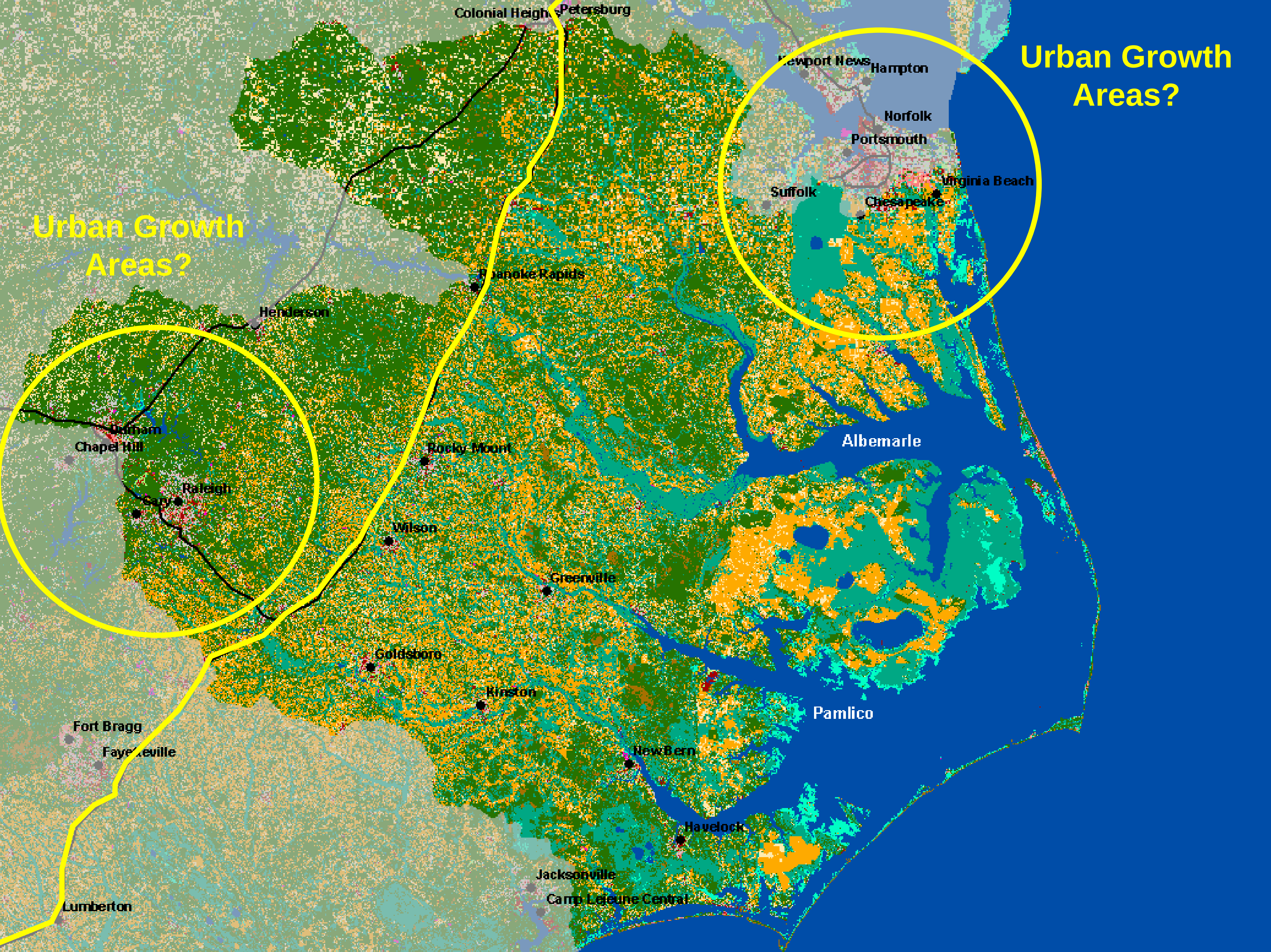
Modeling Land Change in Large Regions: The Chesapeake Bay Watershed Example

Albemarle-Pamlico National Estuary Program Scientific and Technical Advisory Committee Quarterly Meeting

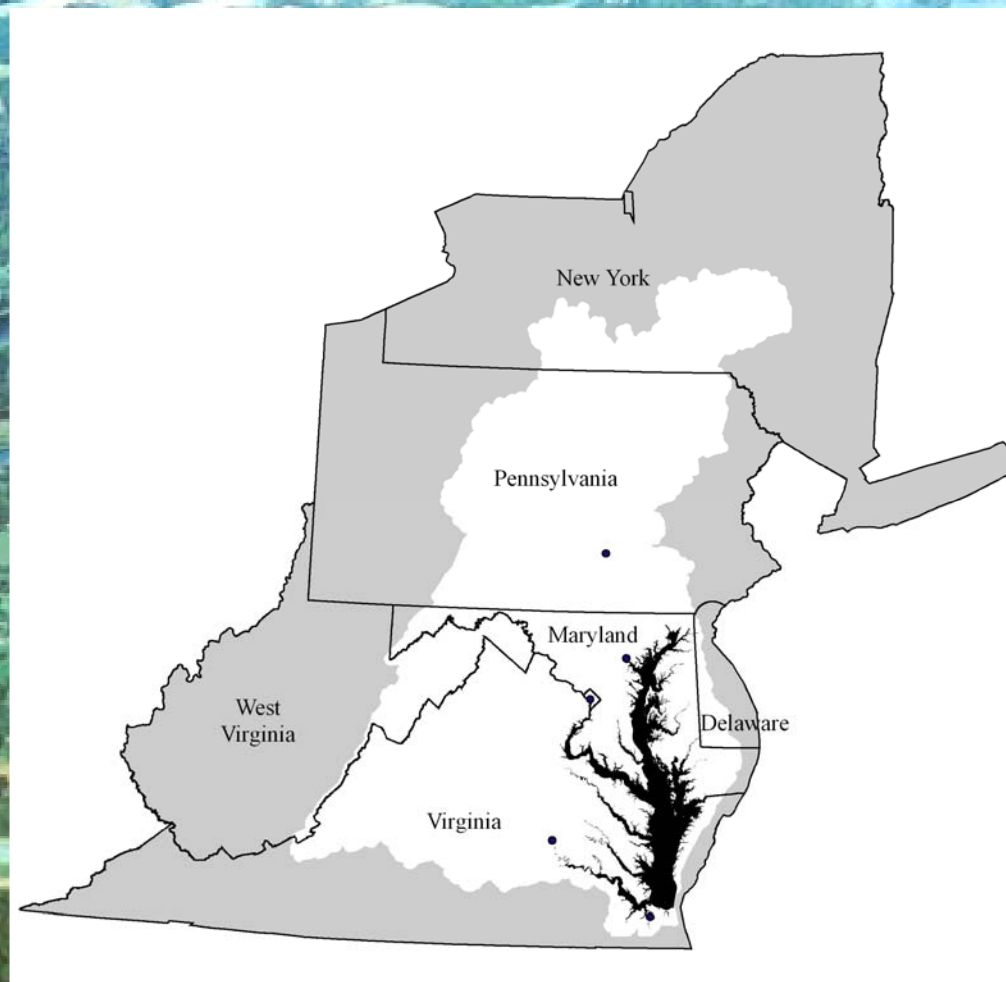
May 3, 2006

Peter Claggett,
U.S. Geological Survey



Urban Growth Areas?
Urban Growth Areas?
Colonial Heights
Petersburg
Newport News
Hampton
Norfolk
Portsmouth
Virginia Beach
Suffolk
Chesapeake
Roanoke Rapids
Henderson
Durham
Chapel Hill
Raleigh
Cary
Rocky Mount
Wilson
Greenville
Albemarle
Goldsboro
Kinston
Pamlico
Fort Bragg
Fayetteville
New Bern
Havelock
Jacksonville
Camp Lejeune Central
Lumberton

Modeling Land Change in Large Regions: The Chesapeake Bay Watershed Example

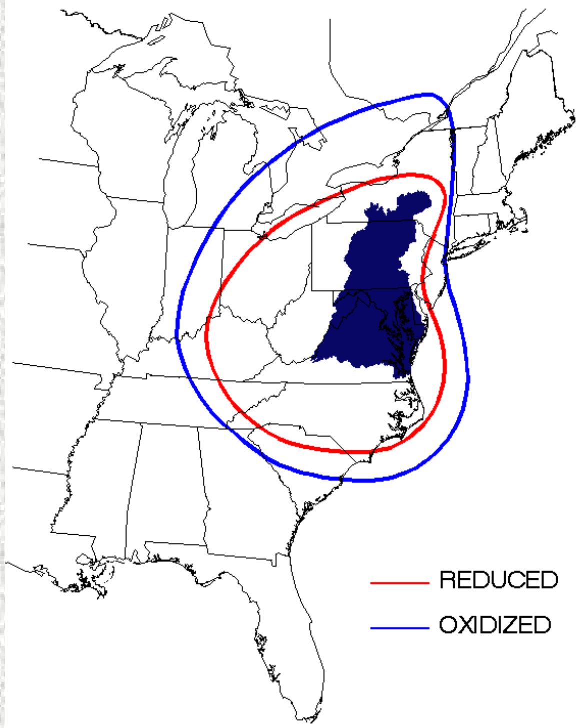


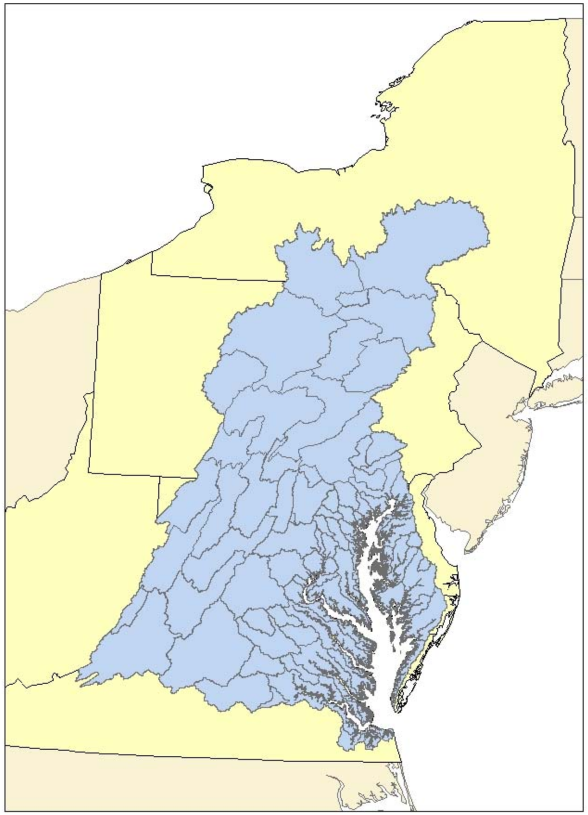
USGS
science for a changing world

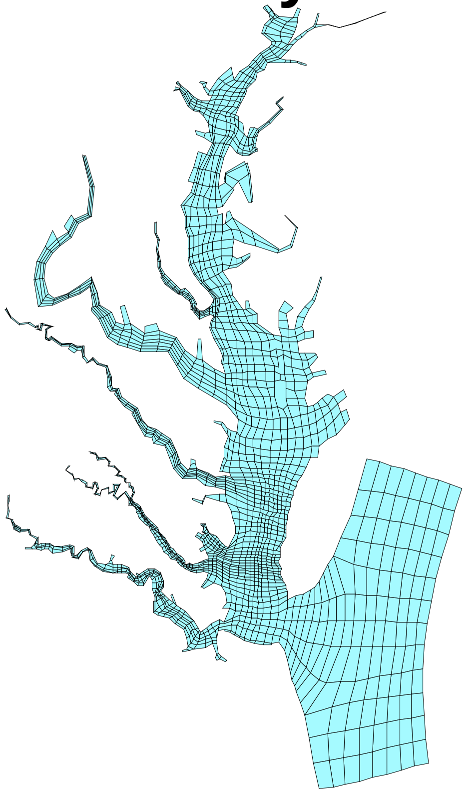
Chesapeake Bay Program
A Watershed Partnership

Chesapeake Bay Program Current Modeling Structure

Airshed → **Watershed** → **Estuary**







Nitrate and ammonia deposition from <u>Regression Model</u> (NADP concentrations, precipitation, time, and latitude) applied to precipitation data from gauging stations.

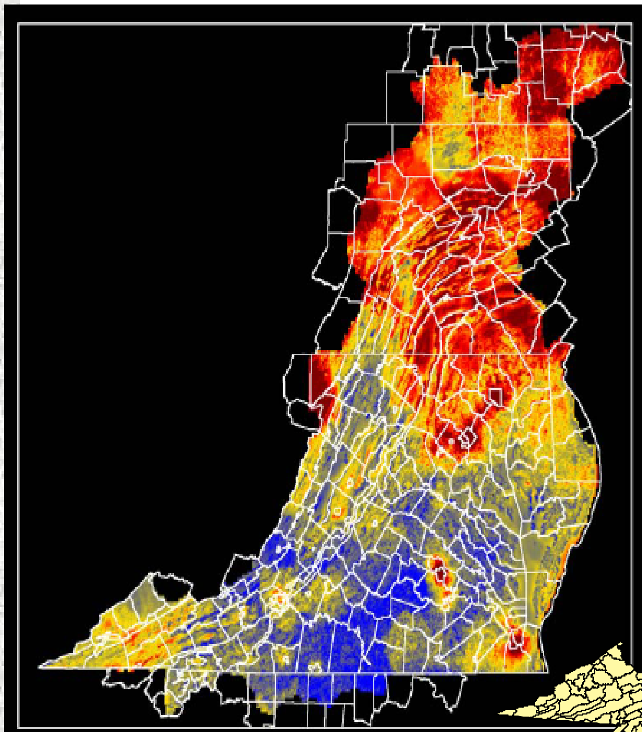
Adjustments to deposition from <u>Regional Acid Deposition Model (RADM)</u>

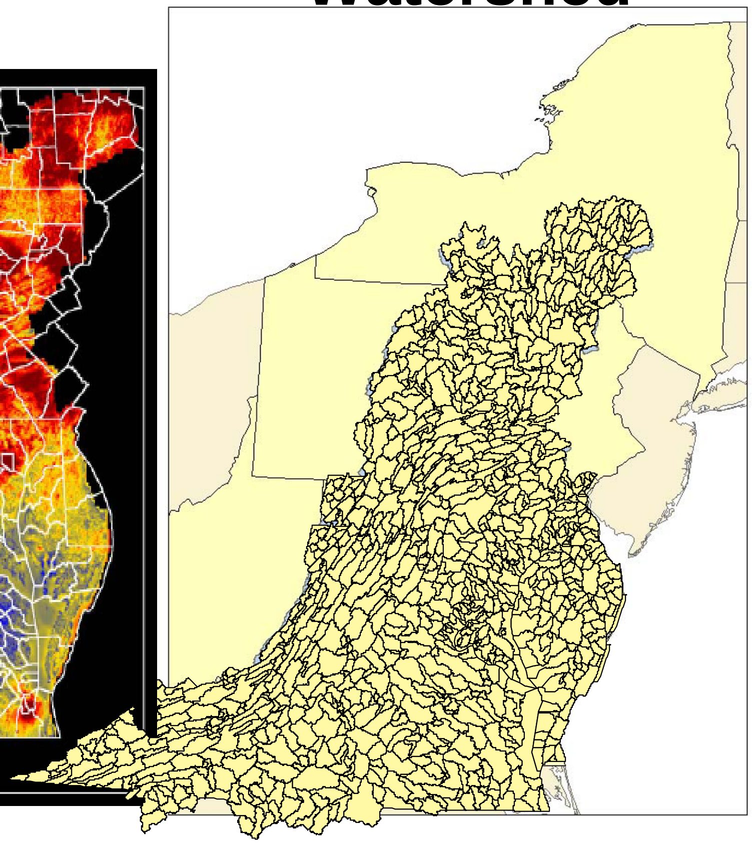
<u>Chesapeake Bay Watershed Model</u>
Lumped-parameter, physically-based Land and water simulation, Nutrient and sediment simulation

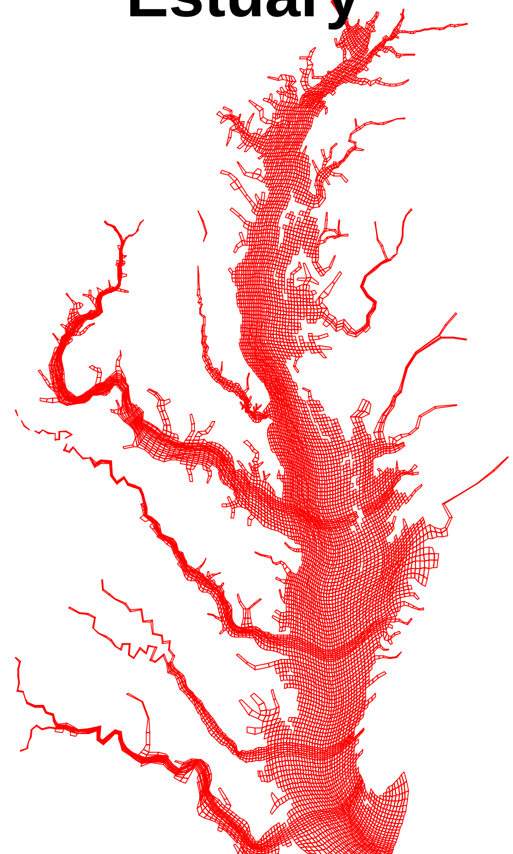
<u>Chesapeake Bay Estuary Model Package</u>
Hydrodynamic Model, Sediment Benthic Model, and Submerged Aquatic Vegetation

Chesapeake Bay Program
New Modeling Structure

Airshed → Watershed → Estuary







Nitrate and ammonia deposition from improved Daily Nitrate and Ammonium Concentration Models

Adjustments to deposition from Models-3/Community Multi-scale Air Quality (CMAQ) Modeling System

Phase 5 Watershed Model
Better year-to-year simulation – mass balance modeling; Large aggregate land simulation with distributed rivers; Time series of management practices; Automated calibration

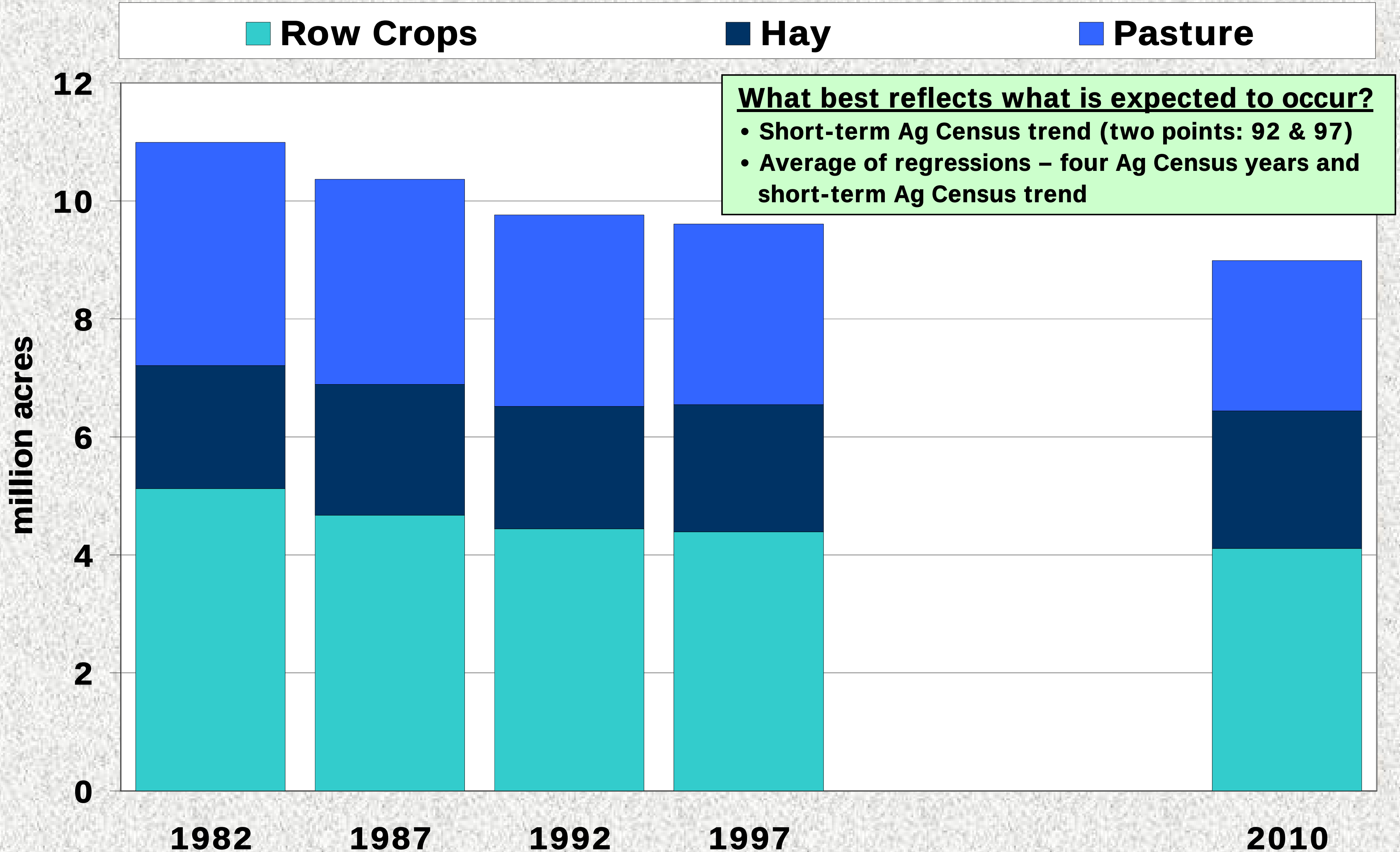
Chesapeake Bay Estuary Model
New grid; Bank loads; Nutrient controls on TSS and chlorophyll-a sinking/suspension; Hydrodynamic and Wave Models for sediment re-suspension in the Water Quality Model

Chesapeake Bay Watershed Modeled Landuses

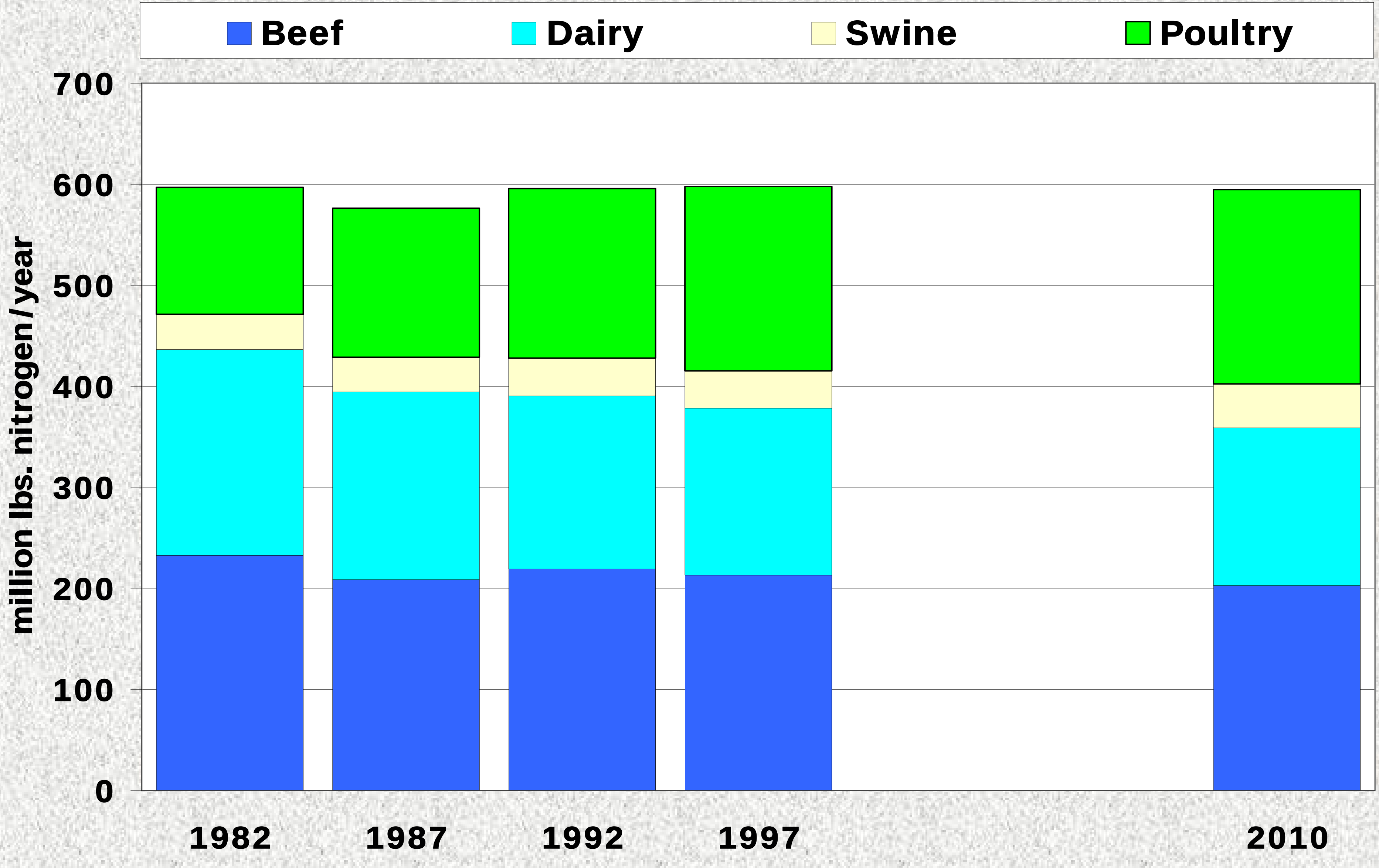
Phase 4.3 Watershed Model Landuses
Agriculture:
Conventional-Till
Conservation-Tillage
Hay
Pasture
Manure Acres
Urban:
Pervious Urban
Impervious Urban
Forest
Mixed Open
Non-Tidal Water

Phase 5 Watershed Model Landuses
Agriculture:
Composite Crop with Manure Nutrients: • Conventional-Till • Conservation-Till
Composite Crop without Manure Nutrients
Hay with and without Manure Nutrients
Alfalfa
Nursery
Pasture
Degraded Stream Corridor
Animal Feeding Operations
Urban:
High- and Low-Density Pervious Urban
High- and Low-Density Impervious Urban
Extractive
Construction
Forest:
Forest and Harvested Forest
Natural Grass
Inland Water

Phase 4.3 Watershed Model
2010 Agricultural Landuse Projections



Phase 4.3 Watershed Model Animal Nitrogen Generation

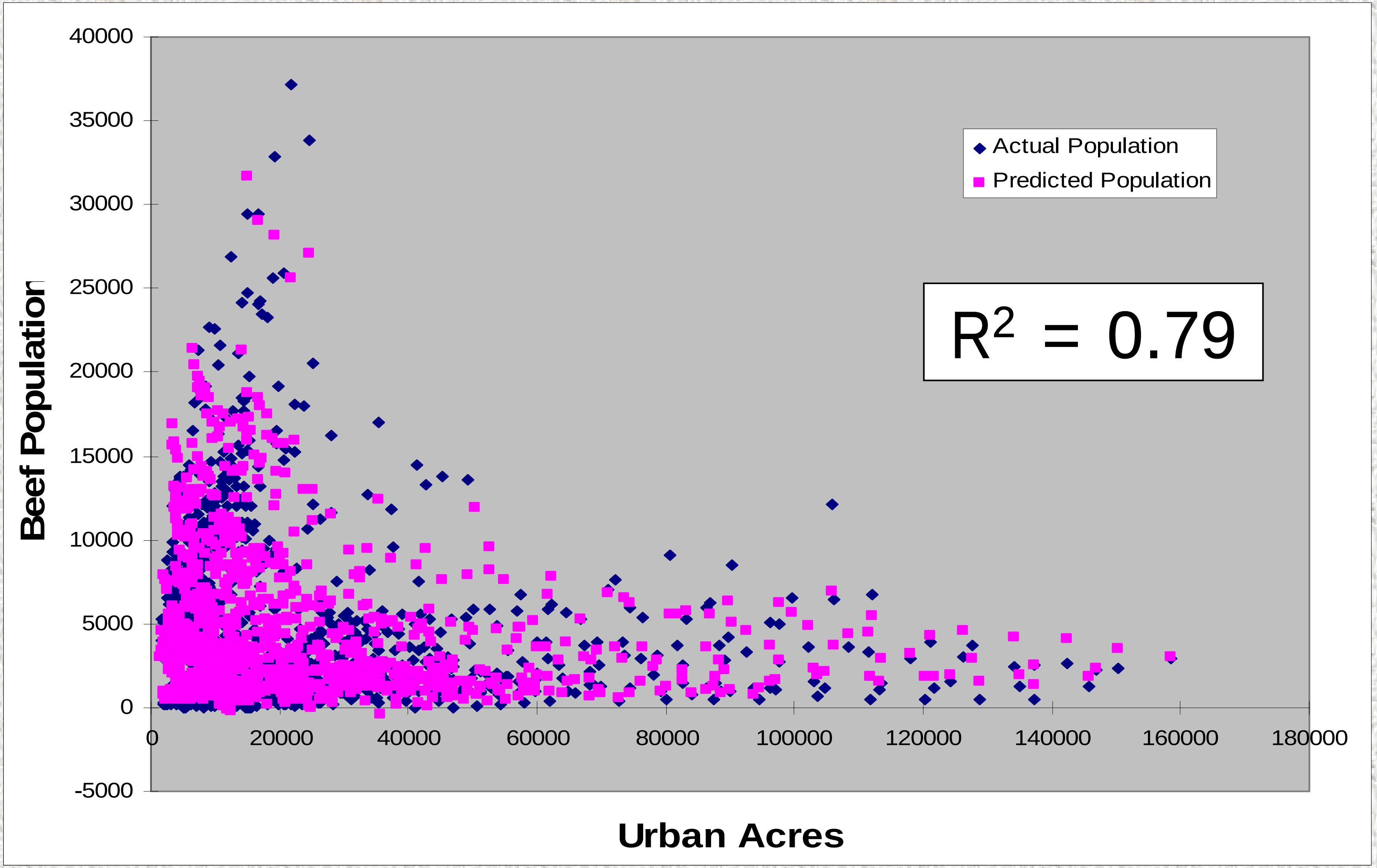


Forecasting to 2030: Multivariate Regression Approach

- Regression model using pasture (x_1), high urban (x_2), row crops (x_3) and hay (x_4) acreage to predict animal population (y).

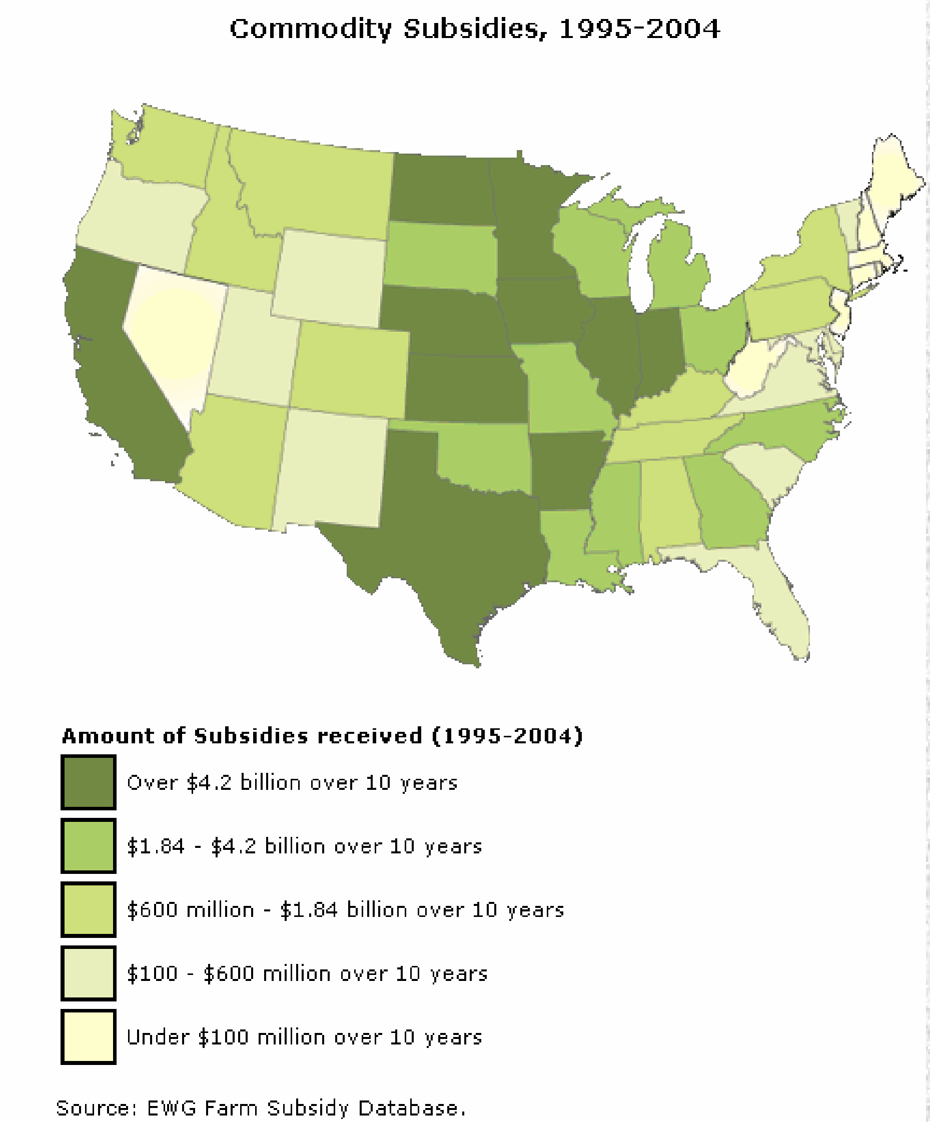
$$y = b + m_1 x_1 + m_2 x_2 + m_3 x_3 + m_4 x_4$$

Multivariate: Beef Cattle

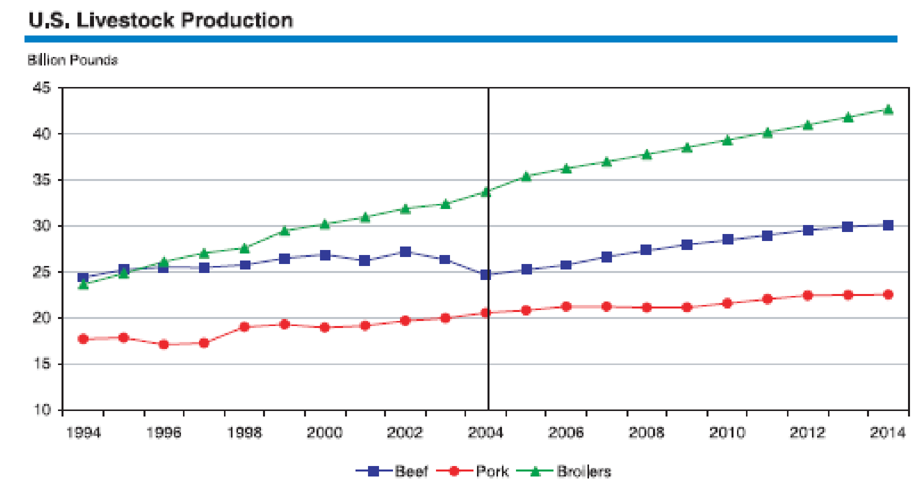


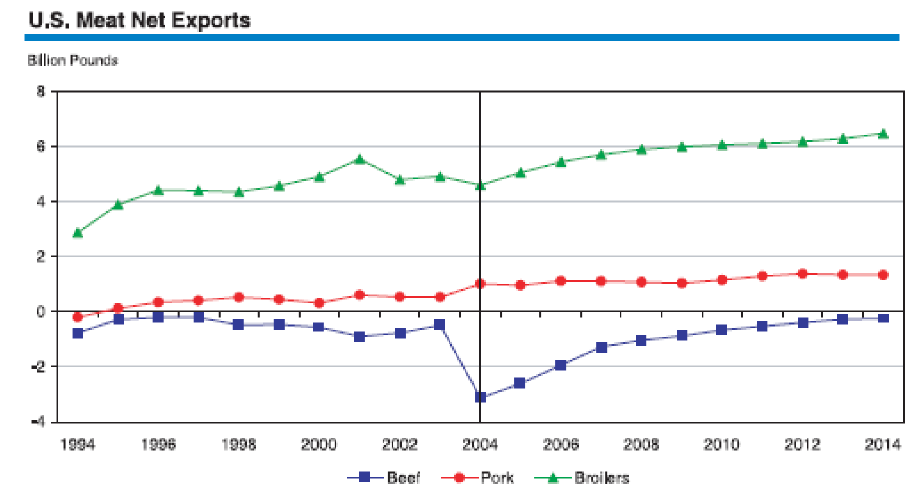
What is the future of Agriculture in the Bay Watershed?

Subsidies…



Economic Forecasts (FAPRI 2005)…

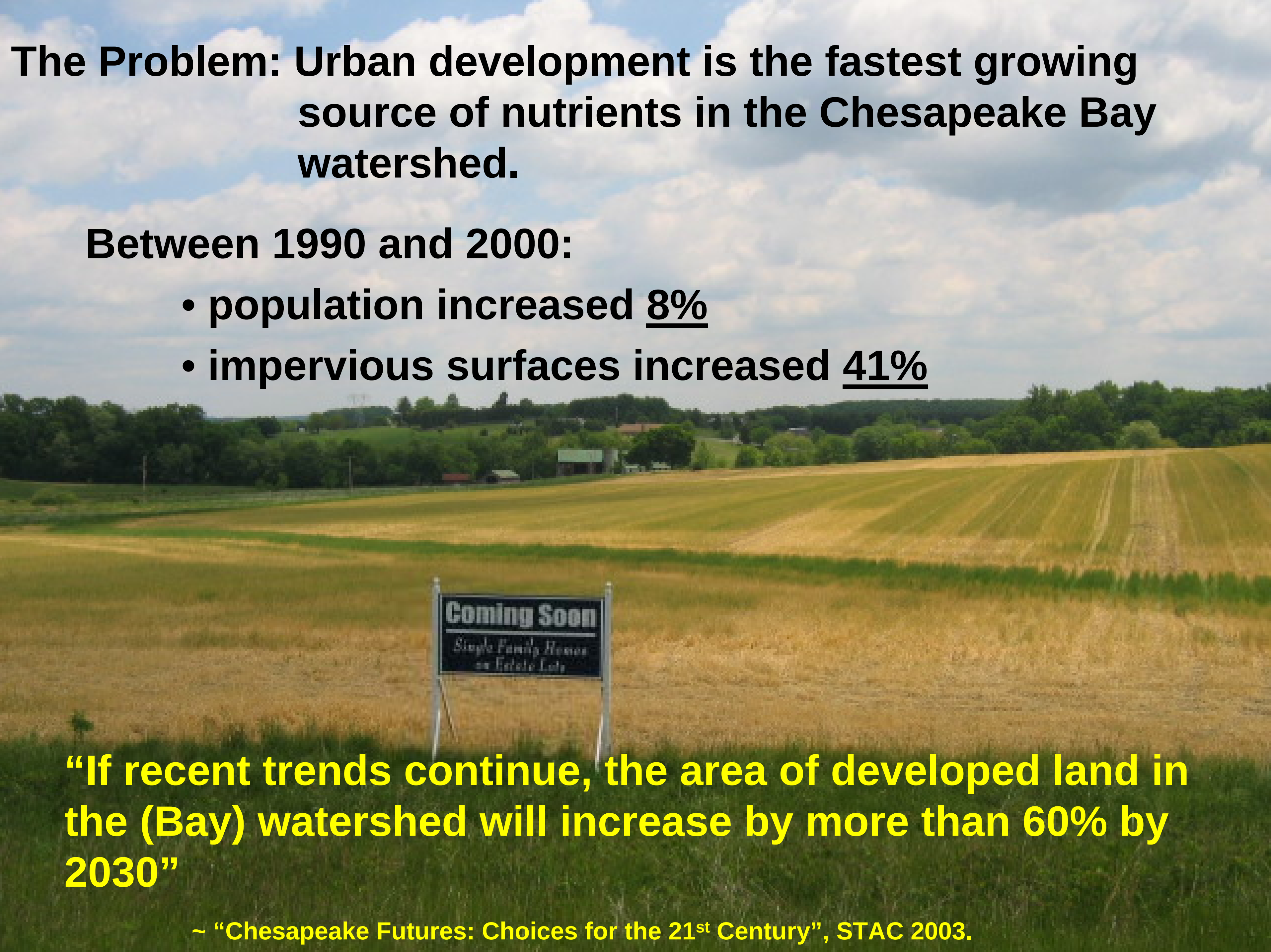




The Problem: Urban development is the fastest growing source of nutrients in the Chesapeake Bay watershed.

Between 1990 and 2000:

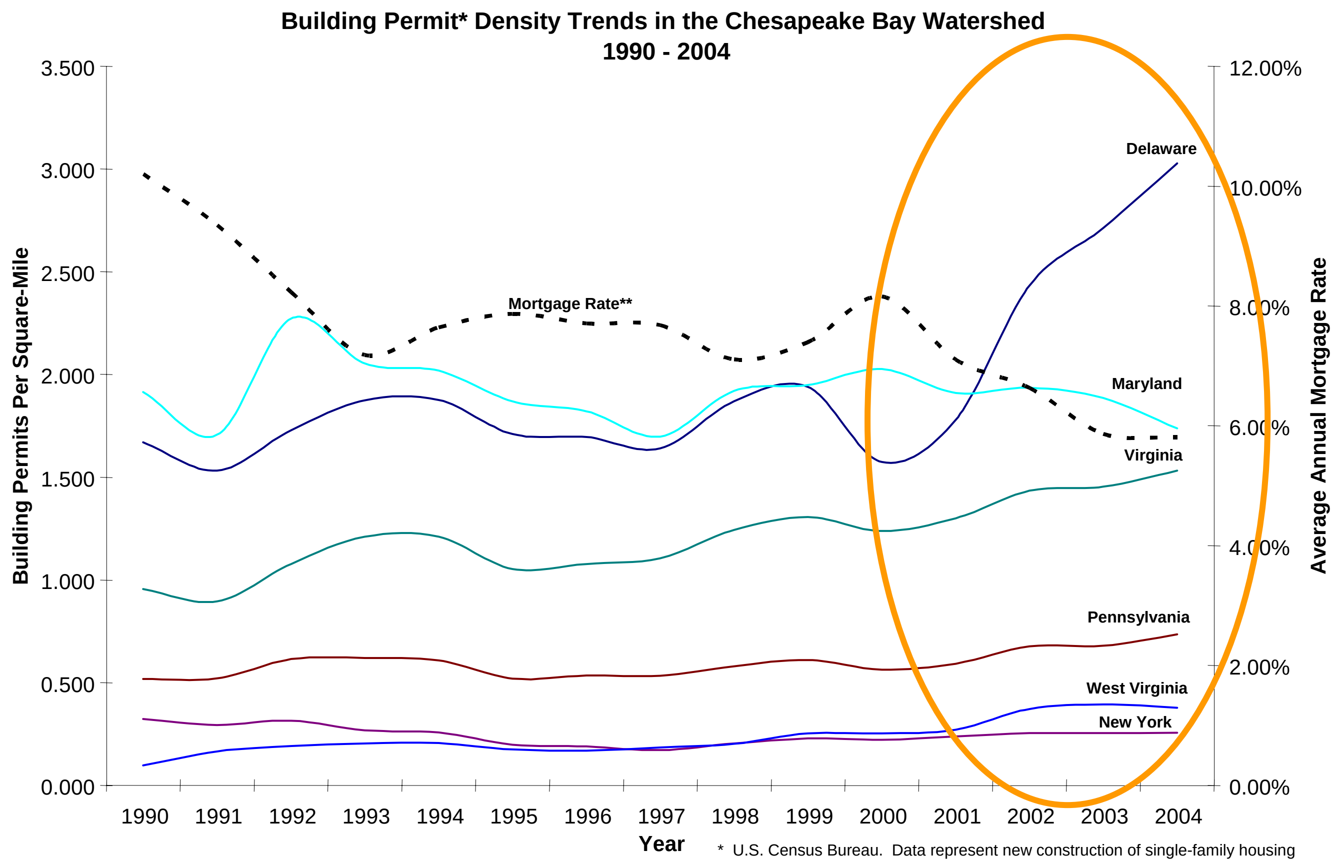
- **population increased <u>8%</u>**
- **impervious surfaces increased <u>41%</u>**



"If recent trends continue, the area of developed land in the (Bay) watershed will increase by more than 60% by 2030"

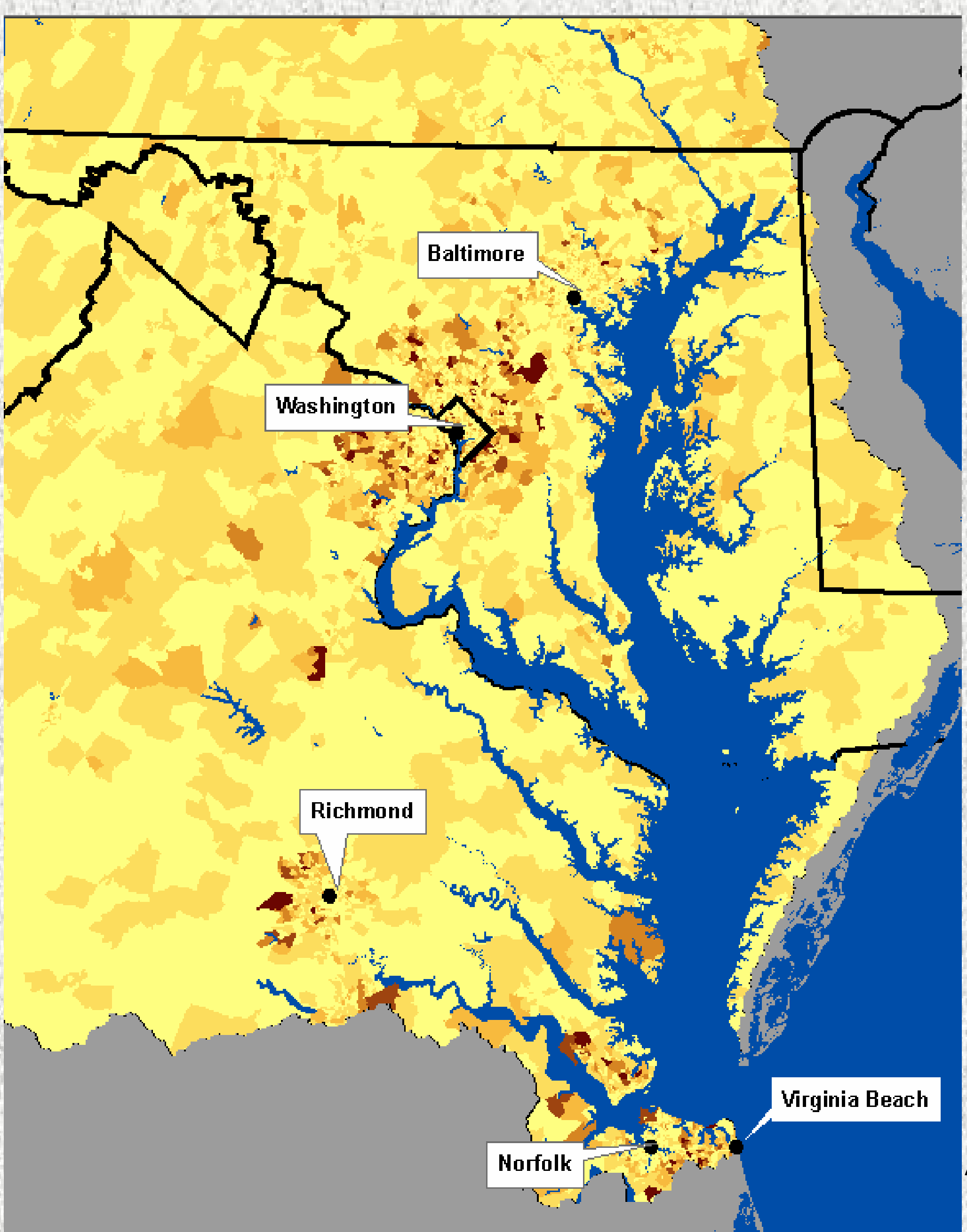
~ "Chesapeake Futures: Choices for the 21[st] Century", STAC 2003.

Recent Urban Growth

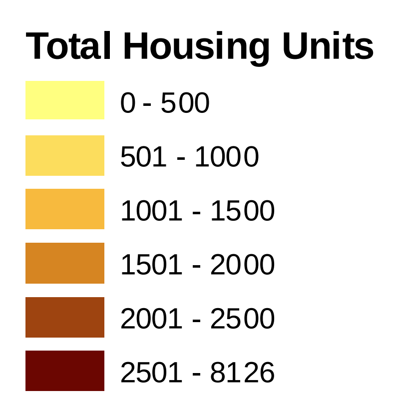


* U.S. Census Bureau. Data represent new construction of single-family housing units, both detached and attached, for counties in the Chesapeake Bay watershed.
** Federal Housing Finance Board

Housing Trends 1960 – 1990 (census block groups)



Total Housing Units 1990

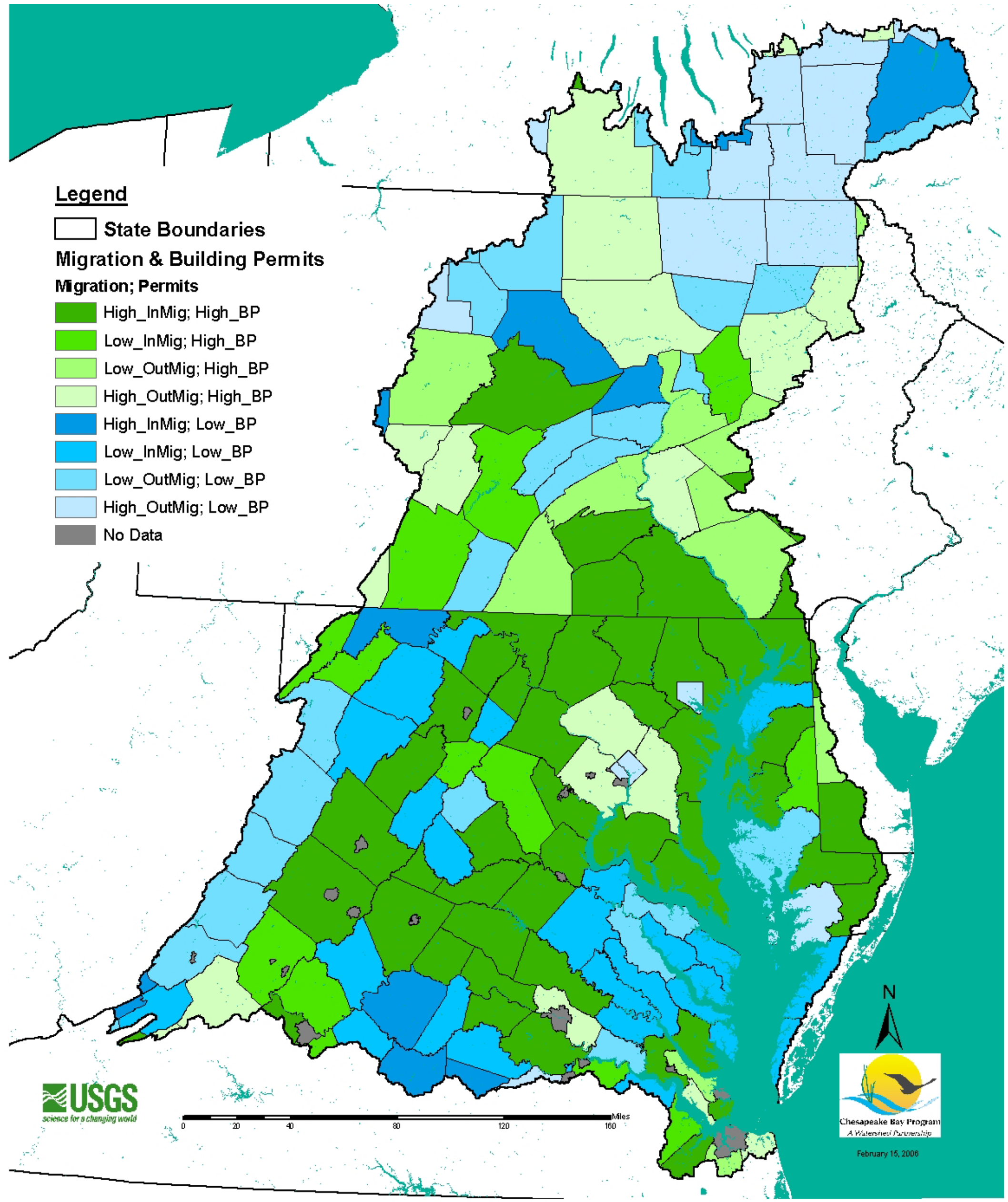


Historical Block Group Analysis courtesy of D. Theobald, 2001

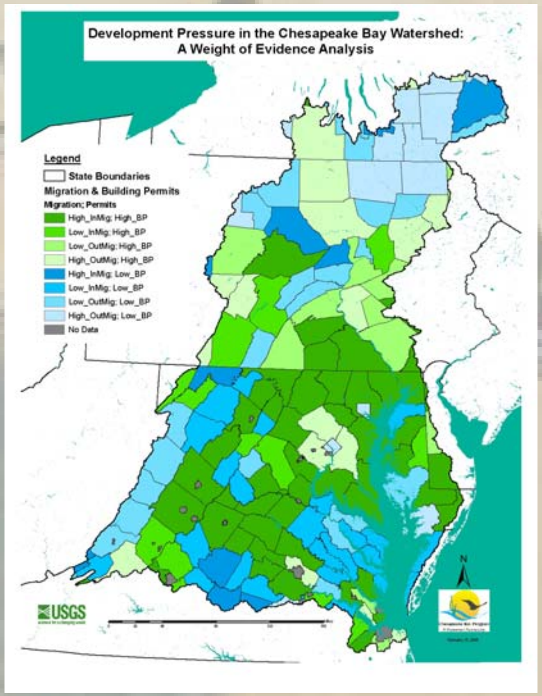
Urban Development Where and Why?

Attraction Factors:
- Economic opportunities
- "Quality of Life" amenities
- Social and cultural ties

Net Domestic Migration and New Building Permits 1995 - 2000



Urban Sprawl Conceptual Model



Attraction Factors:
- **Economic opportunities**
- **“Quality of Life” amenities**
- **Social and cultural ties**

Footprint Factors:
- **Smaller families**
- **Bigger houses**
- **Larger parking lots**
- **“Big box” retail**

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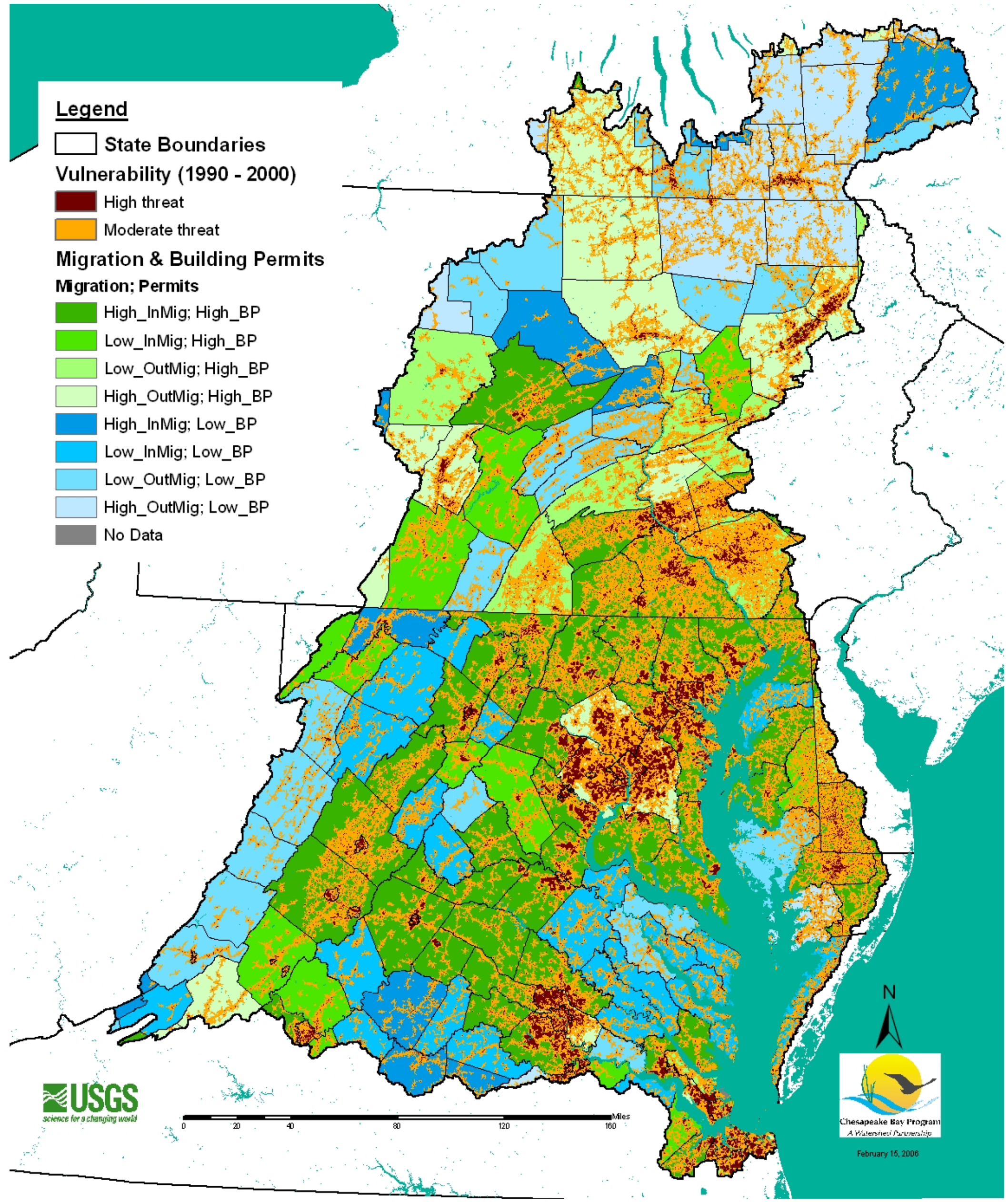
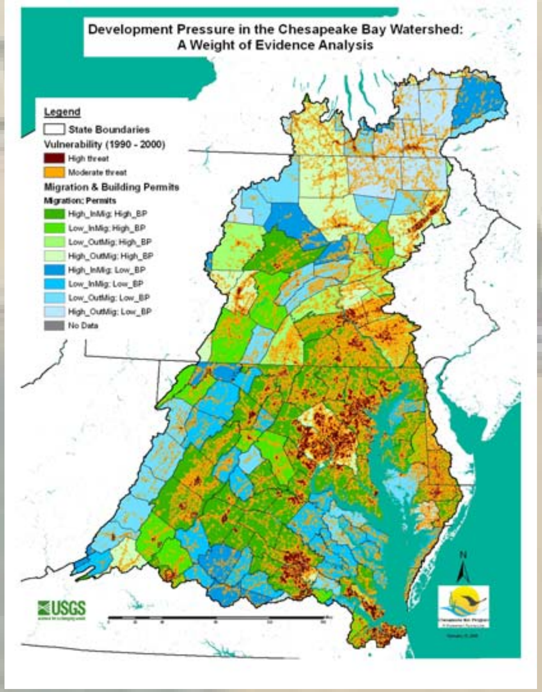
Single-Detached Housing and Impervious Surface Change 1990 - 2000



Urban Sprawl Conceptual Model



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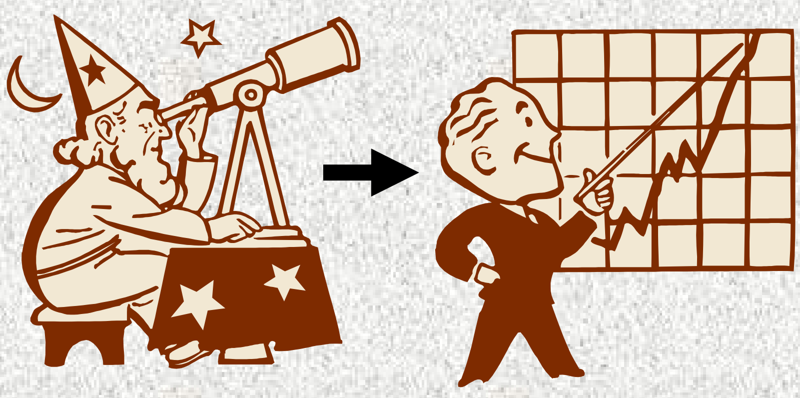
Local Factors:

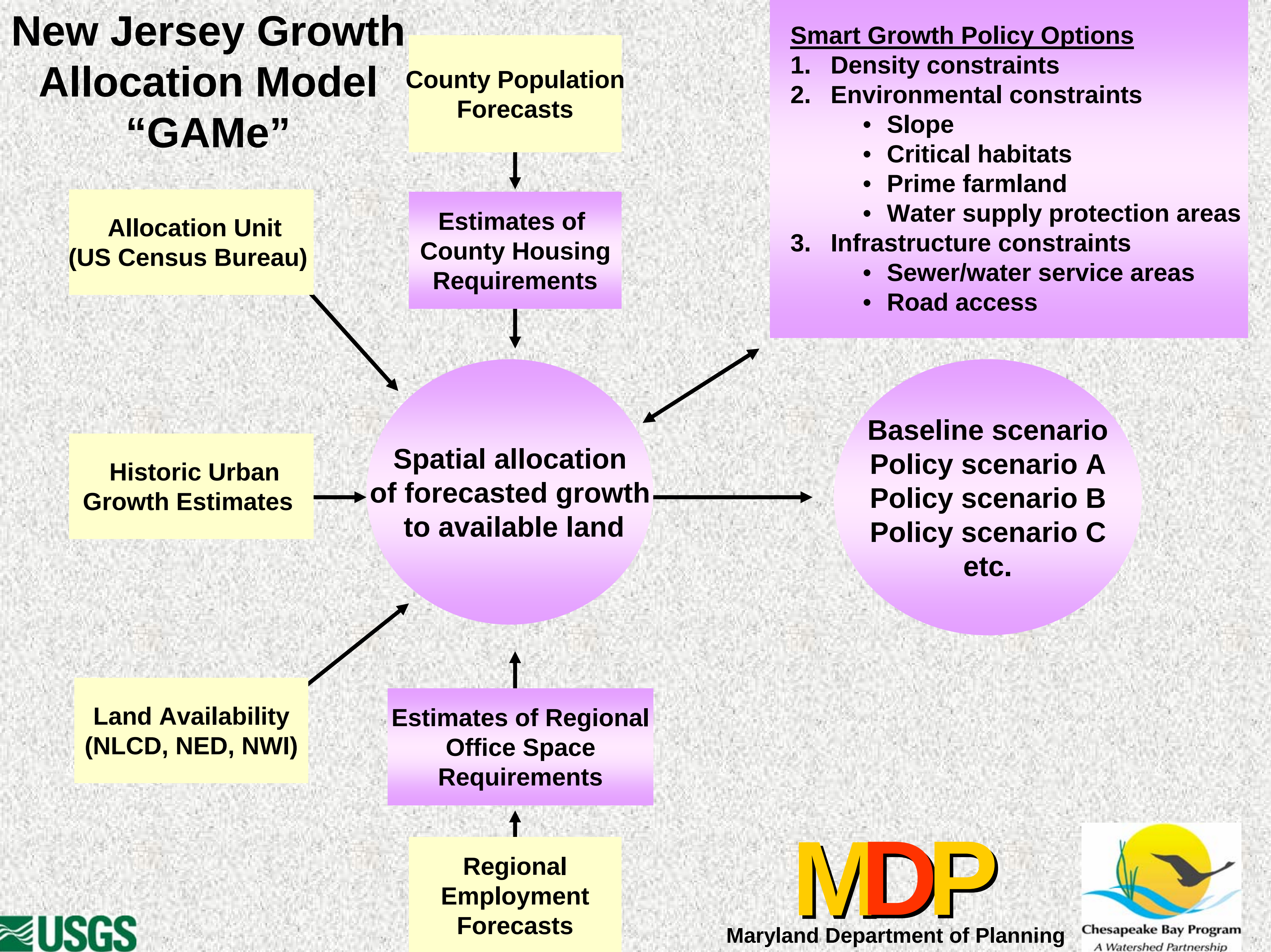
- **Land values**
- **Zoning**
- **Taxes**
- **Schools**
- **Crime**
- **Proximity to work, open space, and schools**

What is the difference between growth forecasting and growth allocation?

Growth Forecasts estimate HOW MANY people, houses, and jobs will be in a region in the future.

Growth Allocations predict WHERE within a region, growth will occur.





New Jersey Growth Allocation Model "GAMe"
County Population Forecasts
Estimates of County Housing Requirements
Allocation Unit (US Census Bureau)
Smart Growth Policy Options
1. Density constraints
2. Environmental constraints
• Slope
• Critical habitats
• Prime farmland
• Water supply protection areas
3. Infrastructure constraints
• Sewer/water service areas
• Road access
Historic Urban Growth Estimates
Spatial allocation of forecasted growth to available land
Baseline scenario
Policy scenario A
Policy scenario B
Policy scenario C
etc.
Land Availability (NLCD, NED, NWI)
Estimates of Regional Office Space Requirements
Regional Employment Forecasts
USGS
MDP
Maryland Department of Planning
Chesapeake Bay Program
A Watershed Partnership

Why use GAMe?

It has produced accurate allocations in New Jersey.

Comparing 1993 – 2000 growth allocation forecasts in 193 municipalities in New Jersey:

MPO's forecasts ~.5 Rsq

County forecasts ~.4 Rsq to ~.7 Rsq

GAMe allocation .92 Rsq

Why use GAMe?

It has policy handles which allow you to develop alternative scenarios.

What if… we preserve all prime farmland…

What if… we preserve most of the natural resources

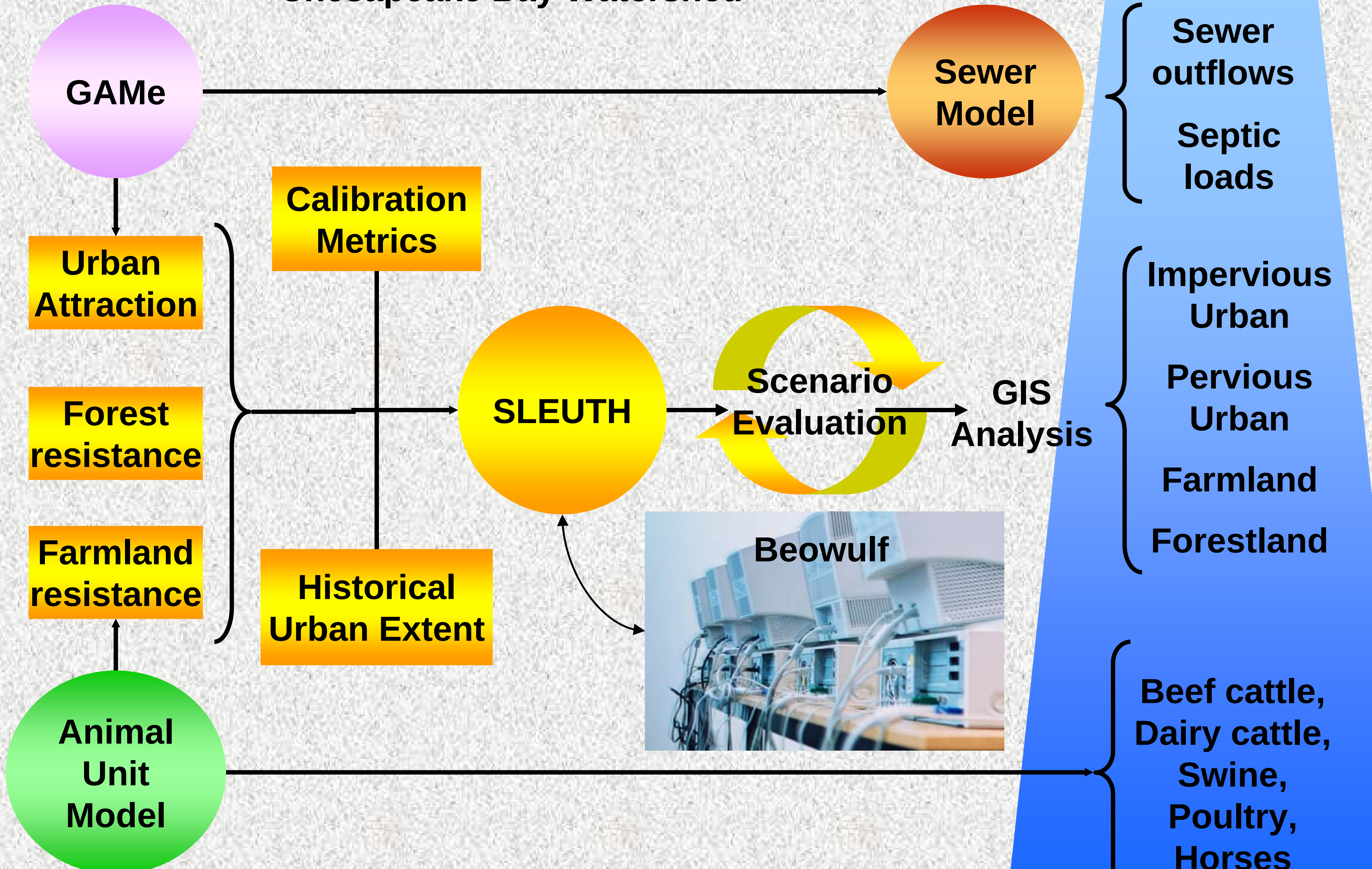
What if … we built a bit more densely

What if… we built more in sewered areas

then, where would growth go?

Forecasting Future Land Cover and Nutrient Sources in the Chesapeake Bay Watershed

Watershed Model



Modeling land cover change in the Chesapeake Bay watershed

An overview of the SLEUTH model

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Scott J. Goetz
The Woods Hole Research Center
sgoetz@whrc.org

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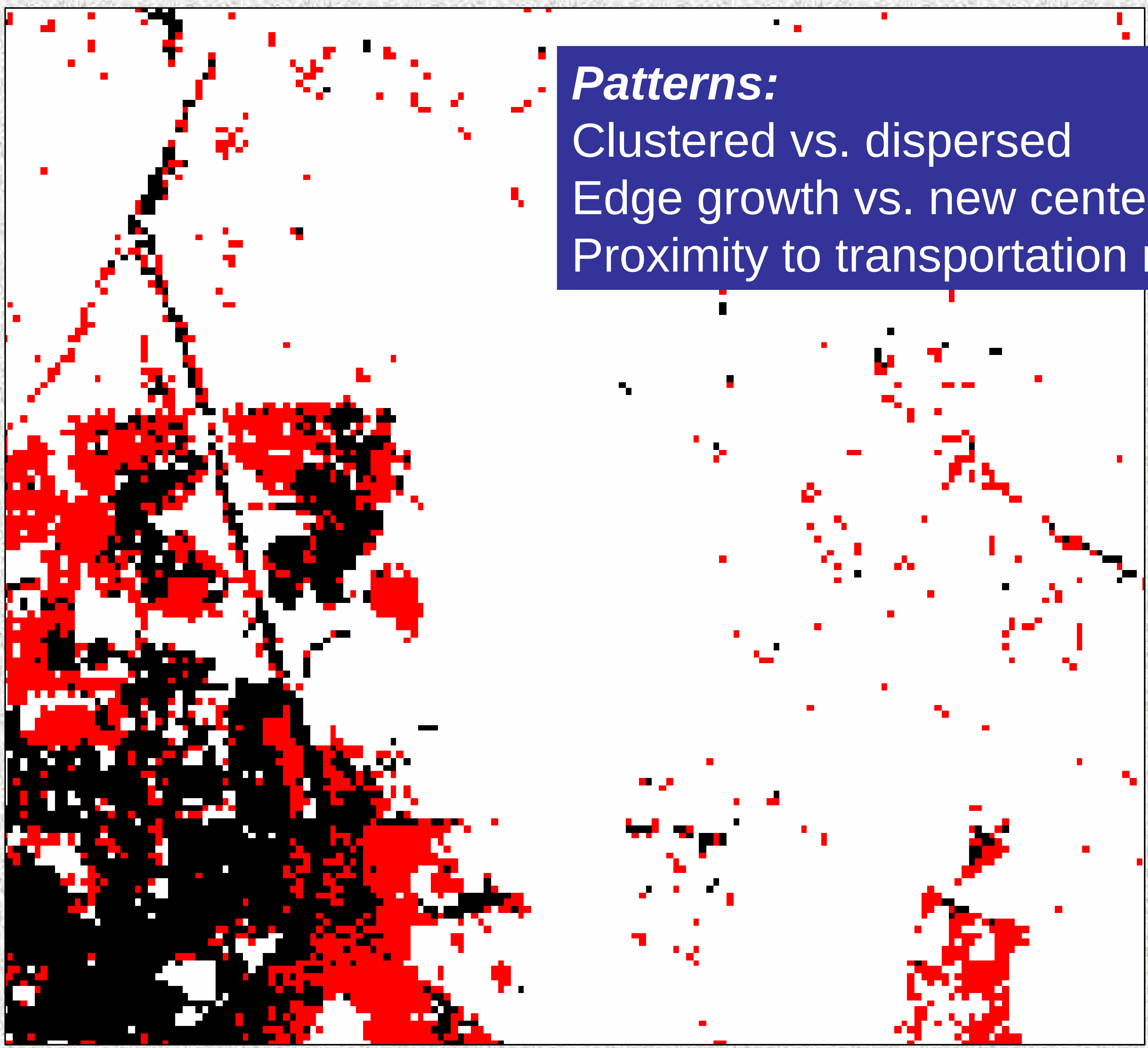
The SLEUTH model

- Developed by Keith Clarke (UCSB), sponsored by the USGS Urban Dynamics Program
- Widely used, well-established

http://www.ncgia.ucsb.edu/projects/gig/



Patterns:

Clustered vs. dispersed

Edge growth vs. new centers of growth

Proximity to transportation network

SLEUTH Urban Growth Model

- Urban / non-urban
- Growth rules
  - Spontaneous *(dispersion coefficient)*
  - New spreading center *(breed coefficient)*
  - Edge *(spread coefficient)*
  - Road-influenced *(road gravity coefficient)*
- Resistance to development
  - Slope *(slope coefficient)*
  - Excluded layer *(user-defined)*

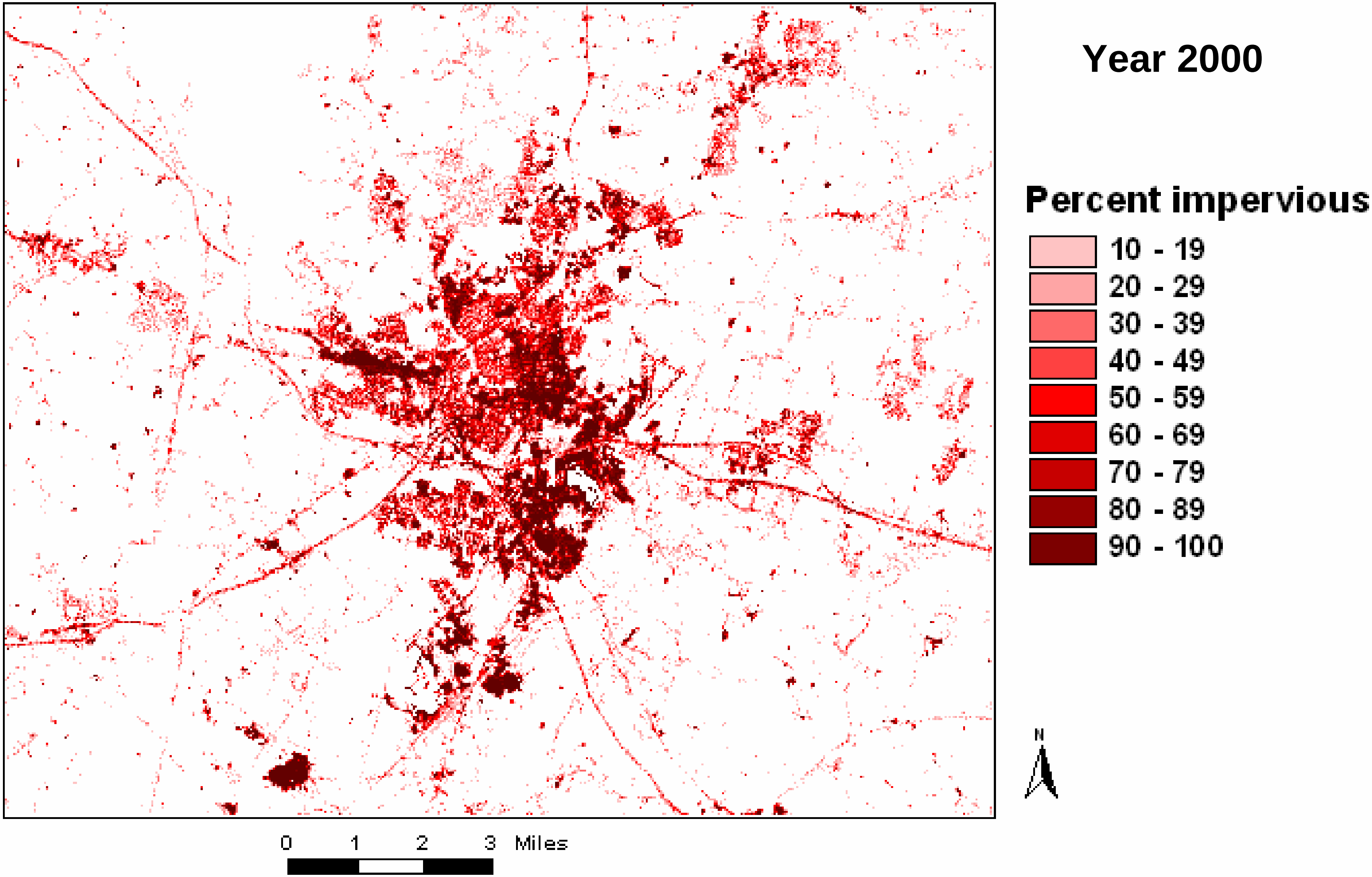
SLEUTH Implementation

- Calibration
  - Train the model to simulate historic patterns of development
- Prediction
  - Forecast historic patterns of development into the future

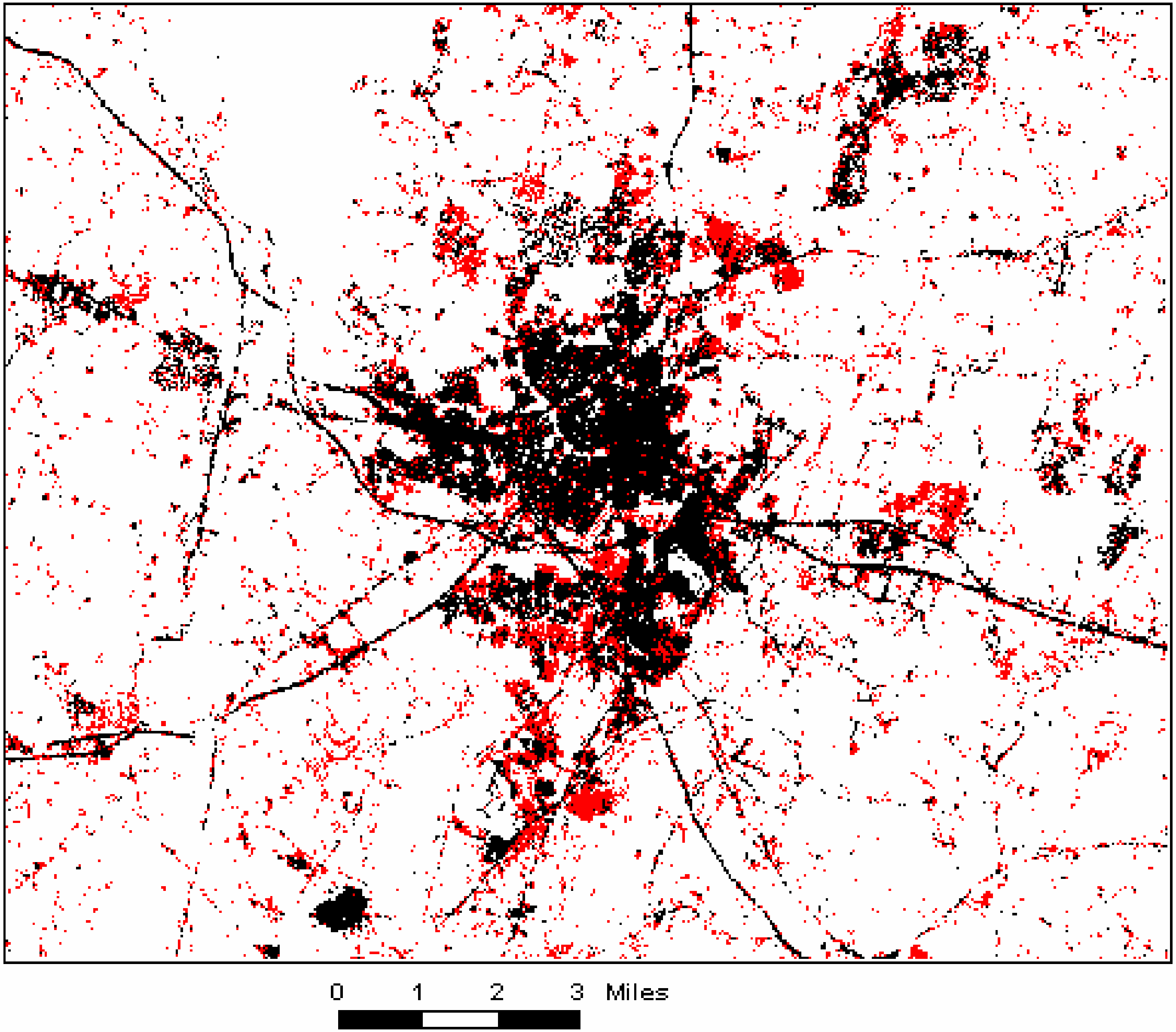
Input data sets

- Transportation
  - TeleAtlas roads
- Slope
  - National Elevation Data
- Areas partially or wholly excluded from development (“excluded layer”)
- Urban time series
  - UMD/CBPO 1990 and 2000 impervious surface

Measuring Urban Extent



Accuracy of Input Data



Year 1990 (BLACK)
Year 2000 (RED)

Urban/non-urban

1990 accuracy >79%

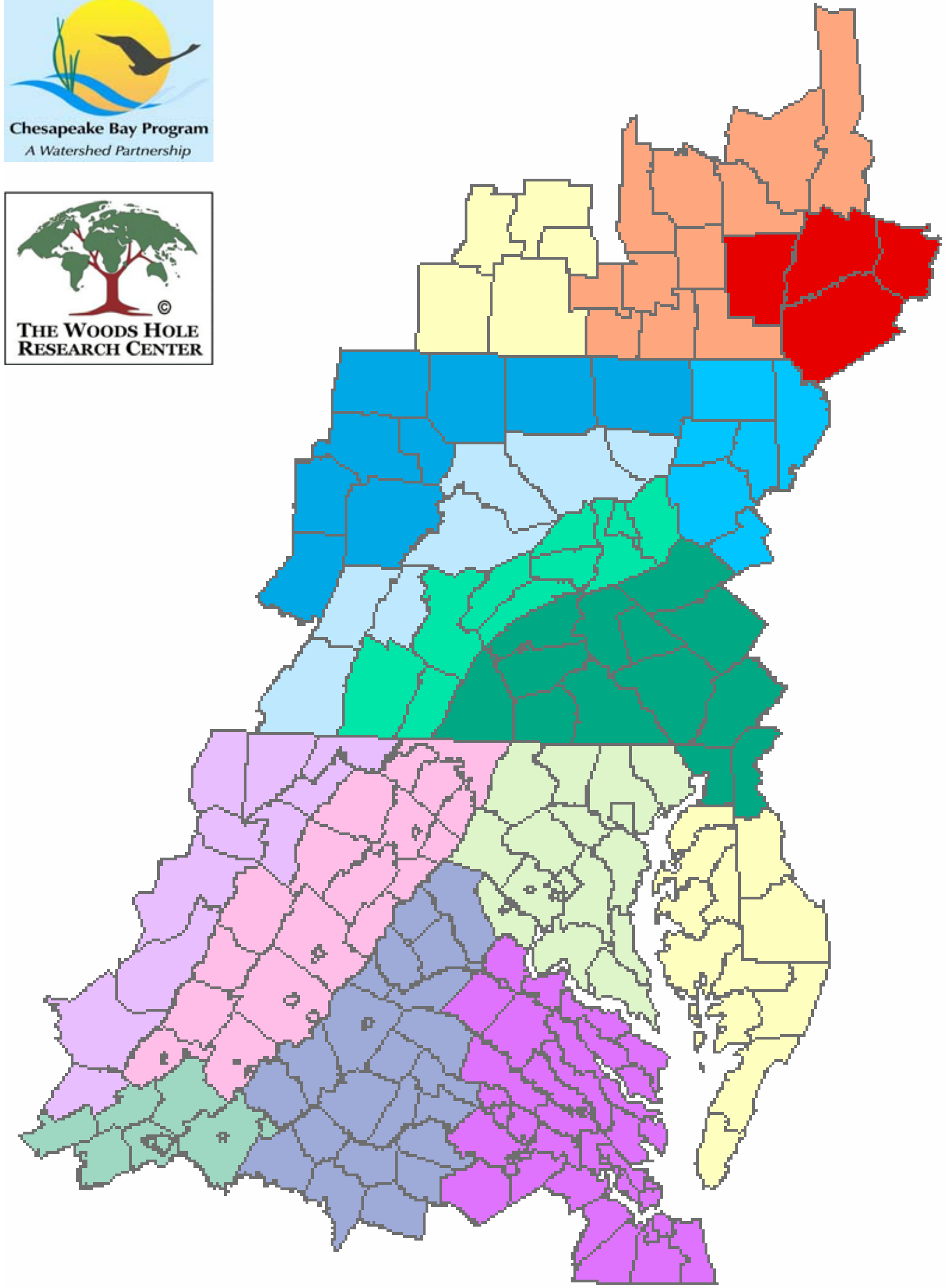
2000 accuracy >83%

Jantz, P.A., S. J. Goetz and C.A. Jantz (2005). Urbanization and the loss of resource lands in the Chesapeake Bay watershed. *Environmental Management* 36(6): 808-825.

Calibrating over a large region

- Challenges
  - Heterogeneity
    - **Patterns, rates of urban development**
    - **Change**
  - Computational challenge
    - **167,000 km^2 ++**
    - **27,976 x 20,129 cells → 563,128,904 cells**
    - ***weeks* of computing time..**

Regional Calibration



Sub-region	Area (km²)
New York west	10,666
New York central	20,454
New York east	10,373
Pennsylvania northwest	21,361
Pennsylvania northeast	9,697
Pennsylvania north central	15,572
Pennsylvania south central	12,701
Pennsylvania southeast	21,878
Virginia west	16,758
Virginia central	22,567
Virginia south	7,180
Virginia south central	22,901
Virginia Richmond-Norfolk	21,640
Washington-Baltimore	17,986
Delmarva	15,152
Total area	246,886

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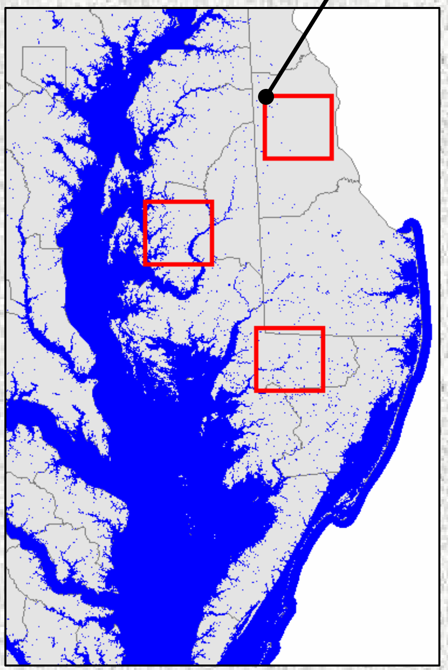
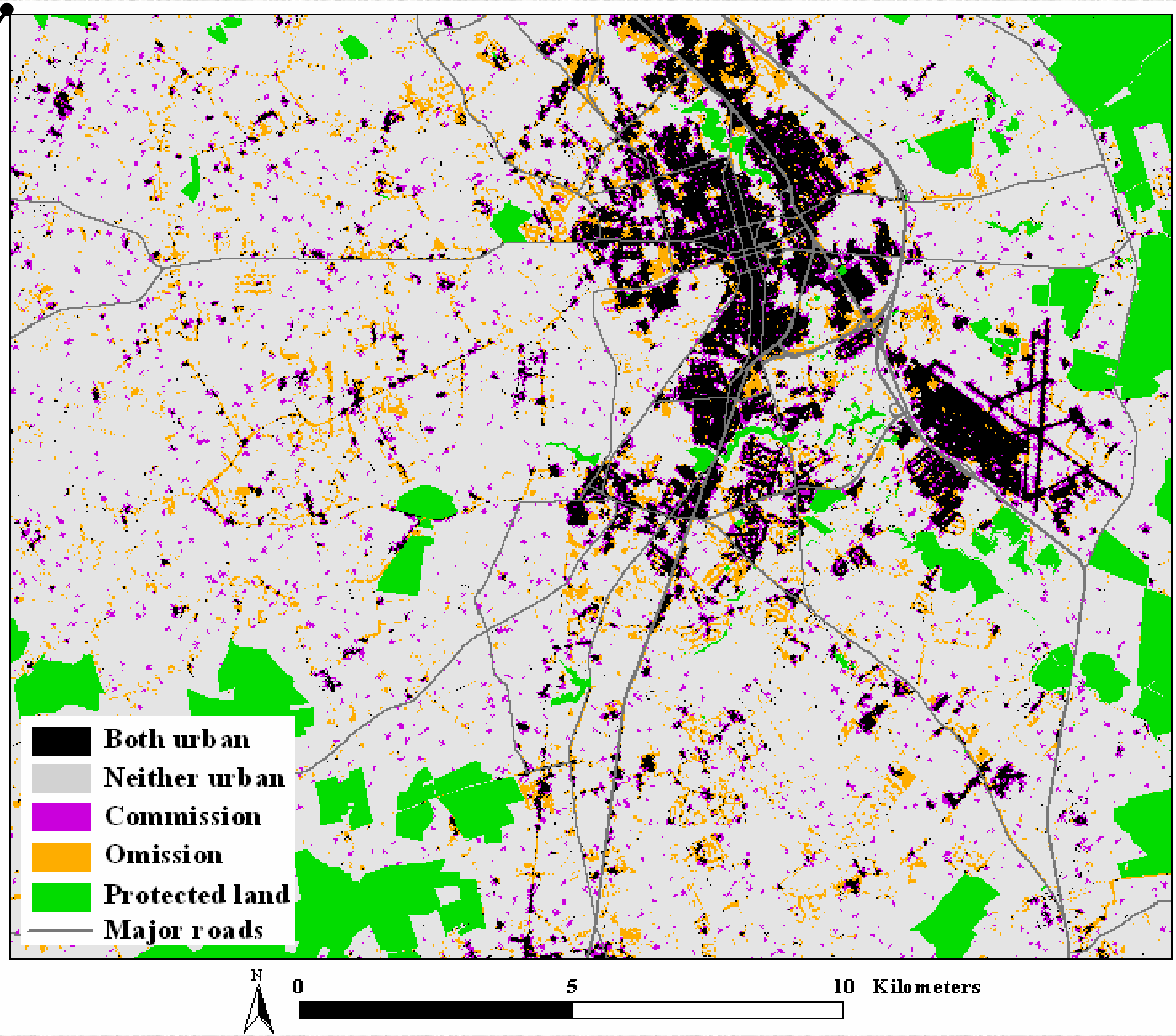
Calibration of the Delmarva

- Area match (ratio) = 0.045
- Clusters match (ratio) = -0.004

Comparing actual 2000 Impervious to modeled 2000 impervious





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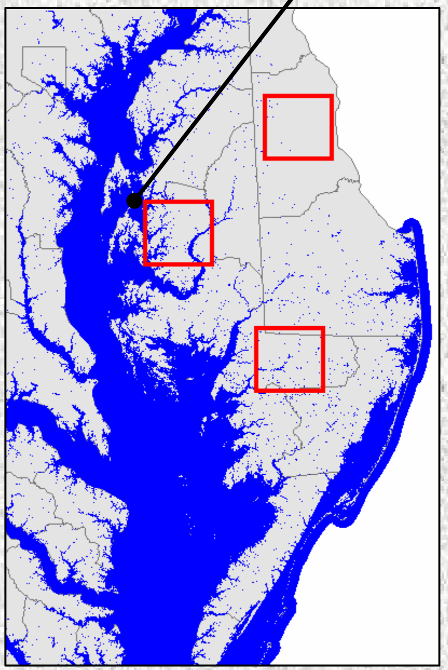

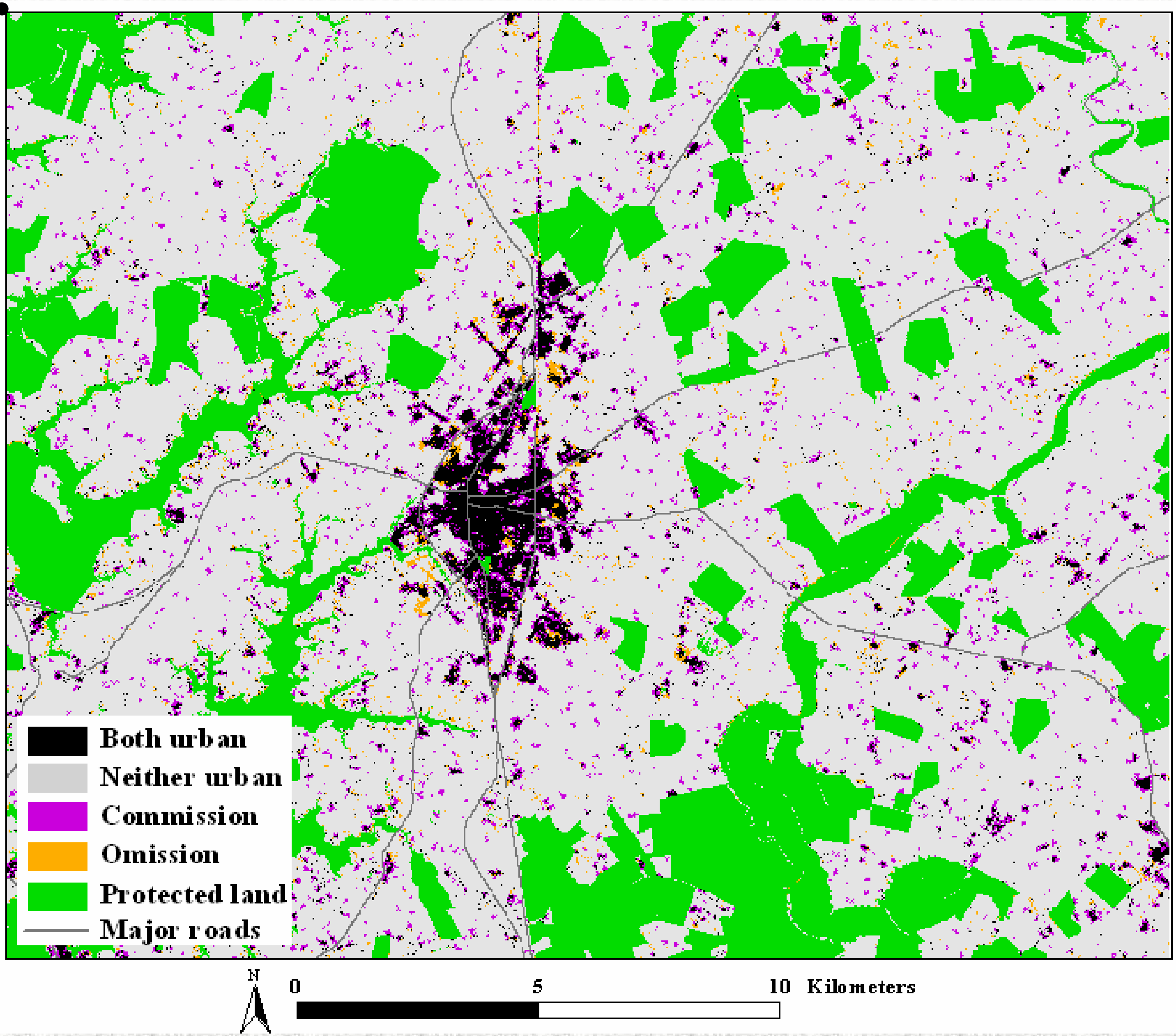

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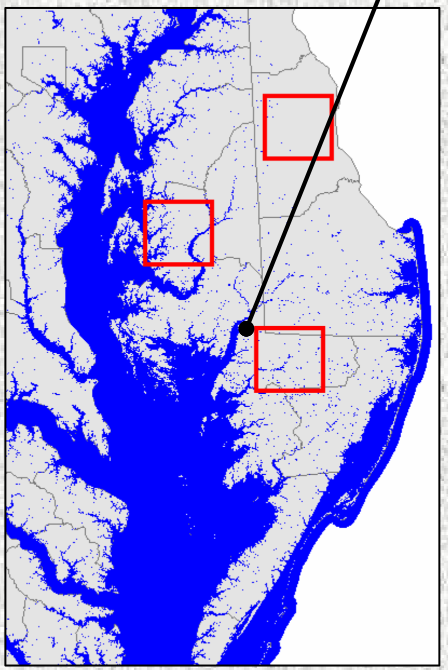

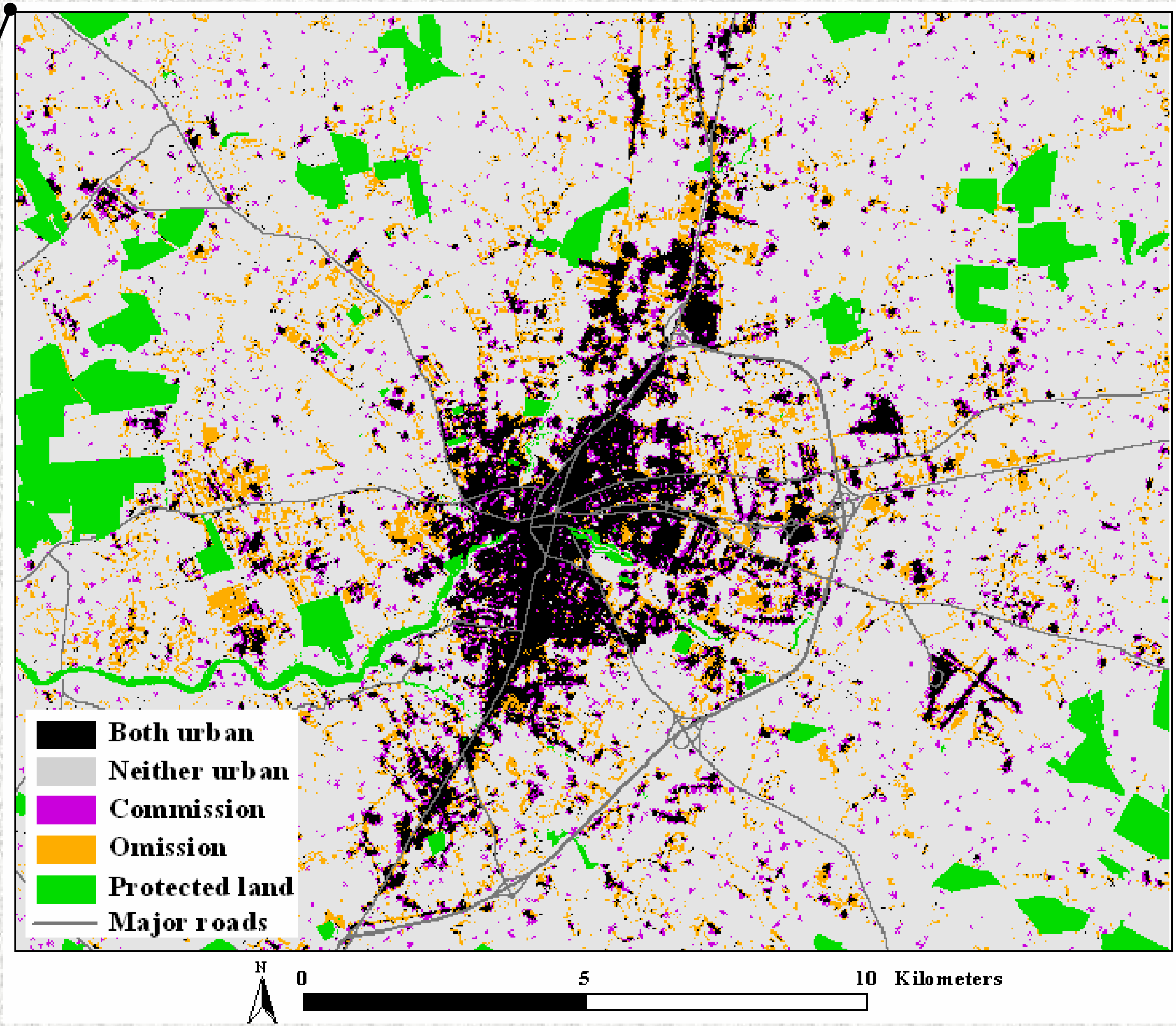

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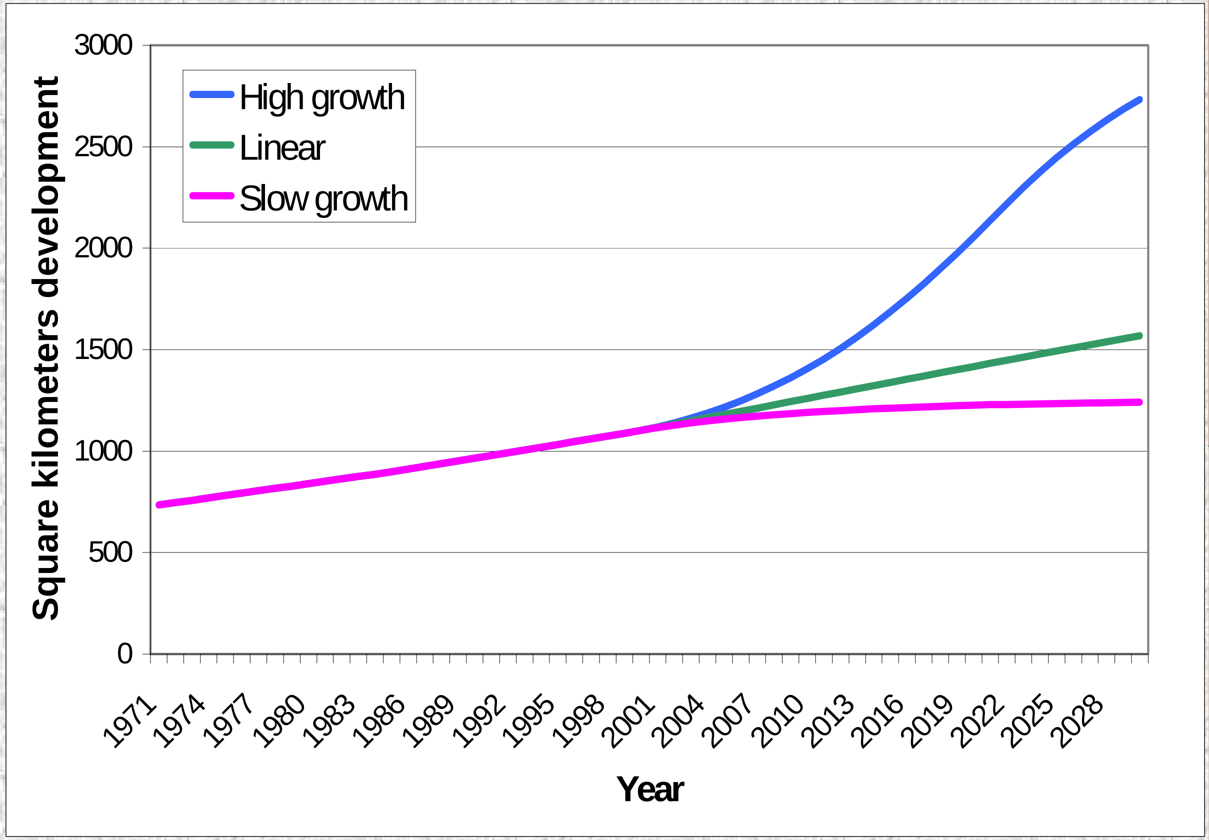
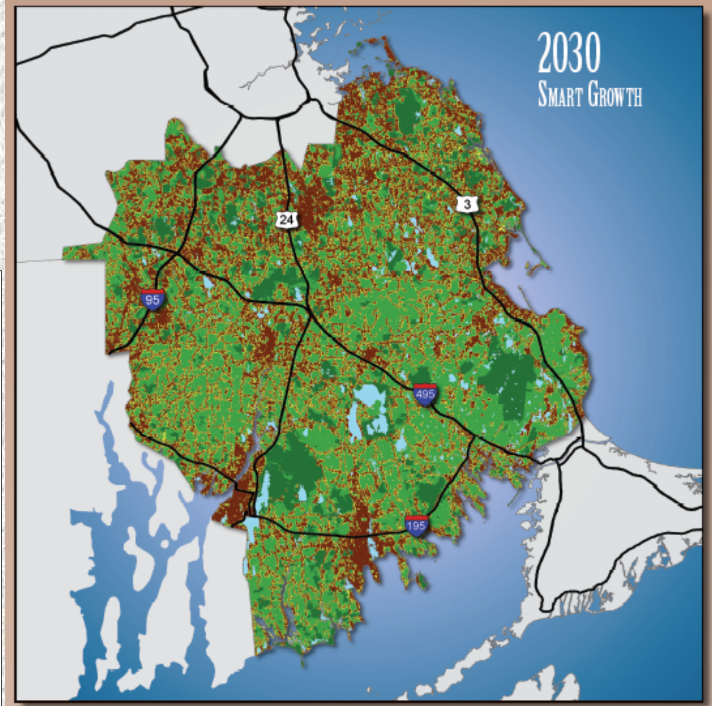
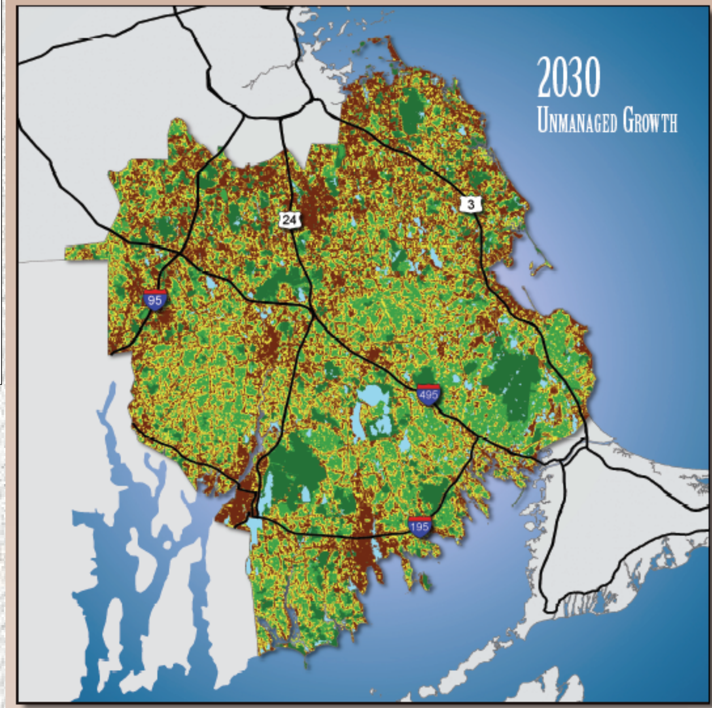
Forecasting

- **Scenarios**
  - "Current trends"
  - Best case vs. worst case
- **User inputs**
  - Excluded layer
  - New roads
  - Dynamic growth rates ("self-modification")
- **Output**
  - Maps showing probabilities of change
  - Tabular summaries

Forecasting







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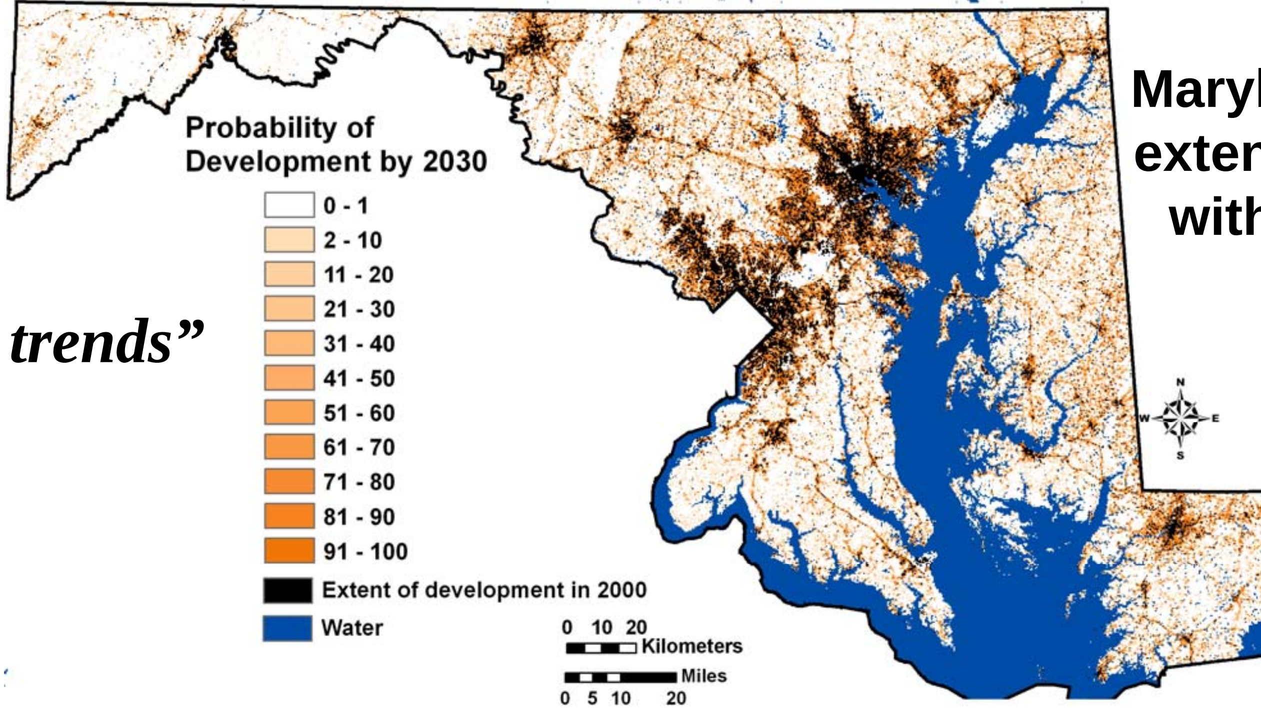
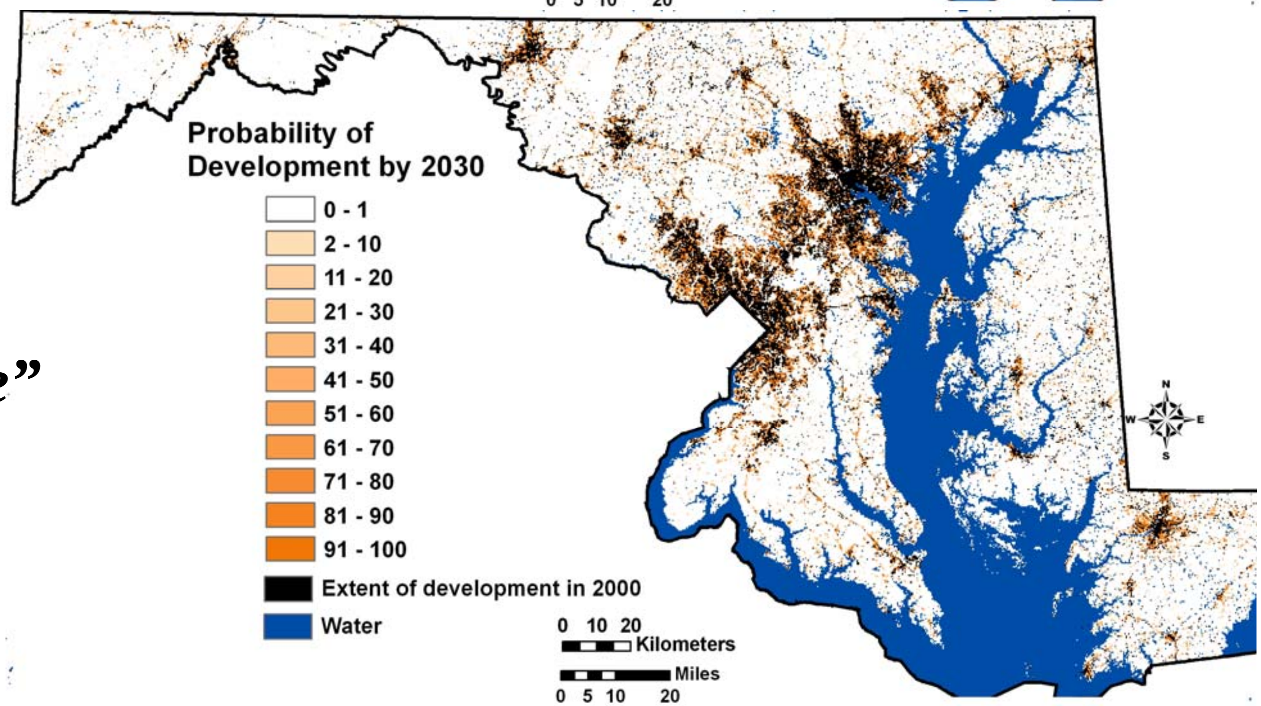
Example from application in southeast Massachusetts

Maryland urban extent modeled with SLEUTH

"Current trends"



"Best case"



STATE OF MARYLAND DEPARTMENT OF NATURAL RESOURCES

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Key assumptions

- **Process is not modeled explicitly**
  - Pattern is linked to process
- **Future development patterns are derived from historic trends, but…**
  - Development rates can be modeled dynamically
  - Flexible scenarios set suitability for where exclusions (& attractions) occur
- **Elements in the excluded layer do not change through time**

Limitations

- Sensitivity to scale (grain) of input data
- Calibration parameters are not transferable
  - Scale sensitive
  - Site specific
- Pixel-scale forecasts are probabilistic
- Computational requirements

Advantages

- Capability to create broad-scale dynamic simulations at a high resolution (30 m cells)
- Limited range of data requirements
- Tightly linked to GIS and land cover observational data sets
- Strong visualization capability

Recent advances

SLEUTH, version 3D

- New calibration fit statistics
- Calibration with two time steps of urban land cover—instead of four time steps (necessity)
- Resolved scale issues related to “diffusion” parameter
  - Diffuse development patterns can be captured using fine scale data
- Reduced computer memory requirements

Limitations of the CBP Land Change Modeling Effort

- The course analytical scale of the CBP Watershed Model may wash away many land use policy effects.
- The number of impact assessment tools is very limited.
- The model is very data hungry and the cooperation of the Stakeholders is critical to model development.
- The assistance of stakeholders is vital during the development and analysis of future policy scenarios.

Modeling Land Change in the Albemarle-Pamlico Watersheds: Issues to Consider

- Purpose?
- Audience?
- Data availability?
- Scale?
- Uncertainty?