

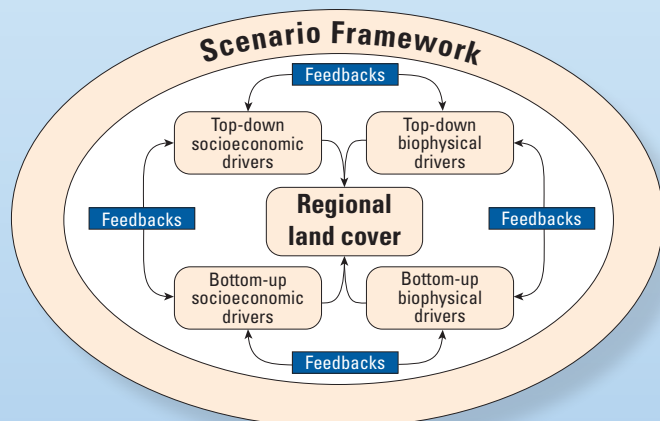
# Land-Use and Land-Cover Scenarios and Spatial Modeling at the Regional Scale

Anthropogenic land-use and land-cover change has altered a large part of the earth's ice-free land surface. Analyzing land-cover change is important because surface changes affect a wide variety of ecological processes. A thorough understanding of past and present land-cover change, in addition to an analysis of potential future change, is necessary in order to better manage potential effects on biodiversity, hydrology, carbon fluxes, climate change, and many other ecological processes.

The U.S. Geological Survey (USGS) is analyzing potential future land-cover change in the United States, using an approach based on scenario construction and spatially explicit land-cover modeling. Similar modeling is being used to model backwards in time. These efforts build on a long history within the USGS of serving as the Nation's provider of consistent land-cover data. In conjunction with USGS databases on historical and current land cover, scenario-based projections of land cover will provide policy makers and other stakeholders with tools to examine past, current, and future effects of land-cover change on ecological and socioeconomic processes.

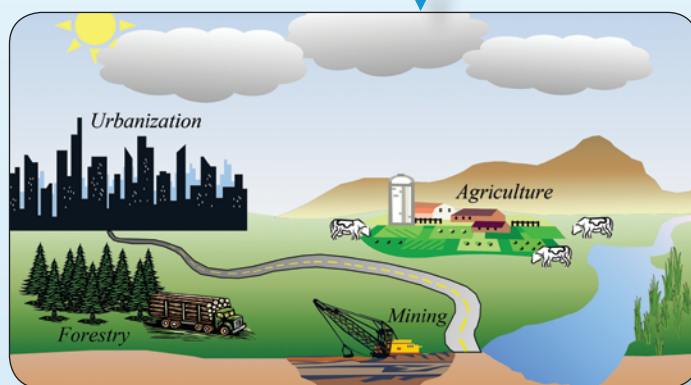
## Challenges for Land-Cover Modeling

Many factors determine how human beings modify the earth's landscape. Changes in land cover occur at the local level, yet broader scale socioeconomic and biophysical factors also affect how human beings make decisions to use the landscape (fig. 1). Projecting future land cover requires modelers to account for driving forces of land-cover change operating at scales from local ("bottom-up") to global ("top-down"), and how those driving forces interact over space and time. As a result of the high level of uncertainty associated with predicting future developments in complex socio-environmental systems, a scenario framework is needed to represent a wide range of plausible future conditions.



**Figure 1.** The USGS is analyzing land-cover change using a scenario-based framework that accounts for driving forces of change operating at multiple scales.

**Why Model Land-Use and Land-Cover Change?** Urban development, forestry, agriculture, mining, and other land uses can substantially alter the Earth's surface. Land use and the resultant change in land cover have important effects on ecological systems and processes. Projecting future land-cover change allows for the optimization and mitigation of potential consequences on numerous ecosystem services such as biodiversity, water quality, and climate.



**Biodiversity**—Land-use change can eliminate or substantially alter natural habitats. Species such as the Upland Sandpiper have drastically declined in regions where native grasslands have been lost (Kirsch and Higgins, 1976).



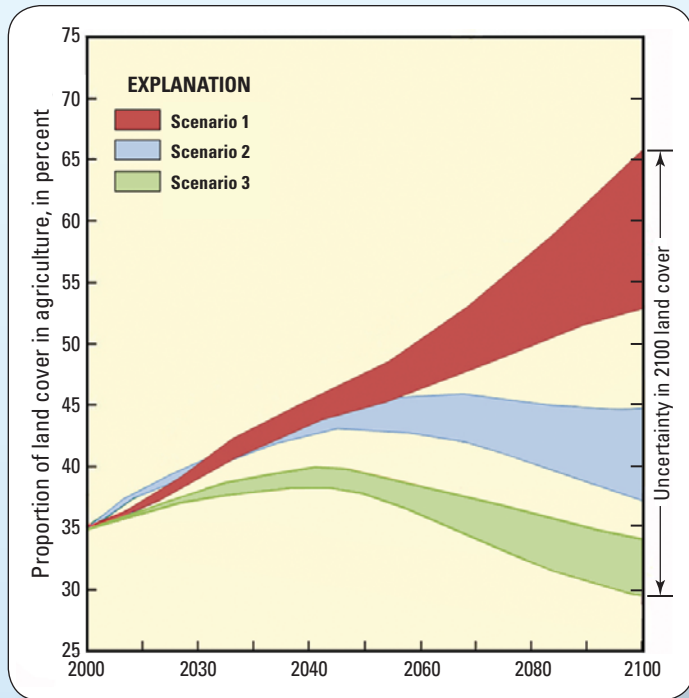
**Hydrology**—Land-management activities such as tillage or fertilizing farm fields can affect water quality. Land-use change alters runoff patterns, can change stream-flows, and can increase the likelihood of flood events.

**Carbon and Climate**—Land-use activities such as logging of forests or urban development can change surface reflectance and local weather patterns. Land-use change can also affect the carbon cycle, contributing to changes in atmospheric carbon dioxide and long-term climate.



## Scenario Development

Because of the inherent complexity of the environmental and socioeconomic processes that drive land-use and land-cover change, it is not possible to predict future land-cover change in the long-term with a great degree of certainty. Scenarios are a useful tool for examining future land-cover change. Rather than attempting to predict future conditions, a scenario-based

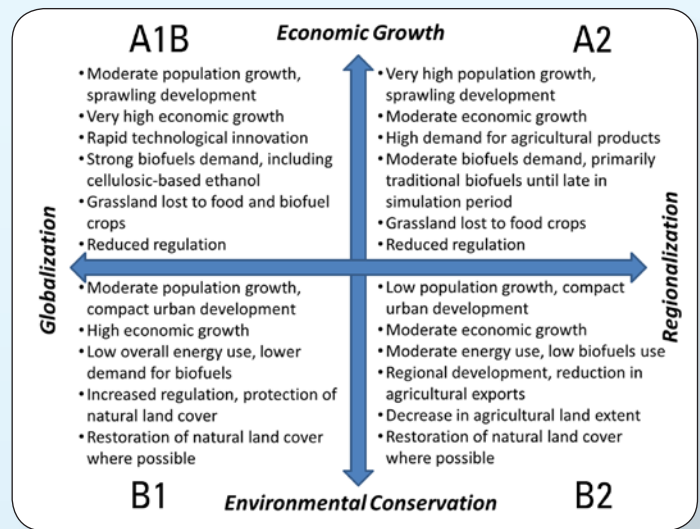


**Figure 2.** A scenario framework can be used to indicate uncertainties in future landscape conditions. For example, the use of multiple scenarios allows a researcher to frame the uncertainties in future trends in agricultural land use, with uncertainty increasing with time.

approach allows us to explore a wide range of possible future conditions resulting from a defined set of input variables that affect land-cover change. The use of scenarios helps to frame overall uncertainties and facilitates the examination of ecological and socioeconomic consequences of land-cover change across multiple future landscapes (fig. 2).

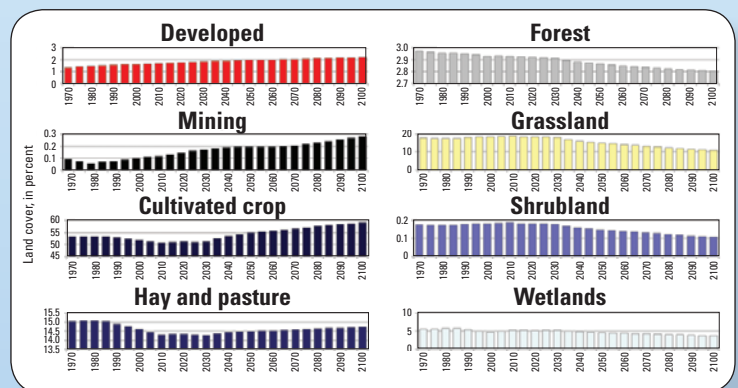
For land-cover modeling, scenarios are used to describe a unique set of socioeconomic and environmental conditions, as well as their effects on land-cover change. The scenarios being developed by the USGS include qualitative and quantitative components. The qualitative component consists of storylines, or narratives, describing future developments and interactions of drivers of regional land-cover change such as population growth, energy usage and demand, and economic growth. The quantitative component consists of proportions of modeled land-cover types at periodic future intervals.

Scenarios can be tailored to facilitate the analysis of a specific ecosystem process, or they can be based on existing scenario frameworks. Widely used scenario frameworks such as those developed to support the Intergovernmental Panel on Climate Change (IPCC) (fig. 3) have appeal for land-cover modeling, but as global scenario frameworks, they are not directly



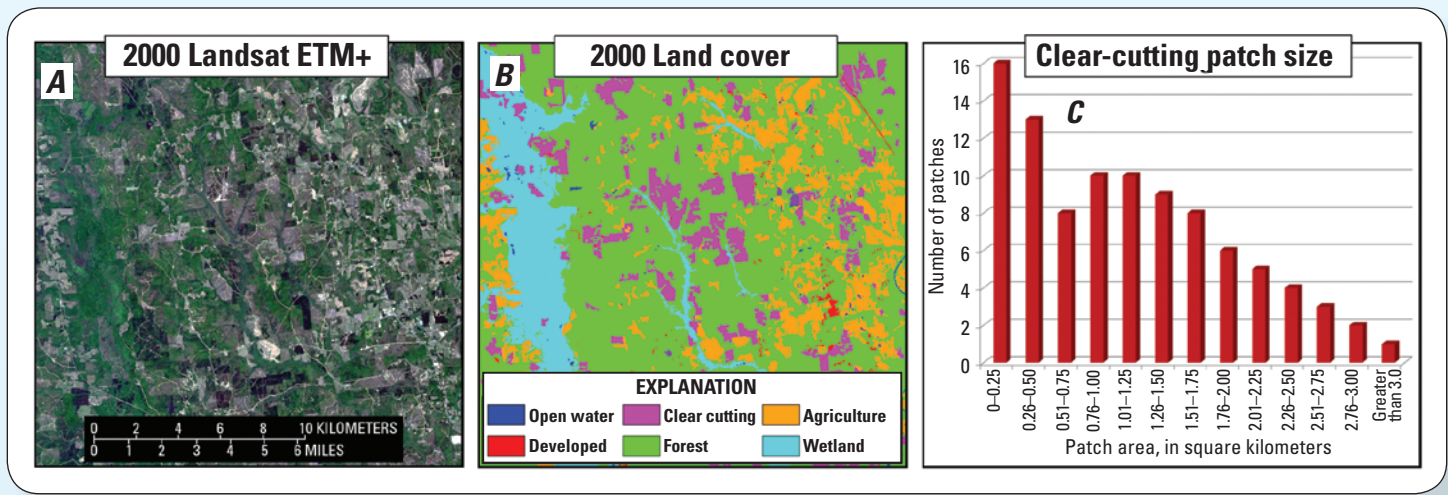
**Figure 3.** The International Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) framework provides a set of four primary scenario families, oriented along two axes: 1) economic growth vs. environmental conservation, and 2) globalization vs. regional growth. The scenarios include assumptions on socioeconomic factors that drive land-cover change, and can be used to construct regionally specific land-cover storylines.

applicable to regional land-cover modeling. The USGS is producing scenarios consistent with IPCC scenario assumptions through a unique scenario-downscaling procedure (Sleeter et al. 2012). Storylines are constructed by downscaling IPCC scenario assumptions to hierarchically nested ecological regions. Quantitative proportions of land cover are developed through the use of 1) qualitative storylines, 2) existing model results from researchers associated with the IPCC, 3) regional land-cover histories from USGS, 4) feedback from land-cover experts, and 5) a scenario-downscaling model. Regional scenario workshops are conducted to integrate these components and produce quantitative, regionally specific proportions of future land-cover change at 5-year intervals into the future (fig. 4).



**Figure 4.** Qualitative storylines are used in conjunction with a quantitative spreadsheet model to produce quantified scenarios that consist of proportions of land-cover classes for future time periods. Quantified information on land-cover proportions serve as a land-cover “prescription” for a spatially explicit land-cover model.





**Figure 5.** The FORE-SCE model relies heavily on historical land-cover information. *A*, The Landsat Enhanced Thematic Mapper (ETM+) image in this figure represents a 20km by 20km area in western Alabama. *B*, Landsat serves as a data source for mapping land cover. The magenta patches in the 2000 land-cover image represent patches of forest that recently have been clear-cut. *C*, A distribution of typical patch sizes for forest clear-cuts in the region can be used to parameterize FORE-SCE and produce realistic forest cutting patterns in the future.

## The Forecasting Scenarios of Land-Cover Change (FORE-SCE) Model

The FORE-SCE model was developed by USGS to produce spatially explicit maps of future land-use and land-cover change (Sohl et al. 2012a; Sohl et al. 2012b). FORE-SCE is designed to produce regional land-cover projections at a moderately high spatial resolution (typically 250-meter grid cells) for a complete suite of land-cover types. FORE-SCE has been used to produce land-cover projections based on extrapolations of historical land-cover trends, projections based on multiple future scenarios, and “backcast” land-cover maps for historical periods. Additionally, the modeling framework has the flexibility to model most types of landscapes at a variety of spatial or thematic resolutions.

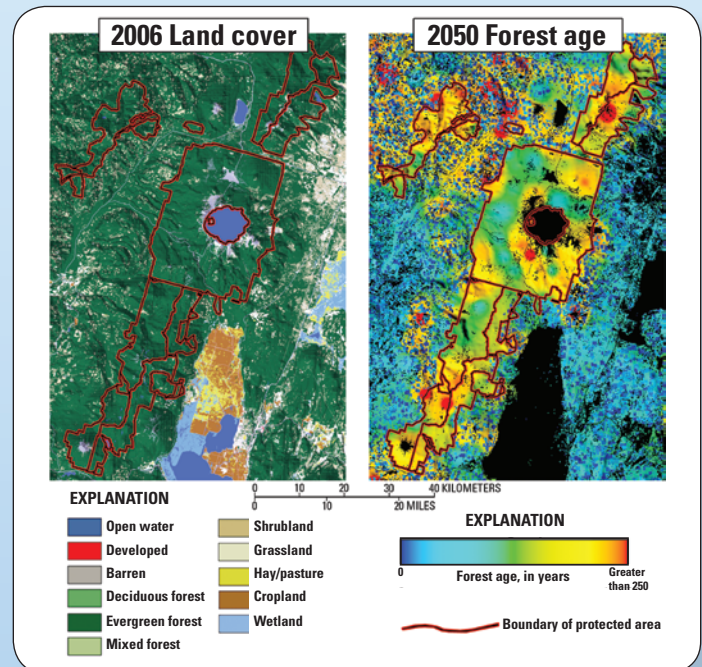
FORE-SCE uses two distinct but linked components, “demand” and “spatial allocation.” The demand component provides regional, annual proportions of modeled land-cover classes; in effect, the demand component is a regional prescription for future proportions of land-cover change. Scenario development provides “demand” for future projections, whereas reconstructions of regional land-cover history provide demand for backcasting.

The proportions of land-cover demand serve as input into the spatial allocation component. The spatial allocation component of FORE-SCE was designed to take advantage of the land-cover data and research of USGS. FORE-SCE’s unique patch-based spatial allocation procedure uses historical data to parameterize the model and produce new land-cover patches that mimic realistic patch sizes for a given land-cover type (fig. 5). The placement of change is dictated by the development of statistical “suitability” surfaces for each land-cover type. Suitability surfaces are constructed through analyses of empirical relations between existing land-cover patterns and a wide array of spatially explicit data such as climate, soils, topography, or population data. Individual patches of land-cover change are placed on the landscape in suitable locations, with patch allocation continuing until scenario or backcasting “demand” is met.

## Forest Structure and Protected Lands

The FORE-SCE model uses a spatial database of protected lands to eliminate or control the types of modeled changes occurring on protected landscapes, such as national parks or wilderness areas. Decision rules regarding protected lands can be tailored to match the storyline of a given scenario.

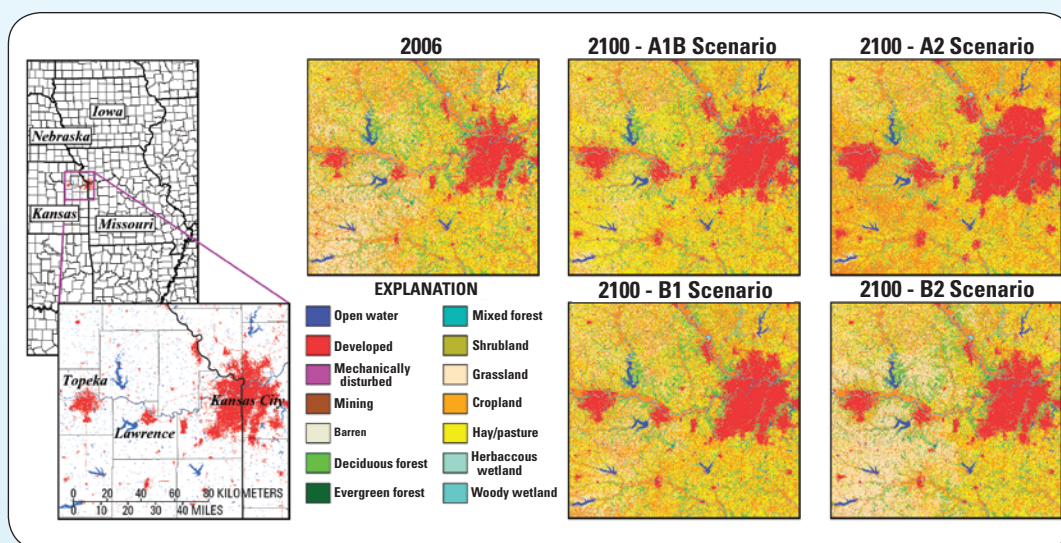
To better inform applications related to carbon or biodiversity, FORE-SCE also models forest age. Current forest age is mapped from sample-based forest data or remote-sensing data. As the model runs, undisturbed forest patches “age” with each yearly model iteration, while forest age is reset to zero whenever a forest patch is disturbed (i.e., clear-cut) (fig. 6).



**Figure 6.** Modeling forested lands near Crater Lake. In land-cover simulations to 2050, the protected lands of Crater Lake National Park and surrounding wilderness areas result in oases of older forest, surrounded by a more heavily fragmented and younger forest landscape.

## The Final Product

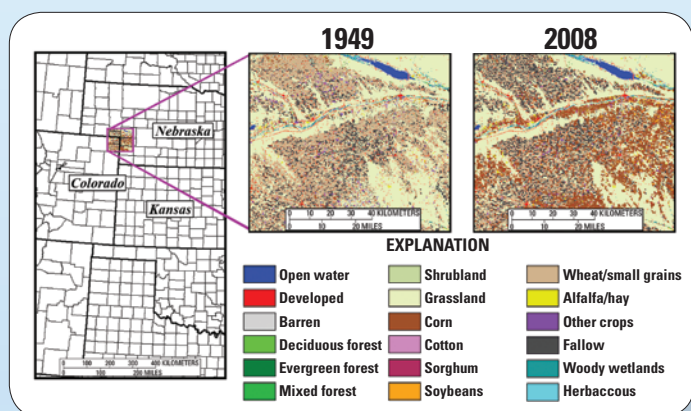
In an uncertain future, a scenario-based framework allows for analysis of multiple potential future landscapes. Results from four IPCC scenarios are shown in figure 7 for an area near Kansas City, Missouri. Urban expansion is prevalent in all scenarios, but is substantially greater in the economically focused A1B and A2 scenarios. Agricultural lands expand in all scenarios except B2, which is the only scenario to preserve most of the remaining natural grassland cover.



**Figure 7.** Modeled land-cover change from 2006 through 2100 near Kansas City, Missouri.

## Back to the Future

The same techniques used for producing future projections of land-cover change are also being used to produce historical land-cover maps. Agricultural census data, population census data, and other historical data sources are used to reconstruct historical proportions of mapped land-cover types, whereas the FORE-SCE model creates spatially explicit land-cover maps for the past (fig. 8).



**Figure 8.** In this part of the western Great Plains, backcasting was used to depict substantial agricultural change from 1949 to 2008. The introduction of center-pivot agriculture, starting in the 1950s, has resulted in a tremendous expansion of agricultural land use, and changes in crop type.

## USGS Land-Cover Databases:

The USGS Land Cover Trends project has mapped historical land-cover change from 1973 to 2000 using the Landsat satellite image archive. The National Land Cover Database (NLCD) provides consistent, periodically updated maps of land cover for the United States, with mapped dates for 1992, 2001, 2006, and 2011. The Landscape Fire and Resource Management Planning Tools Project (LANDFIRE) provides a suite of landscape attributes to support land managers and modelers. In combination with backcast and forecast land-cover products, the USGS can provide consistent land-cover data for historical, current, and future time frames to support a variety of research applications.

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