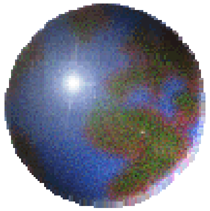

16. Spatial Modeling with GIS

Geographic Information Systems and Science

SECOND EDITION

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Outline

- Why model?
- Types of model
- Technology for modeling
- Multicriteria methods
- Accuracy and validity

What Is a Model?

- A *data* model provides a template for representing the real world in a GIS
  - For modeling how the world *looks*
- This chapter is about models that represent real processes
  - Or how the world *works*

Spatial Models

- Represent variation over the Earth's surface
  - Produce results that change when the locations of features change
  - GIS provides a suitable platform
- Manipulate geographic information in multiple stages
  - Representing either a single point in time, or predictions about future points in time

Spatial and Temporal Resolution

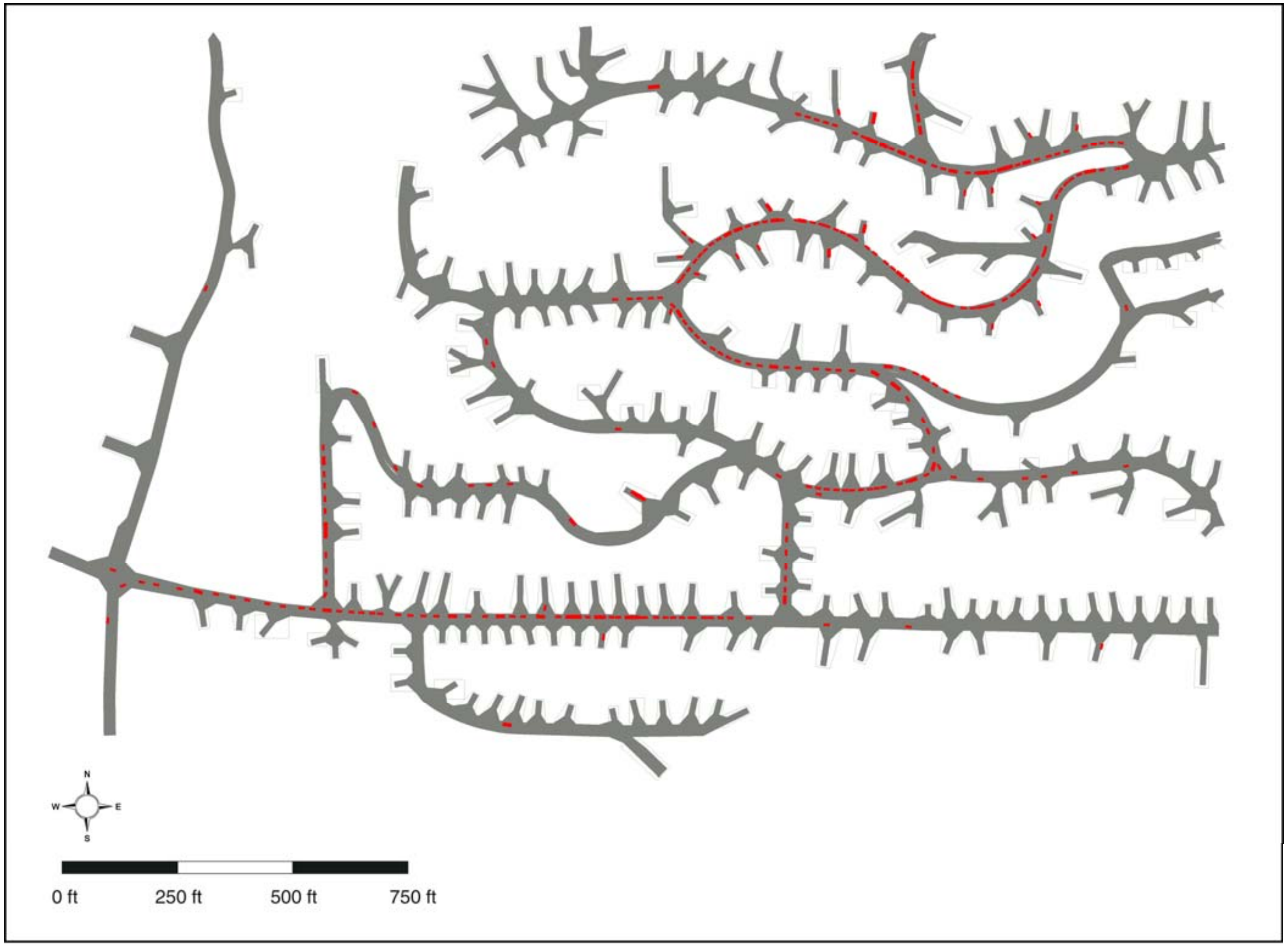
- Models work at defined levels of resolution
  - All variation at finer resolutions is ignored
  - The model must leave the user uncertain to some degree about the real world
  - A model of a dynamic process has a temporal resolution equal to the size of its time steps

The Value of Models

- They allow experiments to be conducted on simulated systems, rather than the real thing
  - Cheaper, less invasive
- They allow alternative scenarios to be evaluated
  - Different policy options and their impacts on the future

To Analyze or to Model?

- Analysis is static
  - Revealing what would otherwise be invisible
  - Looking for anomalies, patterns
  - Leading to hypotheses about systems
- Modeling can be dynamic
  - Testing hypotheses about systems
  - Evaluating alternative scenarios

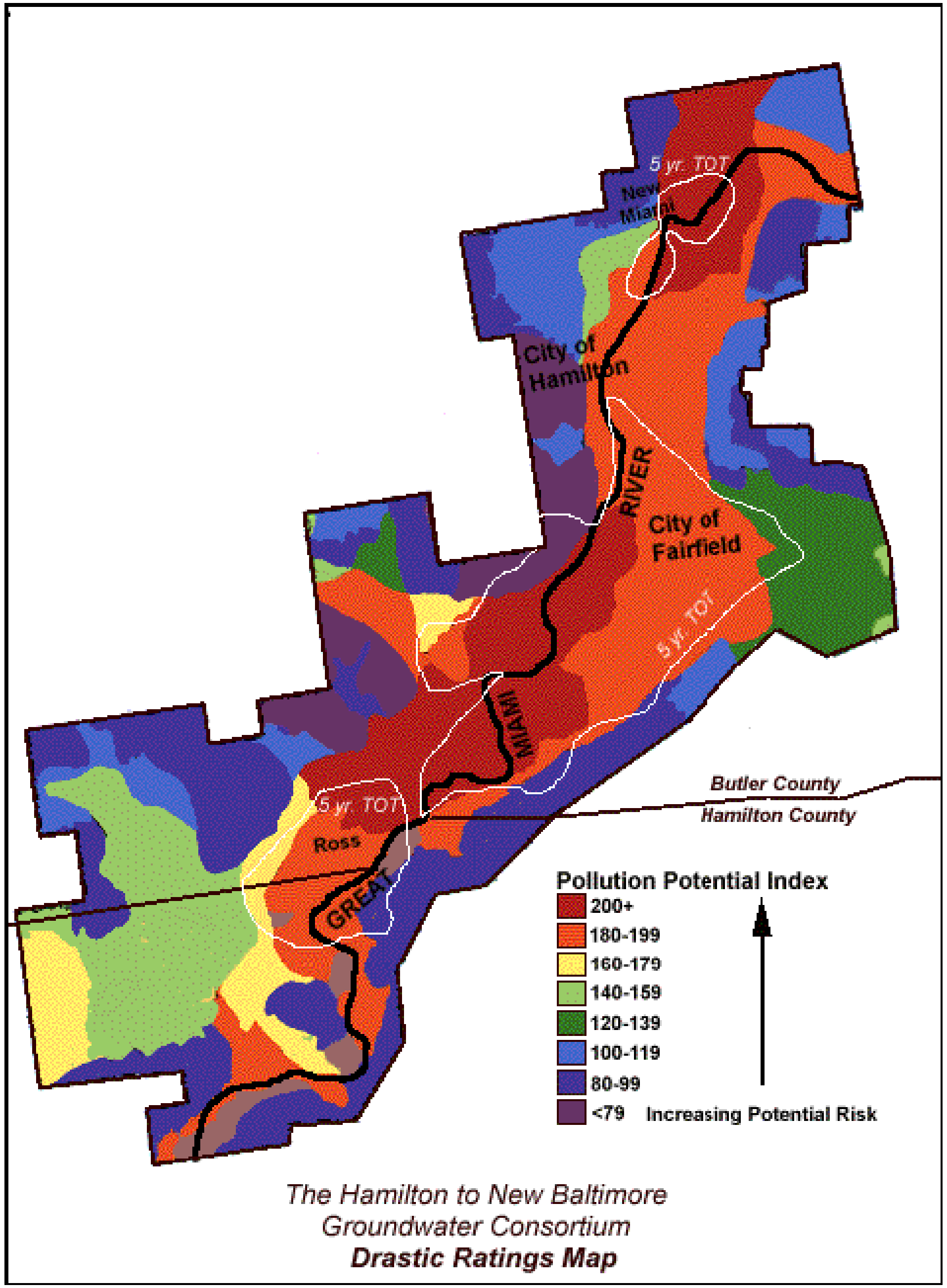


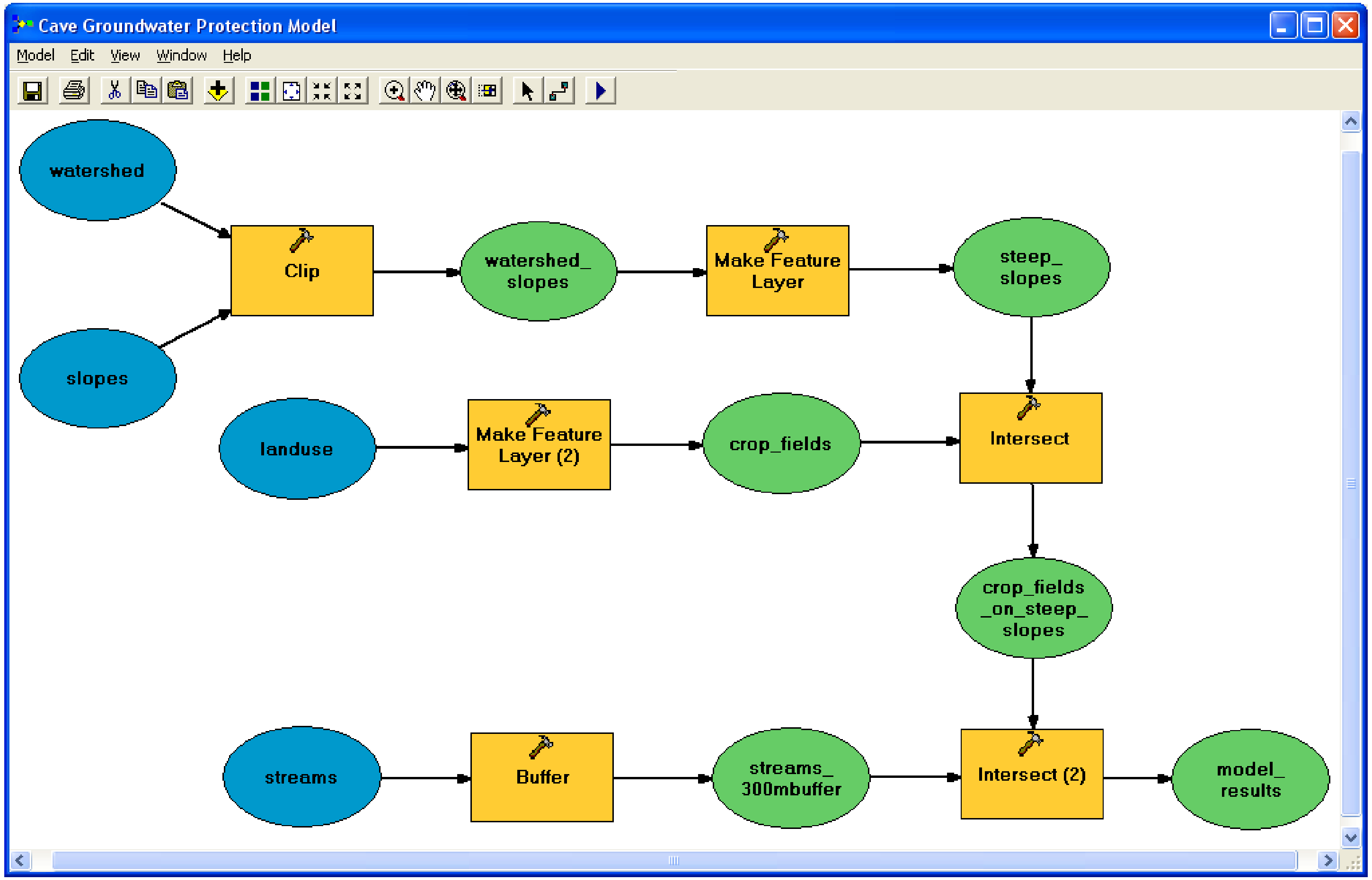
Simulation of driver behavior in an evacuation of the Mission Canyon area of Santa Barbara, California, U.S.A., some minutes after the initial evacuation order. The red dots denote the individual vehicles whose behavior is modeled in this simulation.

Types of Model

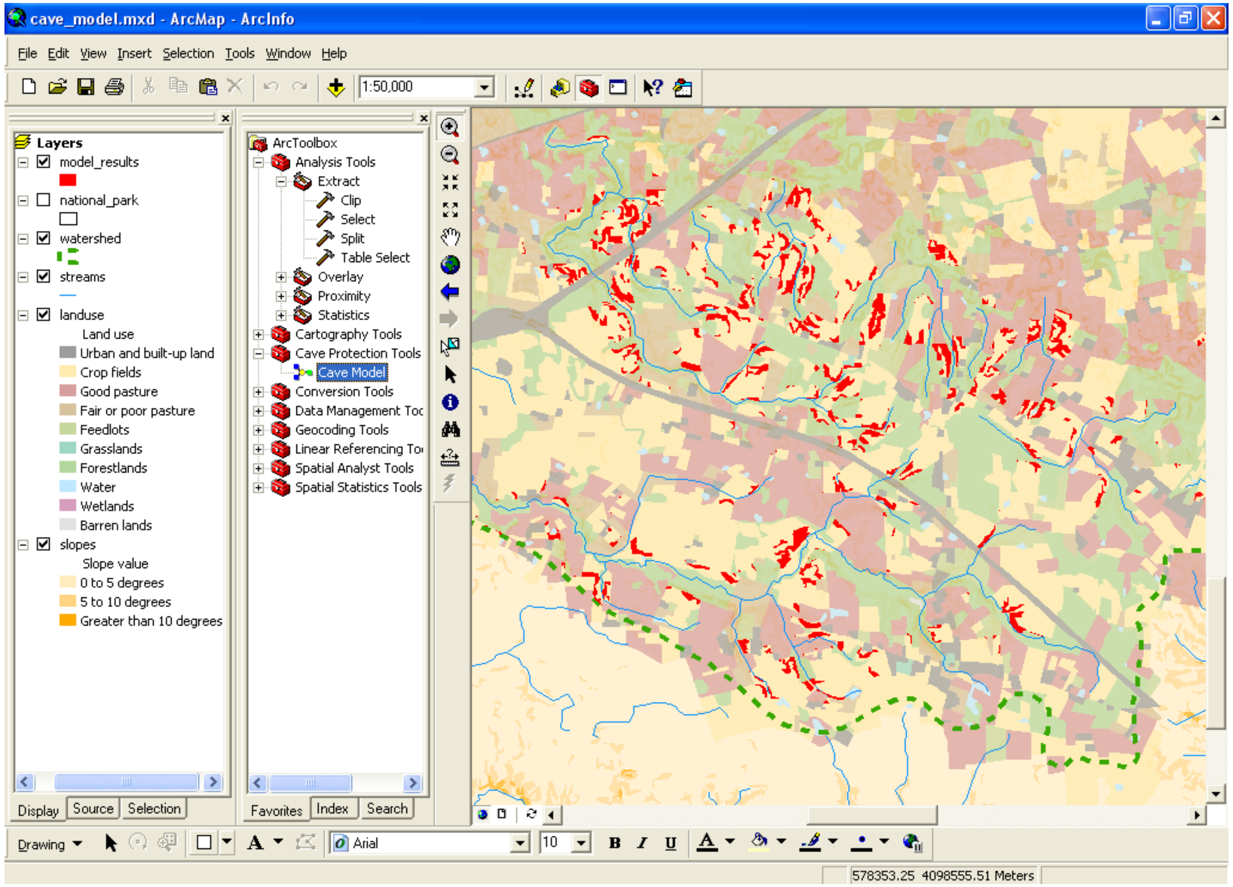
- Static models and indicators
  - Take multiple GIS inputs, and compute useful indices
  - The Universal Soil Loss Equation
    - predicting erosion from five inputs
  - The DRASTIC groundwater vulnerability model
    - predicting an index of vulnerability to pollution

The results of using the DRASTIC groundwater vulnerability model in an area of Ohio, U.S.A. The model combines GIS layers representing factors important in determining groundwater vulnerability, and displays the results as a map of vulnerability ratings.





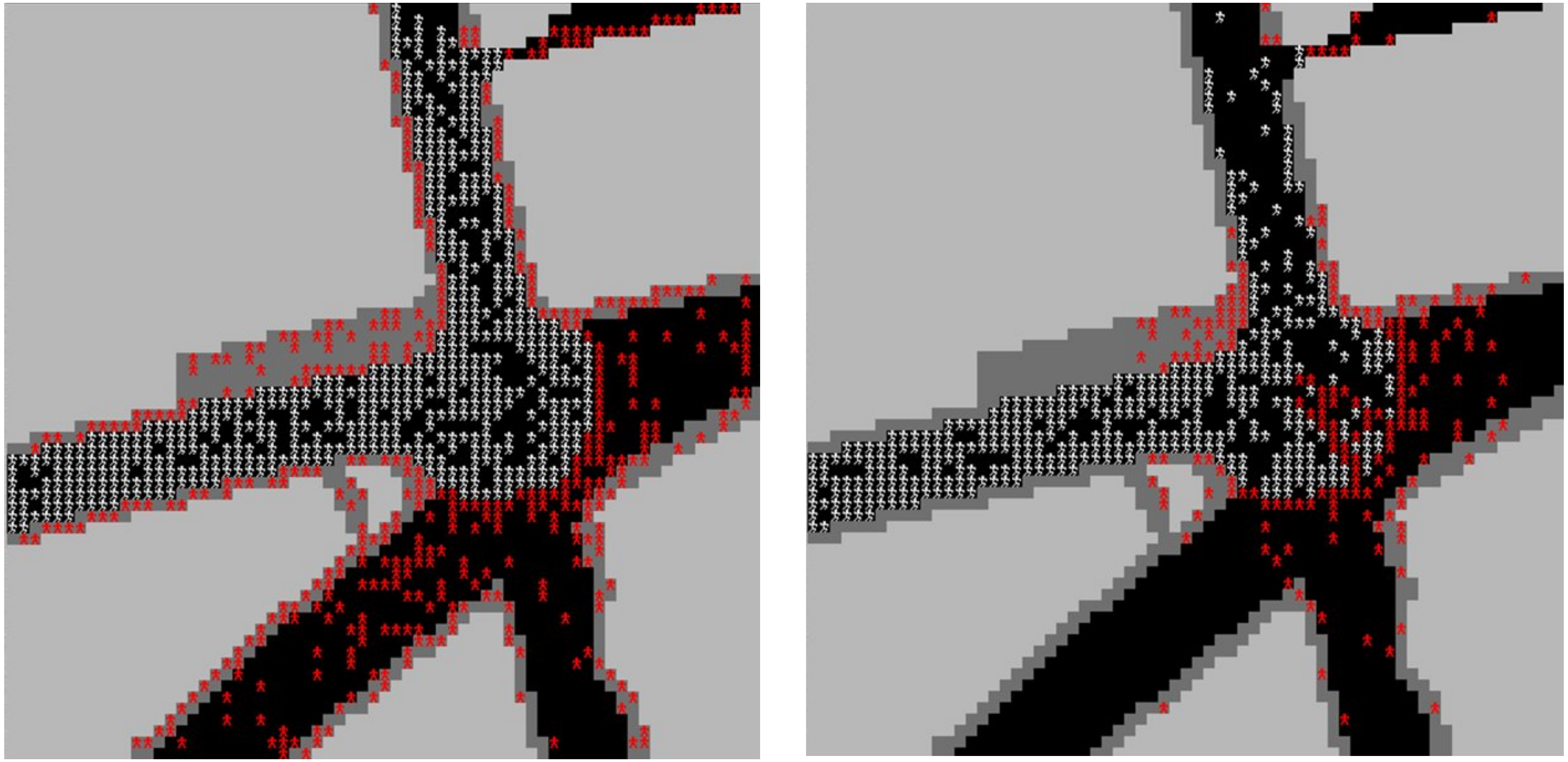
Graphic representation of the groundwater protection model developed by Rhonda Pfaff and Alan Glennon for analysis of groundwater vulnerability in the Mammoth Cave watershed, Kentucky, U.S.A.



Results of the groundwater protection model. Highlighted areas are farmed for crops, on relatively steep slopes and within 300m of streams. Such areas are particularly likely to generate runoff contaminated by agricultural chemicals and soil erosion, and to impact adversely the cave environment into which the area drains.

Individual and Aggregate Models

- Individual models simulate the behavior of every individual in the system
  - Every person in a crowd
- Aggregate models are used when there are too many individual elements to model
  - Impossible to model every molecule of water, grain of sand



Simulation of the movement of individuals during a parade. Parade walkers are in white, watchers in red. The watchers (A) build up pressure on restraining barriers and crowd control personnel, and (B) break through into the parade.

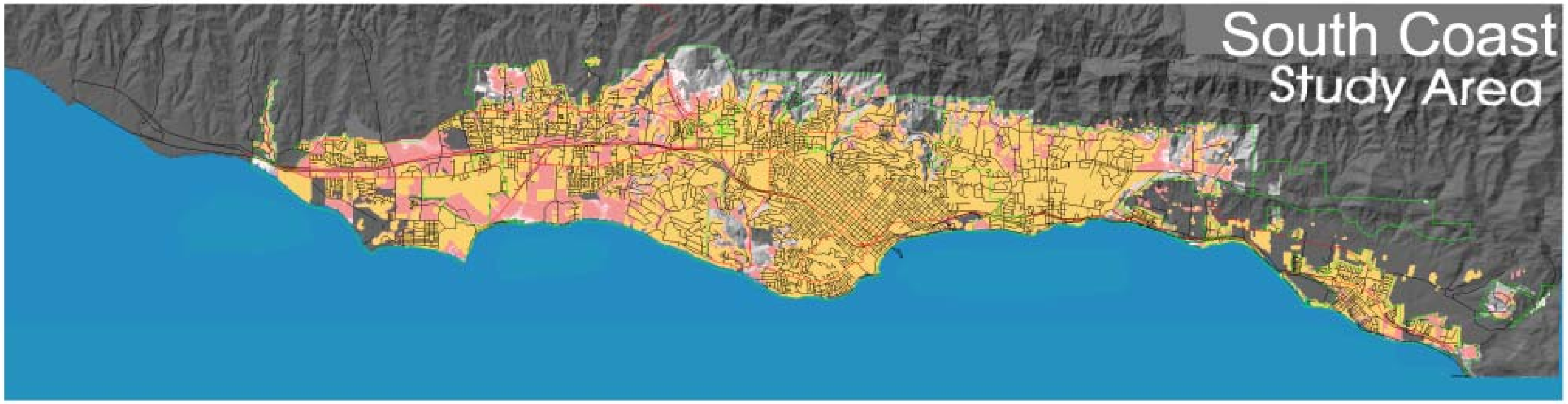
Cellular Models

- Model a system using a raster
- Each cell can be in one of a number of states
  - Change through time is represented by change of cell state
  - Change is defined by a series of rules
  - Depending on the state of the cell and its neighbors

Cellular Models of Urban Growth

- Each cell is either undeveloped or developed
- Transitions may occur at each time step from undeveloped to developed
  - Depending on the state of neighboring cells
  - And on the characteristics of the cell
    - slope, access to transportation, protected status, etc.

Urban Growth Boundary Exclusion



Only Parks are Excluded

Simulation of future urban growth patterns in Santa Barbara, California, U.S.A. (Upper) Growth limited by current urban growth boundary; (Lower) growth limited only by existing parks.

Cartographic Modeling and Map Algebra

- Organizes all GIS operations on a raster into four types
  - *Local* operations are determined by the attributes of each cell alone
  - *Focal* operations are determined by a cell's neighbors
  - *Global* operations compute properties of the entire raster layer
  - *Zonal* operations apply to all contiguous cells with the same value

Technology for Modeling

- Scripts
  - Sequences of GIS operations that can be stored and shared
    - written in a scripting language such as Visual Basic for Applications, Perl, Python, or JScript
    - a model can be written and executed as a script
  - Scripts can be manipulated visually
    - e.g., through ESRI's ModelBuilder

Coupling

- Models often exist as separate, stand-alone programs
  - Can be used in conjunction with a GIS through various forms of coupling
- *Loose* coupling
  - The GIS and the model exchange data in the form of files
- *Close* coupling
  - Both GIS and the model read and write to the same file through a common interface

Multicriteria Methods

- Many decisions depend on numerous factors
  - The factors must be combined in some fashion
  - Often stakeholders disagree on how the factors should be combined
  - Multicriteria methods attempt to reconcile such differences and to reach consensus

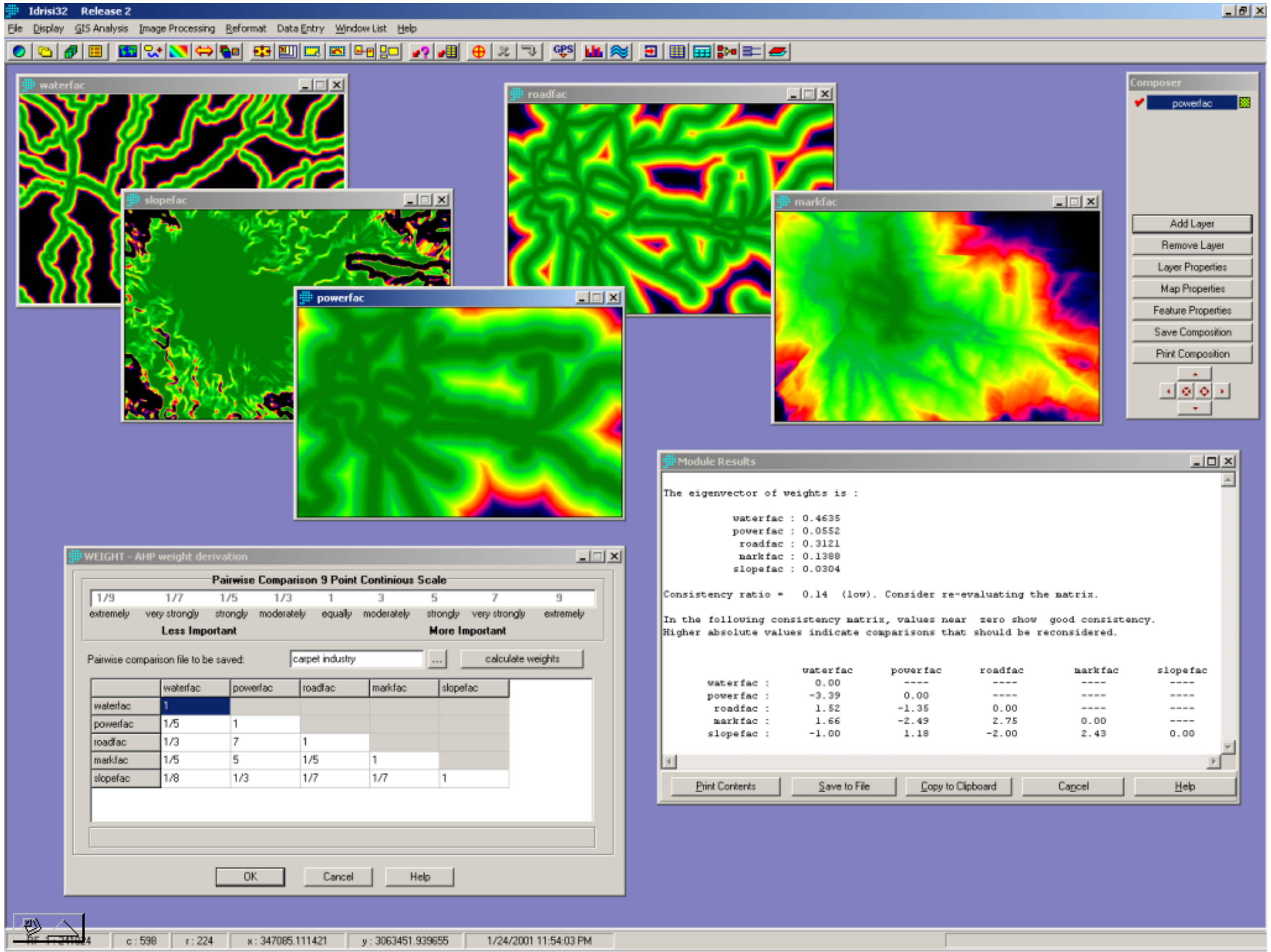
Saaty's Analytical Hierarchy Process (AHP)

- Each stakeholder compares each pair of factors
  - Indicating relative importance as a ratio
- The ratings are combined to produce a consensus set of weights
  - Along with a measure of the strength of agreement or disagreement

One Stakeholder's Weights

- An example using the three factors in the Pfaff and Glennon groundwater protection model

	Slope	Land use	Distance from Stream
Slope		7	2
Land use	1/7		1/3
Distance from Stream	1/2	3	



Screen shot of an AHP application using IDRISI (www.clarklabs.org). The five layers in the upper left part of the screen represent five factors important to the decision. In the lower left the image shows the table of relative weights compiled by one stakeholder. All of the weights matrices are combined and analyzed to obtain the consensus weights shown in the lower right, together with measures to evaluate consistency among the stakeholders.

Accuracy and Validity

- How can the results of a model be assessed?
  - Is the vulnerability index correct?
  - Are the predictions of a scenario correct?
- A model is only as accurate as its inputs
  - And the rules used to emulate real processes
  - And subject to the limitations of its spatial and temporal resolution
- Models help to reduce uncertainty about the future
  - But can never reduce it to zero

Error Propagation

- Methods for assessing the effects of known degrees of error in a model's inputs
  - Producing measures of confidence in model outputs
  - Normally by simulation

Sensitivity Analysis

- Used to assess the effects of uncertainty in model parameters and assumptions
  - Systematically raise and lower the value of each parameter
  - Observe the effects on model predictions
  - Helps in identifying those parameters that are more important and need to be carefully examined