Introduction: Overview of LUCC trends, consequences, and definitions

August 28, 2007

Plan for today

- Introduction – myself
- Course logistics
- Introductions – yourselves
- Questions
- Trends in LUCC and their consequences
- Modeling definitions and classifications
- Drivers and consequences of LUC in Northern Virginia

My background

- Graduate training in environmental and resource economics
- Post-doc at CIPEC, interdisciplinary
- Major research areas: land-use modeling, human/environment interactions, complexity theory
- Many current/ongoing research projects
- Other important info

Course logistics (see syllabus also)

- Description: Review of fine-scale empirical models of land-use and land-use change; hands-on test drives of models when possible
- Format: lecture, student presentations, lab sessions when possible, and discussion.
- Office hours: Wednesday and Thursday 3-4; and by apt.

Goals of the course for students

- Critically review and interpret a land-use model
- Understand strengths, weaknesses, and limitations of particular models
- Understand what techniques can be applied to a given data set
- Understand what techniques are appropriate for particular research questions
- Obtain hands-on experience with models and some possible modeling tools

Desired prerequisites

- Introductory GIS class (including spatial data structures)
- Understanding of basic regression analysis
- Ability to follow and interpret algebraic manipulations of systems of linear equations
- Some social science background
- Hard-working students have succeeded in the past without these prerequisites

Course Requirements and Grading

- Short writing assignments, lab reports, and participation in class discussions (25%) (can make up 2 missed assignments)
- In-class presentations of required readings (25%) (make sure you can present your chosen article(s))
- Term paper (25%)
- Take-home final exam (25%)

(Policy details on syllabus)

Course web sites

- Public--resources and lectures (note: new lecture notes are likely to be posted at the last minute http://mason.gmu.edu/~dparker3/lumta_04/lumta.html
- Password-protected web site--May or may not set up Blackboard
- Please e-mail me your assignments and paper presentation slides

Structure of the class

- Intro: this lecture, model overviews, urban and rural drivers of LUCC
- Evaluating model performance & map comparison
- CA models
- Statistical models
- Optimization models
- Multi-Agent System models
- Integrated models
- Comparisons, open questions, and student presentations

Break for questions, introductions, and break

Trends in LUCC and their consequences

Land-use modeling techniques and
applications, Lecture 1
Dawn Parker, George Mason University

Land-cover vs. Land-use (Turner et al. 1995)

Land Cover: "the biophysical state of the earth's surface and immediate subsurface"

Land Use: "involves both the manner in which the biophysical attributes of the land are manipulated and the intent underlying that manipulation - the purpose for which the land is used."

We measure land cover, but model land use!

Land-use conversion vs. modification (Lambin, Geist, Lepers 2003)

- Conversion: replacement of one category by another
- Modification: changes that affect the character without changing the classification (example: ag intensification, selective logging)
- Both are important examples of land-use change
- Discrete representation of data has led to too much emphasis on conversion vs. modification
- Measuring and representing modification is hard
- Examples of both?

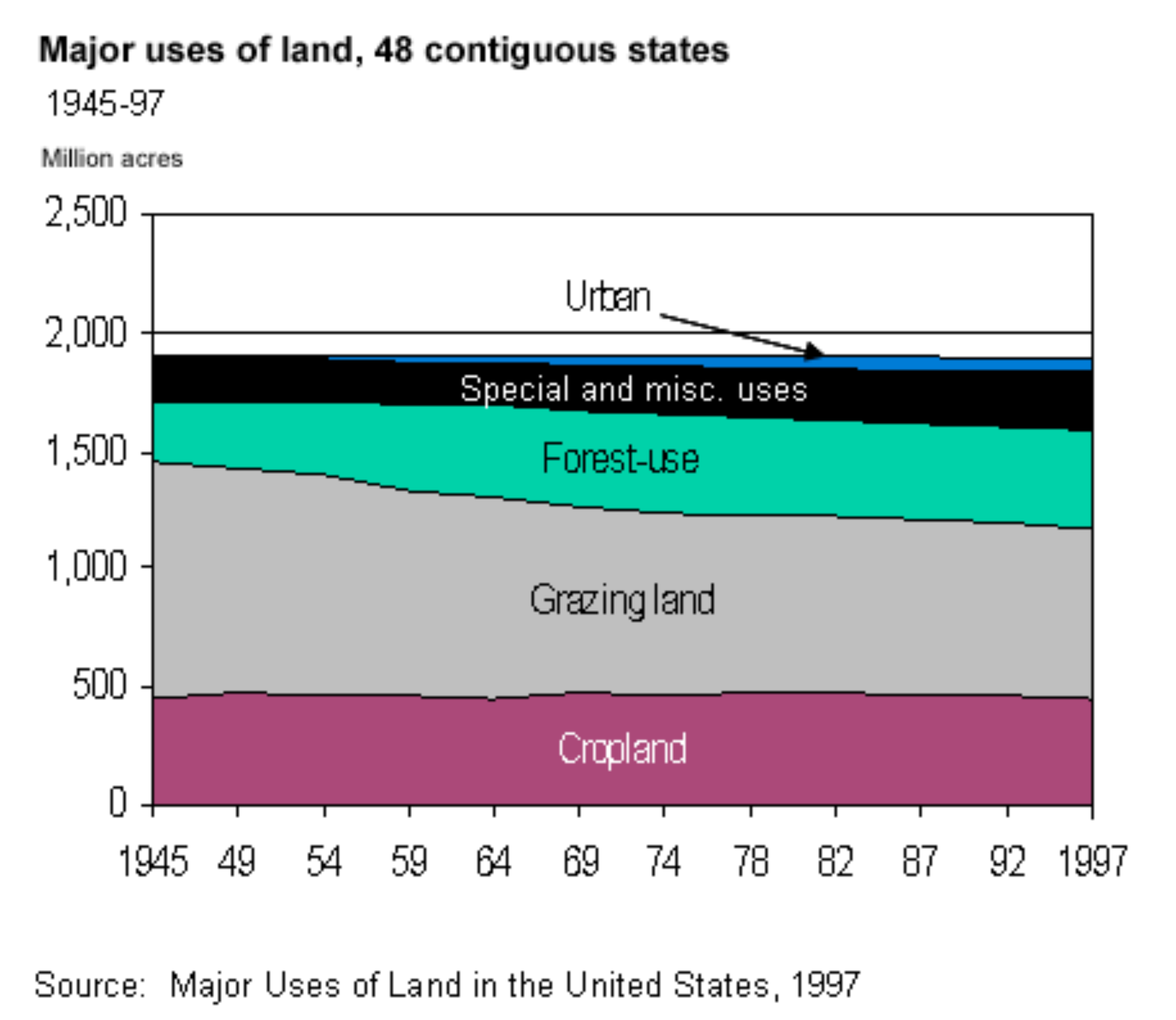
Global trends in land-use change (Turner et al., 1995)

- From 1700 to the mid-1980s, cropland area has increased from 392% to 466%, replacing forest, grassland, and wetlands. Cropland is now decreasing in developed countries and increasing in developing countries.
- Net global area of irrigated cropland has increased by 2,400% over the last 200 years
- Worldwide forest/woodland/tree cover has decreased by about 15% since pre-agricultural times (Lambin states 40%)
- Reforestation occurring in Europe and regions of the US, while deforestation due to logging, cropping, and livestock grazing is occurring in tropical regions

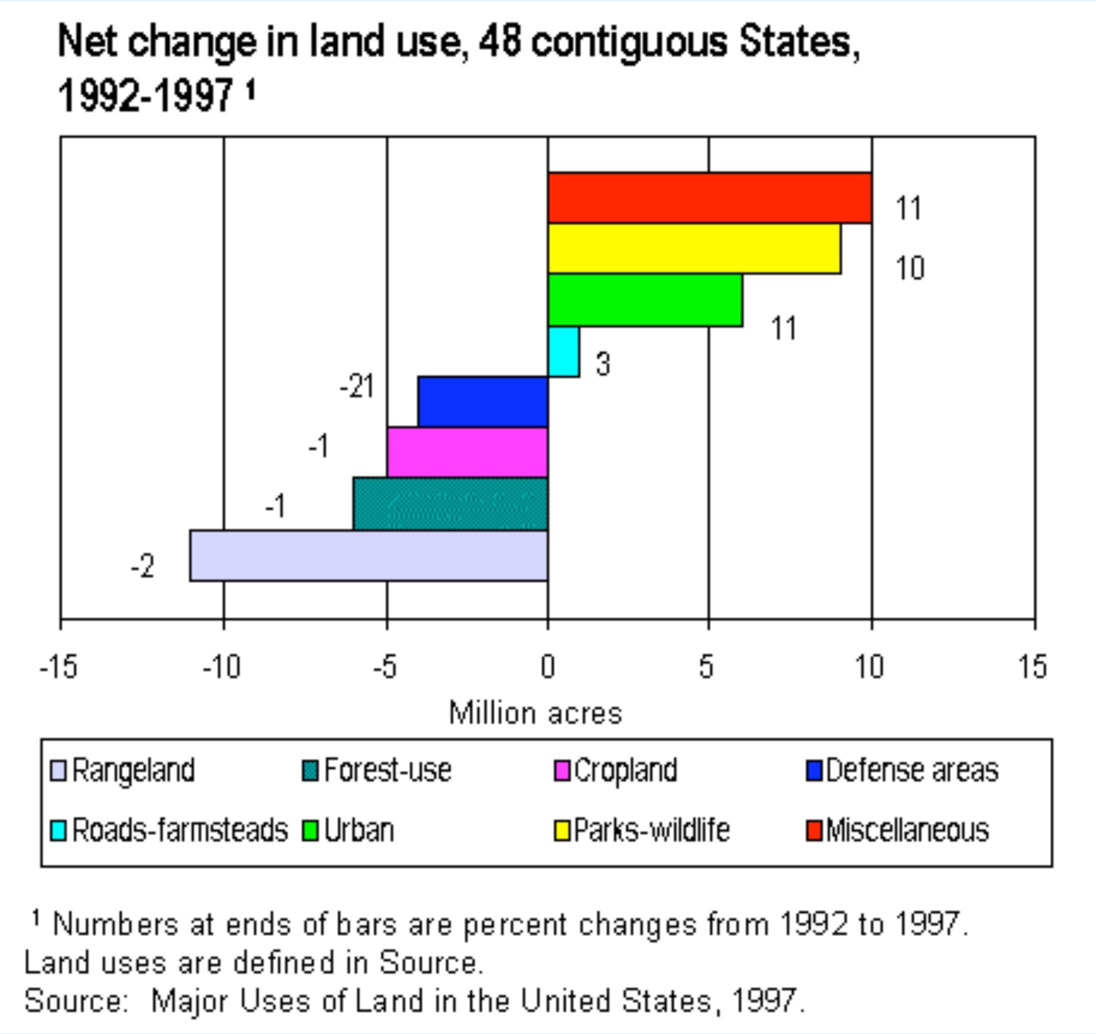
Most rapid changes recent changes (Lambin, Geist, Lepers 2003)

- Globally, forest cover has decreased by around 5% per year from 1990-1997
- Rates are highest in Southeast Asia and Latin America; lower in Africa
- From 1961-96, food production has increased faster than land under cultivation (1.97/1.098), but irrigated land and fertilizer use have also increased more.
- Built-up or paved areas occupy around 2-3% percent of land, but urban footprints and sprawl have larger impacts
- Most populated cites are along coastlines and waterways. Fastest growing cities are in developing countries.

Trends in the US (Vesterby and Krupa, 2001)



Net change in land use, US (Vesterby and Krupa, 2001)



Social consequences of land-use change

- **Economic**: property values, commuting costs, level of business and industrial activity, mix of outputs, efficiency of land use, future income potential from land
- **Quality of life**: environmental amenities recreational opportunities, social interactions, accessibility to work, school, shopping, etc., health
- **Political**: changes in relative political influence of regions, changes in makeup of stakeholder groups, trigger of political action for stakeholder groups

Environmental/Ecological consequences of land-use change

- Changes in biodiversity
- Changes in habitat structure and species abundance
- Changes in ecosystem function/services
- Land degradation/restoration
- Changes in hydrologic networks
- Transport and fate of pollutants
- Global climate impacts

Modeling Definitions and Classifications

“Model” (from Briassoulis, 4.1)

- “the formal representation of some theory of a system of interest (Wilson 1974, 4)”
- An abstract, symbolic representation of a real-world system, potentially based on broader theory or concept
- "an idealized and structured representation of the real" (Johnston et al. 1994, 385, 622)
- "an experimental design based on a theory" (Harris 1966, 258; see also, Romanos 1977, 135)

“Theory” and “model” are not equivalent terms.

Theoretical vs. empirical models

- Distinction often not clarified in reviews of LUCC models, *especially* in the economics literature
- Theoretical models are based on abstract or algebraic representations and are not designed to apply to real-world cases
- Empirical models are structured and parameterized to apply to, or reflect a particular time and place

Deductive and Inductive (Parker, Berger, Manson 2002a, section 1.3.1)

- Deductive models: “use a logical procedure to derive some very specific results from basic and unquestioned assumptions (axioms)”.
- Inductive models: “filter patterns from empirical data to identify some general laws behind them”

Types of models

- Analytical: based on a formal and complete mathematical (algebraic) representation of a system. Generally used *deductively*.
- Simulation: based on a mathematical representation of the behavior of individual entities in the system and their interrelationships. Potentially used both *deductively* and *inductively*; controversy here
- Statistical: estimated from real-world data assuming sampling from an uncertain distribution (stochasticity). Use *inductively*.

These models are generally complementary.

Tests for spatial representation (M. Goodchild, in Parker, Berger, Mason 2002a, section 2.2.1)

- The *invariance* test: spatially explicit models (SEM) are not invariant under relocation of the objects of study
- The *representation* test: SEM include representation of location in their implementations
- The *formulation* test: concepts such as location or distance appear directly in the model, in algebraic expressions or behavioral rules
- The *outcome* test: spatial structures of inputs and outputs are different: it modifies the landscape on which it operates

Scope of LUCC models (from Parker, Berger, Manson 2002a and b)

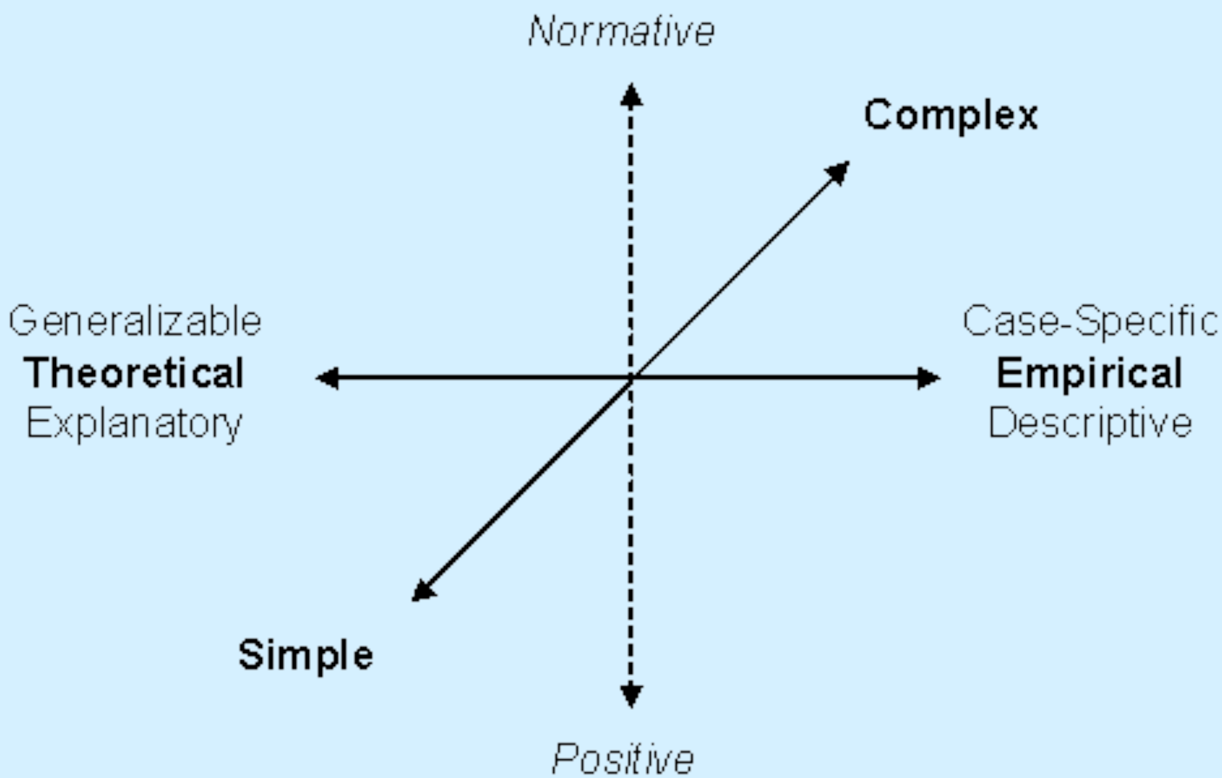


Figure 1. Continua for Categorizing Agent-Based Models

Uses of LUCC models (Briassoulis 1999, Parker, Berger, Mason 2002a and b)

- Explanatory (less so for empirical models)
- Exploratory
- Decision support/policy analysis
- Impact or scenario analysis
- Tell you what *won't* happen (Berger)
- Prediction/forecasting (MANY caveats here!)
- Prescriptive (normative: tell you what *should* happen)

Questions to answer when building a LUCC model

1. What is the model for?
2. What is the ideal spatial and/or temporal representation (structure and resolution) for the model?
3. What data are available for model construction?
4. What real-world spatial, temporal, and behavioral processes do you strive to represent?
5. What is the minimum level of complexity for the model?
6. What modeling methodologies are most appropriate?

Additional questions (less focus in this class)

7. What software will be used, and how will software be integrated?
8. What techniques will be used for calibration, verification, and validation?
9. How will model input data, code, and results be handled?

Classifications of Models by technique

Briassoulis:

- Statistical and econometric models
- Spatial interaction models (not covered)
- Optimization models
- Integrated (hybrid) models

I add two more:

- Cellular automata
- Multi-agent system models

Cellular Automaton Models

- CA models are dynamic simulation models, where cell transitions are based on the state of the current cell and the states of neighboring cells.
- “Neighbors” can be very broadly defined, and may include multi-scale influences
- Transitions may also depend on cell history (Markov models)
- Cellular structures are generally grids, but can be any cellular structure, in principle

Some strengths and weaknesses of cellular automaton models

- Strengths:
  - Models are very strong at representing local spatial processes
  - Models tend to do well at replicating real-world spatial patterns, especially fractal structures
- Weaknesses:
  - Models may place too much emphasis on local interactions
  - Models are not strong at representing behavior, especially when agents are mobile
  - Often, models require projections of rates and quantities of change to run

Statistical/Regression Models

- These models find a set of best-fit model coefficients that express a statistical relationship between a *dependent variable* (often land use or cover) and a series of *independent variables* (representing drivers of LUCC)
- Models produce a transition probability, conditional on states of independent variables
- Models are only dynamic when some set of rules is used to generate transitioned landscapes using those estimated probabilities

Some strengths and weaknesses of spatial statistical/regression models

- Strengths:
  - Models provide information on key drivers of change
  - Spatial and temporal lags can be incorporated
  - Data can be entered at multiple scales
- Weaknesses:
  - Models themselves don’t produce projections of spatial change
  - Arbitrary transition rules may lead to different change projections for the same data
  - Simulations of change require projections of rates and quantities of change
  - Models may have little out-of-sample power

Dynamic Optimization Models

- Optimization models derive an ideal or optimal solution for a given system, based on a quantitative objective
- Dynamic optimization models incorporate temporal lags and/or forward looking behavior
- Models can be positive (modeling how things are), under the assumption that system agents (generally animals or humans) behave as if they optimize
- Models are most often normative (modeling how things should be) and used for policy
- Spatial dynamic optimization models are often difficult to solve

Some strengths and weaknesses of dynamic optimization models

- Strengths:
  - Great for representing temporal dynamics
  - Good models of behavior in certain contexts
  - Useful for creating benchmarks/goals for policy
- Weaknesses:
  - Spatial aspects are incorporated with difficulty
  - Can easily become difficult or impossible to solve
  - For normative models: sometimes knowing the optimal outcomes doesn’t help if we don’t know how to get there

Multi-agent/Agent-Based Models

Spatial agent-based models are simulation models consisting of:

- A collection of autonomous decision-making agents
  - Agent: a self-directed object that can satisfy internal goals through actions based on a set of internal rules or strategies.
  - Agent dynamics behaviors (*methods*) can include discrete rules/actions, movement and change.
- An interaction environment (landscape model)
- Interdependencies among agents, their environment, or both
- Rules governing sequencing of actions and information flows

Some strengths and weaknesses of agent-based models

- Strengths:
  - Models can incorporate important sources of spatial, temporal, and behavioral complexity
  - Very strong format for integrated models (human-environment interactions
  - Potentially strong for cross-scale feedbacks
  - Can link human actions to landscape pattern
- Weaknesses:
  - Can be difficult to map and communicate model mechanisms and outcomes
  - Error propagation is potentially very high
  - Can be very data hungry

Role of GIS in LUC modeling:

- Largely data management, generation of input layers, and visualization of output
- Integrated models are rare due to technical issues
- Very strong interest in more integration of GIS and modeling: ESRI workshop and volume, efforts to develop open GIS and link to models, land-change modeler in IDRISI and ArcGIS
- Data representation (raster vs. vector) affects options for modeling and model precision

Raster vs. Vector Modeling

- Resolution of the data is often defined by raster images
- Parcels have vector boundaries

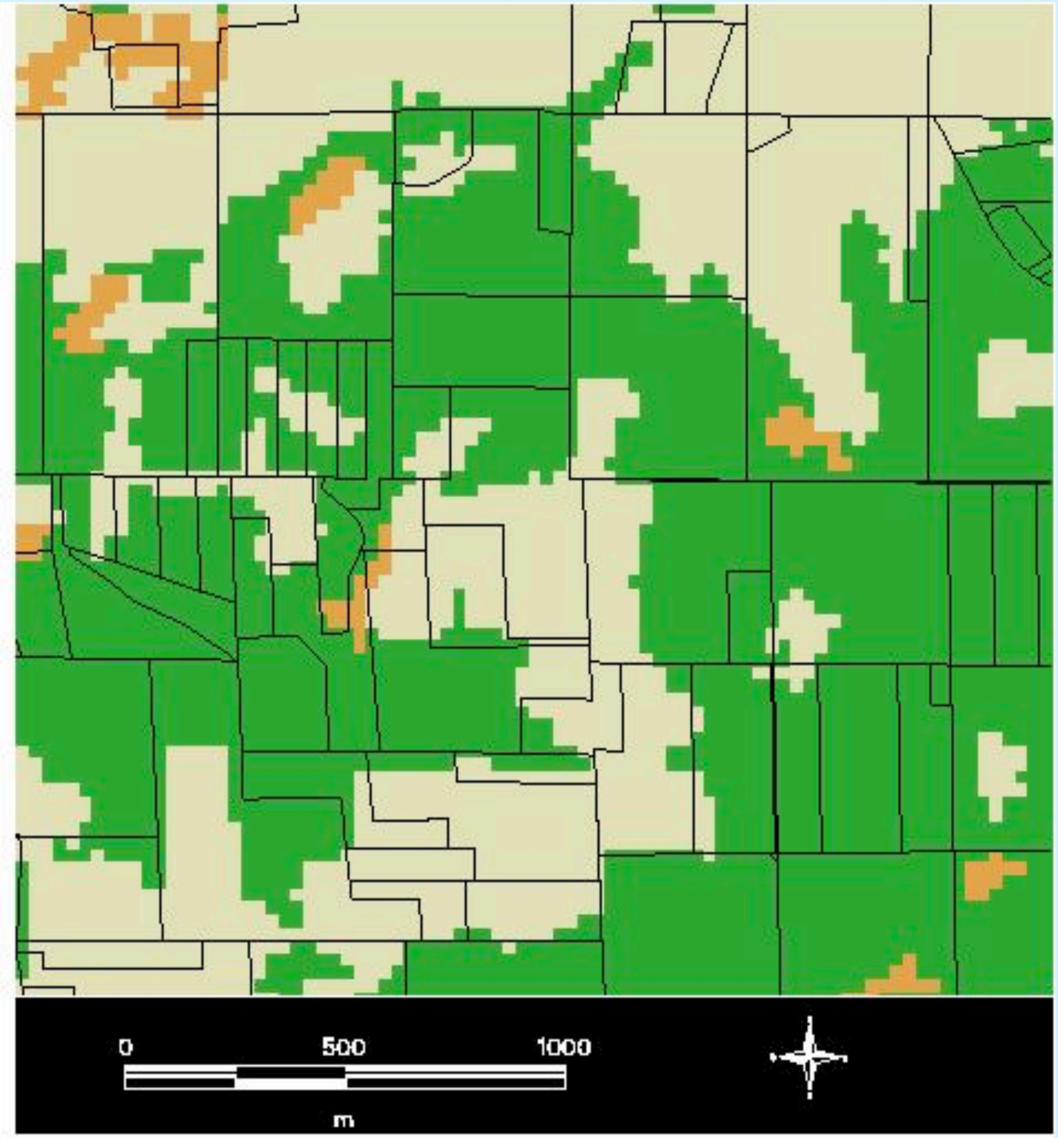


Image credit: Tom Evans, Indiana University

Raster vs. Vector Modeling, cont.

- At what scale do agents make decisions? -- somewhere in between!
- Vector modeling:
  - less computationally intensive (perhaps)
  - More difficult to program outside a GIS
  - More accurate data representation
- Raster modeling:
  - Higher computational and data storage demands (perhaps)
  - Easier to program outside a GIS
  - Difficulty representing topological relationships inside GIS
  - Rasterization introduces more errors

Articles for presentation

- Top 4 choices **due by 9 AM on Sept. 10.** Rank most to least preferred (1-4)
- Use article selection spreadsheet
- Paper choices come from readings NOT marked "not for student presentation," weeks 5-12.
- You must choose papers from at least 2 modeling methodologies. You can do 1 long or 2 short presentations.
- Choose papers from the syllabus, not complete class bib.
- I will post presentation guidelines and we will discuss them later.

Notes for next week's readings:

- **Agarwal et al**: Their definitions of scale are fine, but their "geographers" definition of scale is more of a cartographers. See Gibson, Ostrom, and Ahn for a useful reference on scale. Pay attention to the relationship between scale and hierarchy, and the discussion of scale mismatch. Don't worry about the details of the particular models that they discuss: just get a sense of the framework and issues. Can you classify these models as analytical, simulation, and statistical?

Notes for next week's readings

Briassoulis: This reading will provide you will some background of the theoretical foundations of land-use modeling. Further, there is a nice discussion of disciplinary trends and the need for integration among disciplines.

Verburg et al.: This is a nice recent review that will give you both a sense of important modeling issues and an overview of different applications.

Short writing assignment

- Describe a case of land-use change that interests you. What kind of land-use change has occurred? What do you think are some of the possible causes? What do you think are some possible effects?
- 300 words minimum, 500 max.
- E-mail to me by 9 AM on Wed. Sept. 3.