green Astroturf and natural grass in an image.

Increased spectral information allows a greater degree of automation, keeping labor costs down. Most commercial high spatial-resolution imaging systems have lower-spectral resolution than the moderate resolution earth observing systems such as Landsat TM or MODIS. Research continues into combining (fusing) data from high spatial-resolution sensors with data from high spectral-resolution sensors, and the future looks promising for these hybridized methods.

- **Temporal resolution** refers to the frequency at which a sensor records imagery of a particular area (also known as revisit capability). Think of it as how often a particular imaging satellite passes overhead, or how many times you plan to schedule aerial flights over your state or county. Revisit needs are driven by two factors: rapidity of change, and whether the land use

to be mapped is predominantly progressive or cyclical. In rapidly-growing urban areas, more frequent updates to land-use mapping may be appropriate. Also, when mapping shifting land-use patterns, such as the winter wheat to soybean crop rotation, there is a need for two or more data acquisitions to carry out the mapping goals of the project. More imagery, of course, equals more money and more processing time.

It is always good to have plenty of first-hand knowledge of the area to be mapped. It is also good to have a set of field-collected GPS points by which the accuracy of your final output map can be gauged. For maximum accuracy there should be cooperation between the technical staff (those doing the image processing and GIS work) and those who are collecting the field data. It is also advisable to have

regular feedback from the “client” or end-users of the data. Be sure to collect plenty of GPS points for every category in your classification scheme. Based upon your *a priori* knowledge of your study area, try to balance the collection of points to the spatial coverage of each category. For example, if forest covers 50 percent of the area, try to set 50 percent of your GPS points from forested areas. Some of the

points that you collect can be used to guide your software’s classification algorithms, and to give the image analyst a better understanding of the spectral characteristics of the phenomena to be mapped. The remaining points should be reserved for a simple matrix accuracy analysis in which the actual ground-truth GPS point is compared with the output land-use map.

Practicalities: Dealing with agencies and money

As mentioned previously, it is eminently practical to include all the agencies with a stake in the final product in the planning of the project. A multi-agency approach allows





This *RGIS Innovator* was produced by the National Consortium for Rural Geospatial Innovations. RGIS brings geospatial technologies and the benefits of the Information Age to rural America, where land is fundamental to rural economies and ways of life. Learn more about RGIS at www.ruralgis.org.



Additional support provided by the USDA Cooperative State Research Education and Extension Service (CSREES).

RGIS-Mid-South
University of Arkansas
Center for Advanced Spatial Technologies
12 Ozark Hall
Fayetteville, AR 72701

the pooling of funds, software, equipment, and most importantly, expertise. Stakeholders should guide, but avoid micro-managing the overall project. It is advisable for each party to agree, in advance, on specific obligations and duties. This can be arranged through standard, but clearly stated, memoranda of understanding (MOUs). Once the process has begun, stay in contact through email lists. If possible, include some funds for face-to-face collaboration, but, at the very minimum, maintain an effective feedback loop between the stakeholders and those doing the field and technical work.

Conclusion

The 2004 and 2006 Arkansas LULC maps built on, and substantially improved upon, the existing but incomplete digital LULC maps already available for Arkansas as a whole. In the past, land-use maps portrayed a somewhat static and inconsistent picture of the landscape, but the 2004 and 2006 maps generated for the Arkansas LULC project were developed with a consistent methodology. The depiction of season-to-season land-use patterns adds a new dimension to land-use/land-cover mapping. Not only is the new dataset more encompassing in the temporal dimension, it is also has more categorical detail, and is more accurate spatially. Combined with other natural resource and socio-economic data, the information discussed here should prove useful for natural-resource planners. In addition to the data itself, the methods developed for the project such as quick ground-truth data-collection strategies, and automated image-processing procedures will allow future land-use mapping projects to be completed in less time. Overall, the results of the 2004-2006 LULC studies were quite positive, and further innovations in technologies, and strategies to use them, will continue to improve the accuracy, availability, and utility of digital geospatial data.

This bulletin was prepared by Bruce Gorham at the Center for Advanced Spatial Technologies (CAST) at the University of Arkansas in Fayetteville. Funding was provided by the National Consortium for Rural Geospatial Innovations–Mid-South. Data from the 2000 LULC project can be downloaded from the GeoStor site at www.cast.uark.edu/cast/geostor/. For more information on land-use mapping efforts in Arkansas, contact Bruce Gorham at RGIS–Mid-South, or via email bruce@cast.uark.edu.