A Regional Simulation to Explore Impacts of Resource Use and Constraints

Virginia H. Dale
Oak Ridge National Laboratory

July14, 2006

http://www.esd.ornl.gov/programs/SERDP/RSim/index.html

Contributors

- Latha Baskaran and Lisa Olsen, Oak Ridge National Laboratory -- Geographic information and landscape analysis
- Michael Berry, Matthew Aldridge, Murray Browne, and Eric Lingerfelt, University of Tennessee -- Land use modeling and model integration
- Michael Chang and Farhan Akhtar, Georgia Tech -- Air quality modeling
- Rebecca Efroymson, Oak Ridge National Laboratory -- Risk analysis
- Charles Garten, Robert Washington-Allen and Tom Ashwood, Oak Ridge National Laboratory -- Water quality / nitrogen dynamics
- Catherine Stewart, Aberdeen Proving Ground, U.S. Army Center for Health Promotion and Preventive Medicine (CHPPM)-- Noise modeling
- Virginia Dale, Oak Ridge National Laboratory -- Habitat modeling and integration of impacts

Acknowledgements

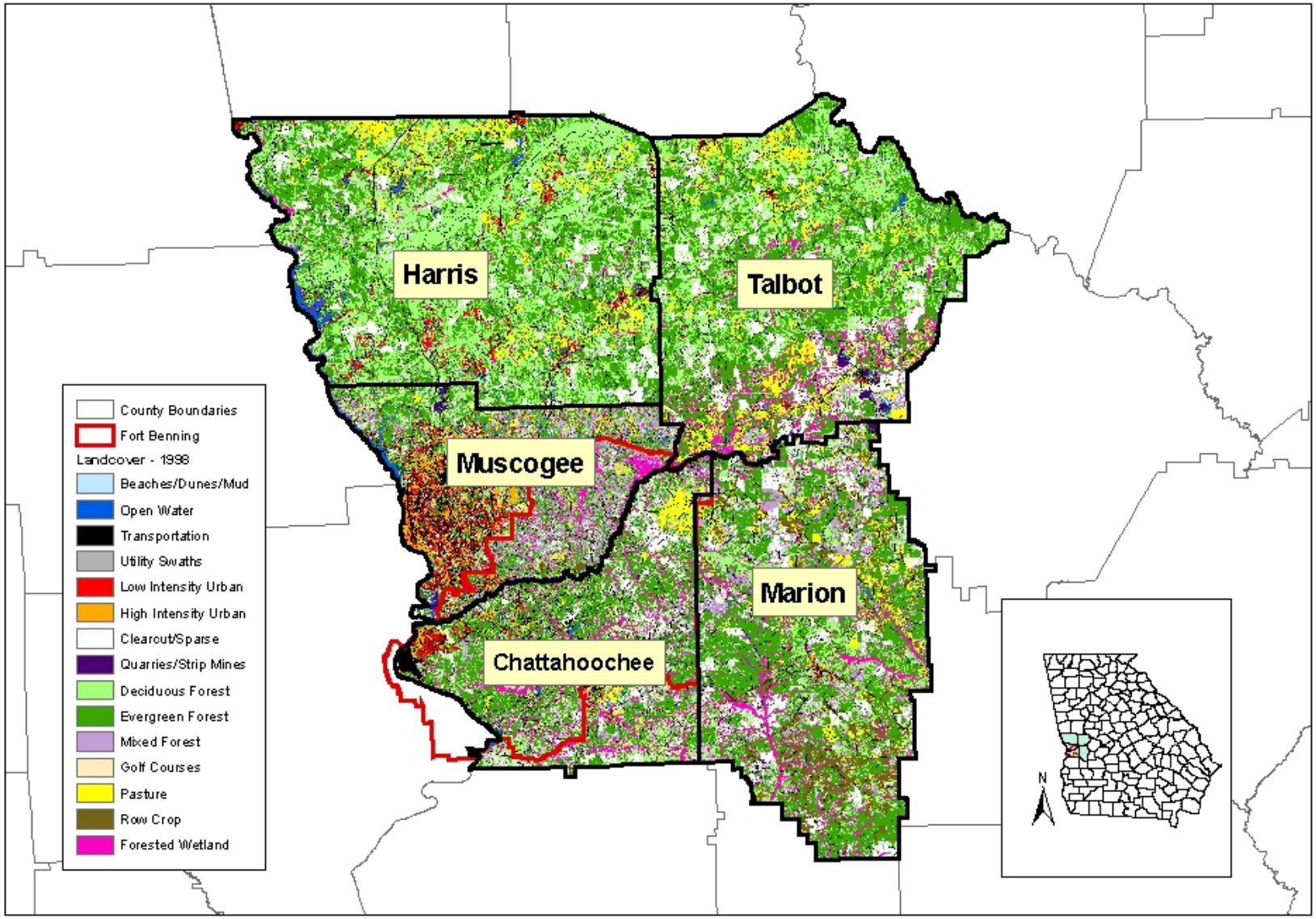
- William Birkhead, Columbus State University
- Hal Balbach, Construction Engineering Research Lab (CERL)
- Wade Harrison, The Nature Conservancy and stationed at Fort Benning
- Val Morrill, Yuma Proving Ground
- Richard Flamm, Florida WC
- Hugh Westbury, CERL and Fort Benning
- Larry Pater, CERL
- Stakeholders in Columbus region
- Reviewers at March 17, 2006, workshop on RSim
  - Jonah Fogel, University of Tennessee
  - Don Imm, Fort Benning
  - Danny Lee, USDA Forest Service
  - James Loar, Oak Ridge National Laboratory
  - Lee Mulkey, SERDP Ecosystem Management Program
  - Stan Wullschleger, Oak Ridge National Laboratory

Technical Objective:

...to develop a spatially-explicit simulation model for military and other planners to understand the implications of land-use change, resource use, and future development policy on the sustainability of military lands and missions and outlying regions.

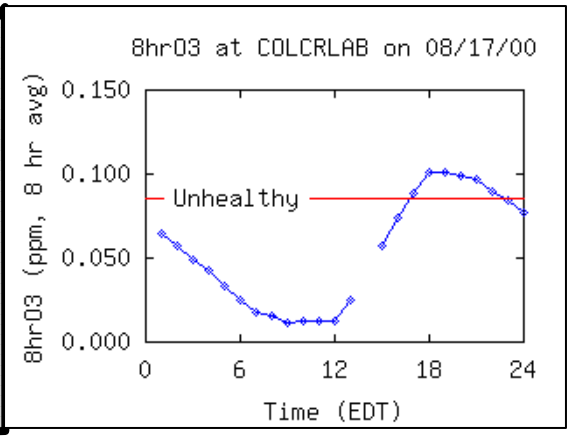
RSim Region

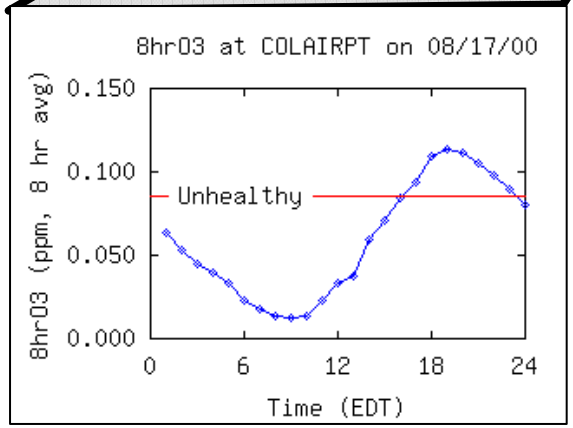
(RSim region encompasses five counties in Georgia)



SERDP
Strategic Environmental Research and Development Program
Improving Mission Readiness Through Environmental Research

Where there is smoke…





Ledger-Enquirer

Columbus violated federal air quality standards Thursday for the second time this year after a record high of 102 degrees combined with haze from a controlled burn at Fort Benning, a state air quality official said.

...there is fire ecology

- The endangered Red Cockaded Woodpecker (RCW) resides in mature longleaf pine forests of the SE US.
- Most of the forests old and large enough to support the RCW are on federal and military lands.
- Longleaf pine ecosystems have adapted to natural fire regimes (wildfires in ~3 to 7 year cycles) and now require periodic burning to maintain health.
- Prescribed burning is a safe and effective alternative to natural fire regimes.

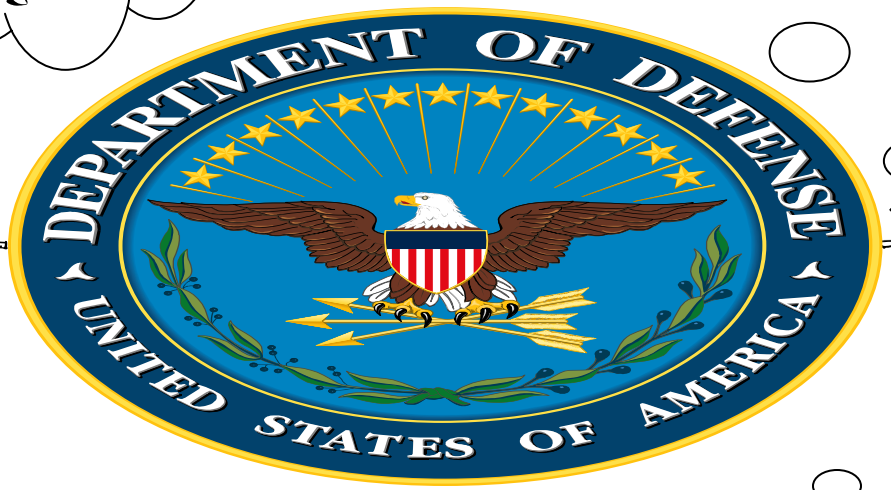
Technical Approach

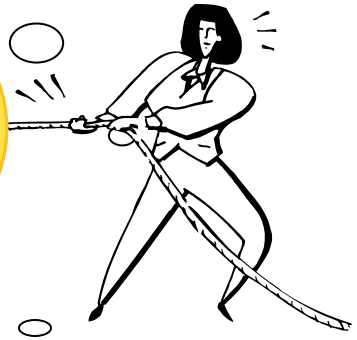
Clean Water Act

Clean Air Act

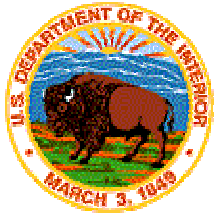
Endangered Species Act

Noise ordinances





Military use



Software Design Overview

- Implemented in Java
  - Allows for platform independence (Win, Mac, Linux)
  - Can be deployed via WWW or CD/DVD
  - Object-oriented nature accommodates modularity of components (simulation modules, visualization, report generation, and user interaction)
    - Increased potential for future code reuse and extension
- Independent of proprietary software (e.g., ESRI)
  - Can be used by anyone with sufficient comp specs
  - Experts can export RSim result for deeper analysis with external software

Urban Growth Model

- Adapted from SLEUTH urban growth model (developed by Dr. Keith C. Clarke, UCSB)
- Modifications needed to handle two urban land cover types
  - Low-intensity vs. high-intensity urban
  - Both classes use similar urbanization rules
- Exclusion areas
  - No urbanization in these areas
  - Ft Benning, conservation areas
  - Also, areas of open water, transportation routes

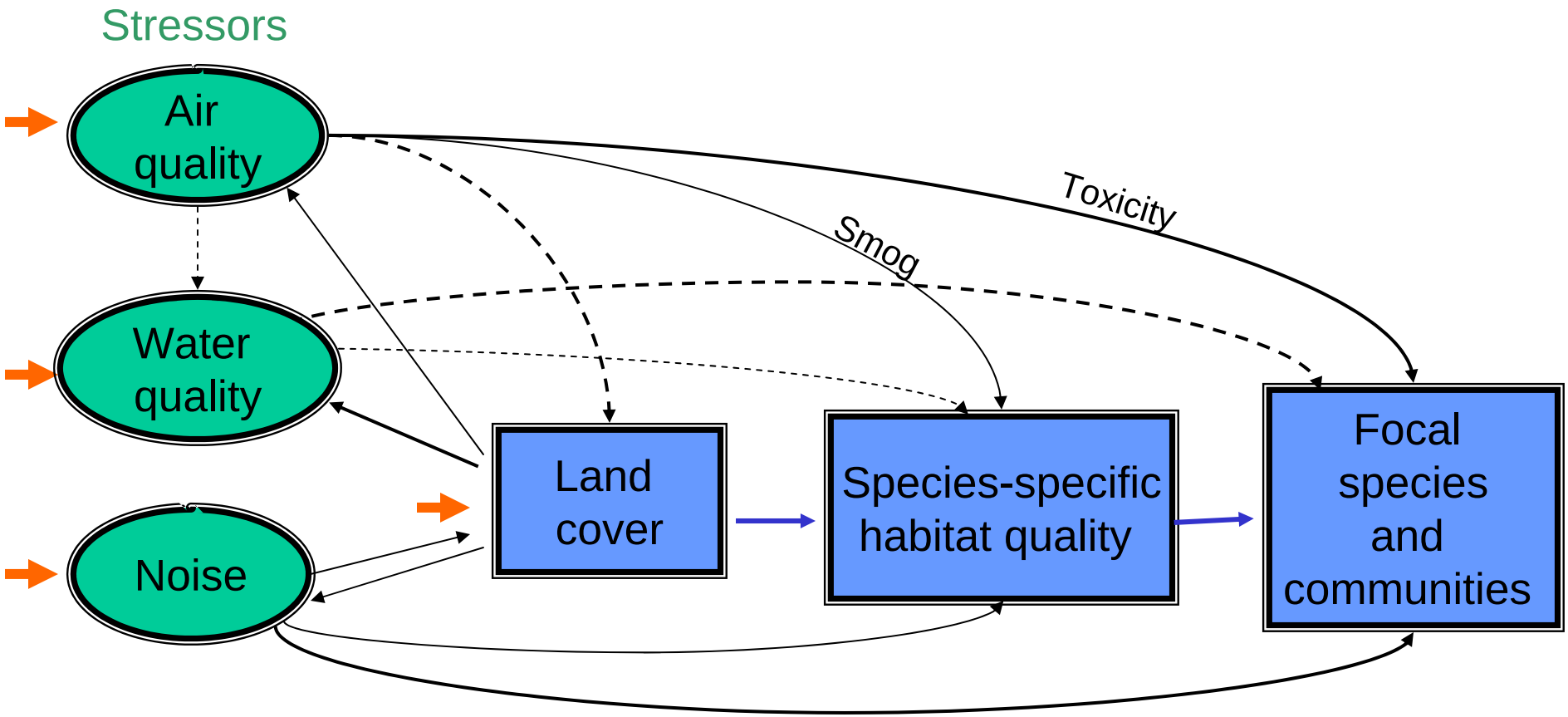
Urban Growth Rules

- Random placement
  - Relatively few by this method
- Edge/spread
  - Majority of new urban cells
  - "Spreading Center": cluster of 3 or more urban cells
    - Some new urban cells by random placement will spawn creation of SC
  - Urban cells that are part of a SC can spawn new adjacent urban cells

Urban Growth Rules (cont'd)

- Road Influenced
  - May be initiated by creation of urban cells using previous rules
  - A major road is sought out, starting from the newly created urban cell
  - If road is found, the road is traversed for some distance
    - 4-lane roads can accommodate longer trips than 2-lane
  - After successful trip, cells next to the end point are examined for possible urbanization

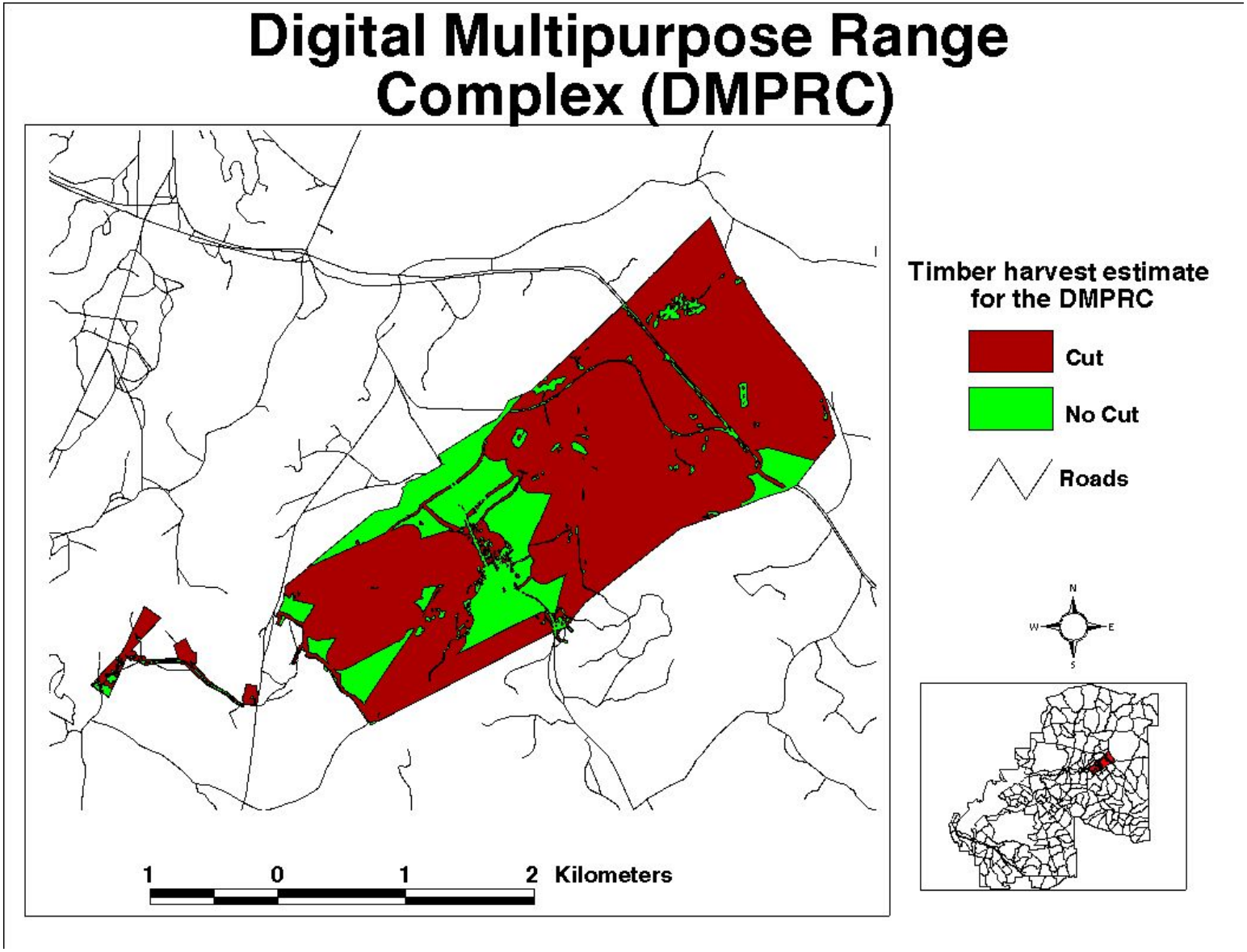
Scenarios influence RSim



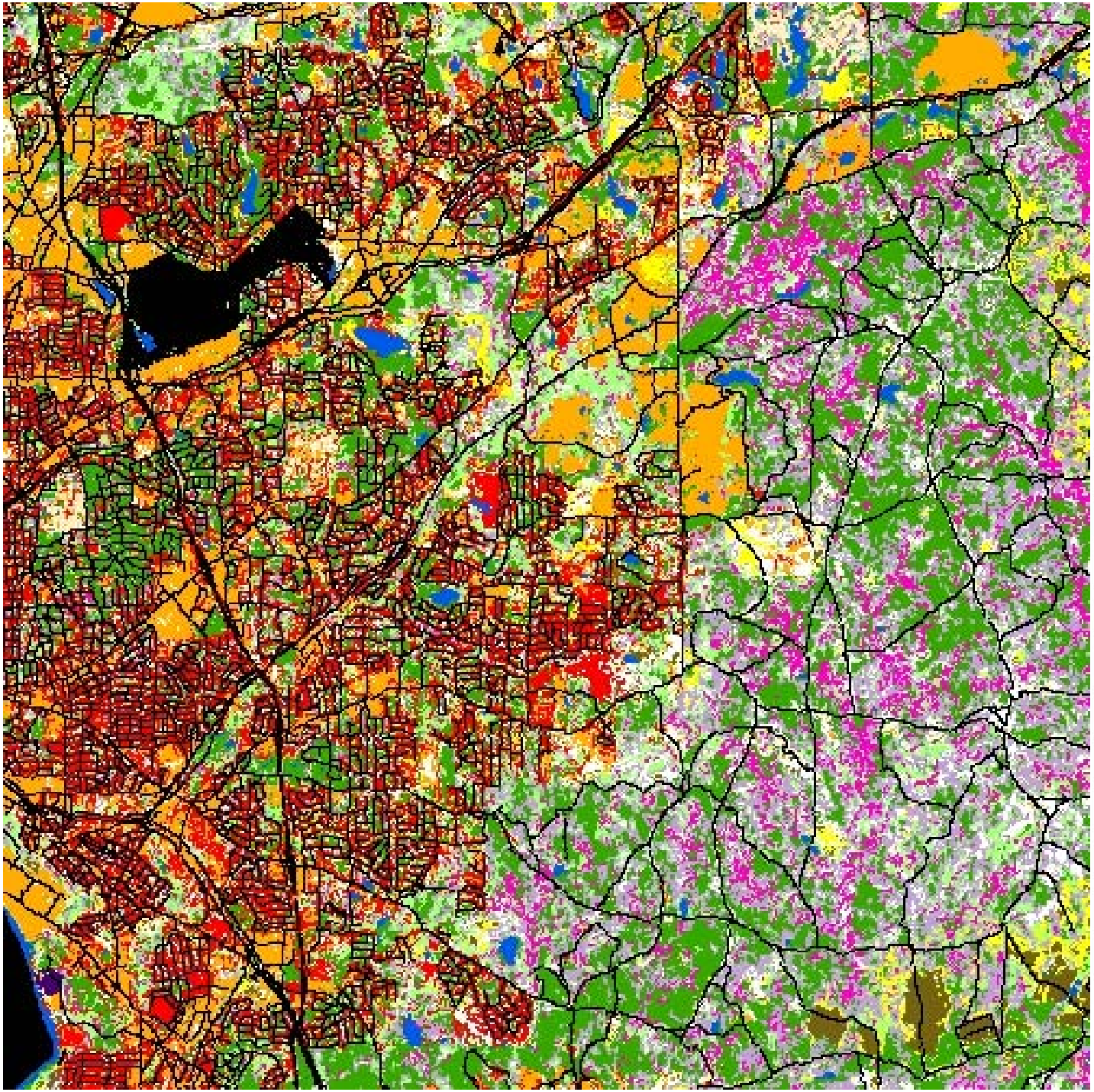
Example Scenarios (➔)

- Urban growth
- Military use
- Road Improvement
- Hurricanes

New Training Area



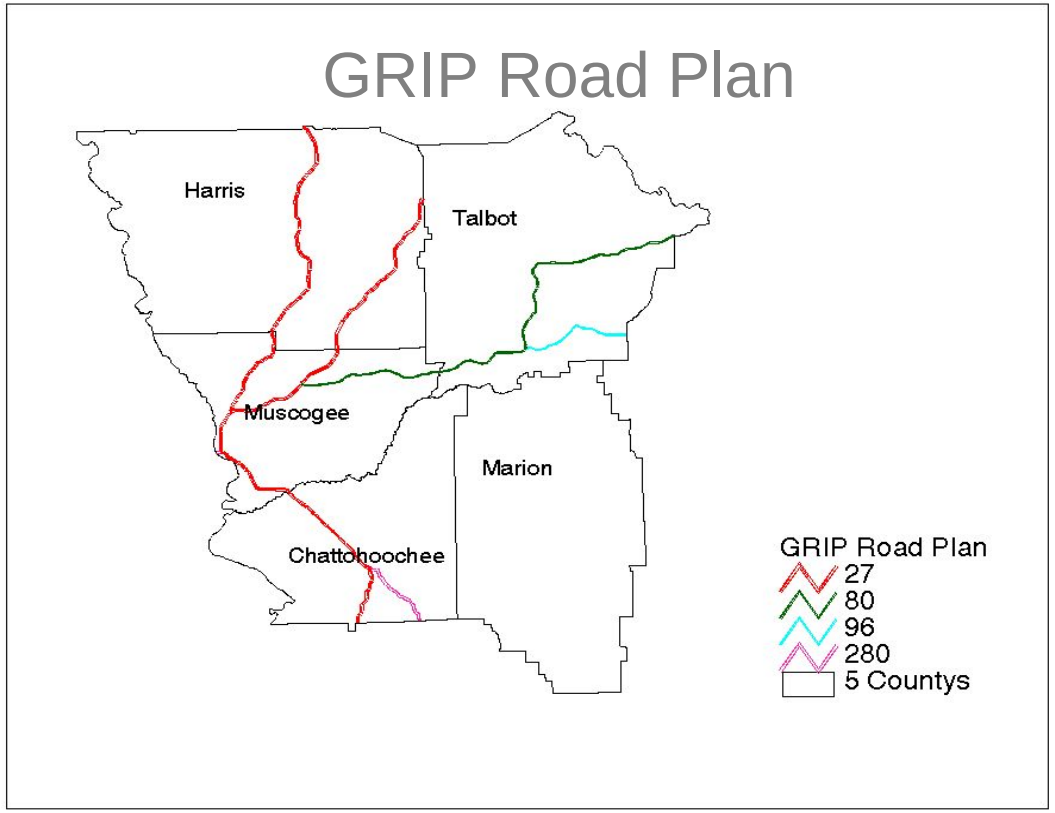
Results: Urban Growth Scenario

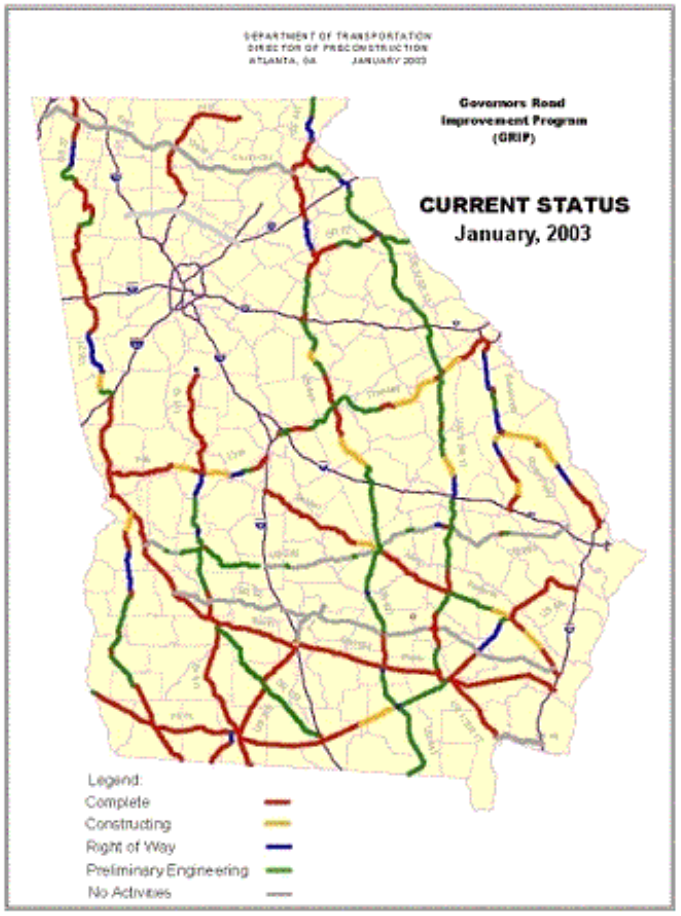


- Beaches/Dunes/Mud
- Open Water
- Transportation
- Utility Swaths
- Low Intensity Urban
- High Intensity Urban
- Clearcut/Sparse
- Quarries/Strip Mines
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Golf Courses
- Pasture
- Row Crop
- Forested Wetland

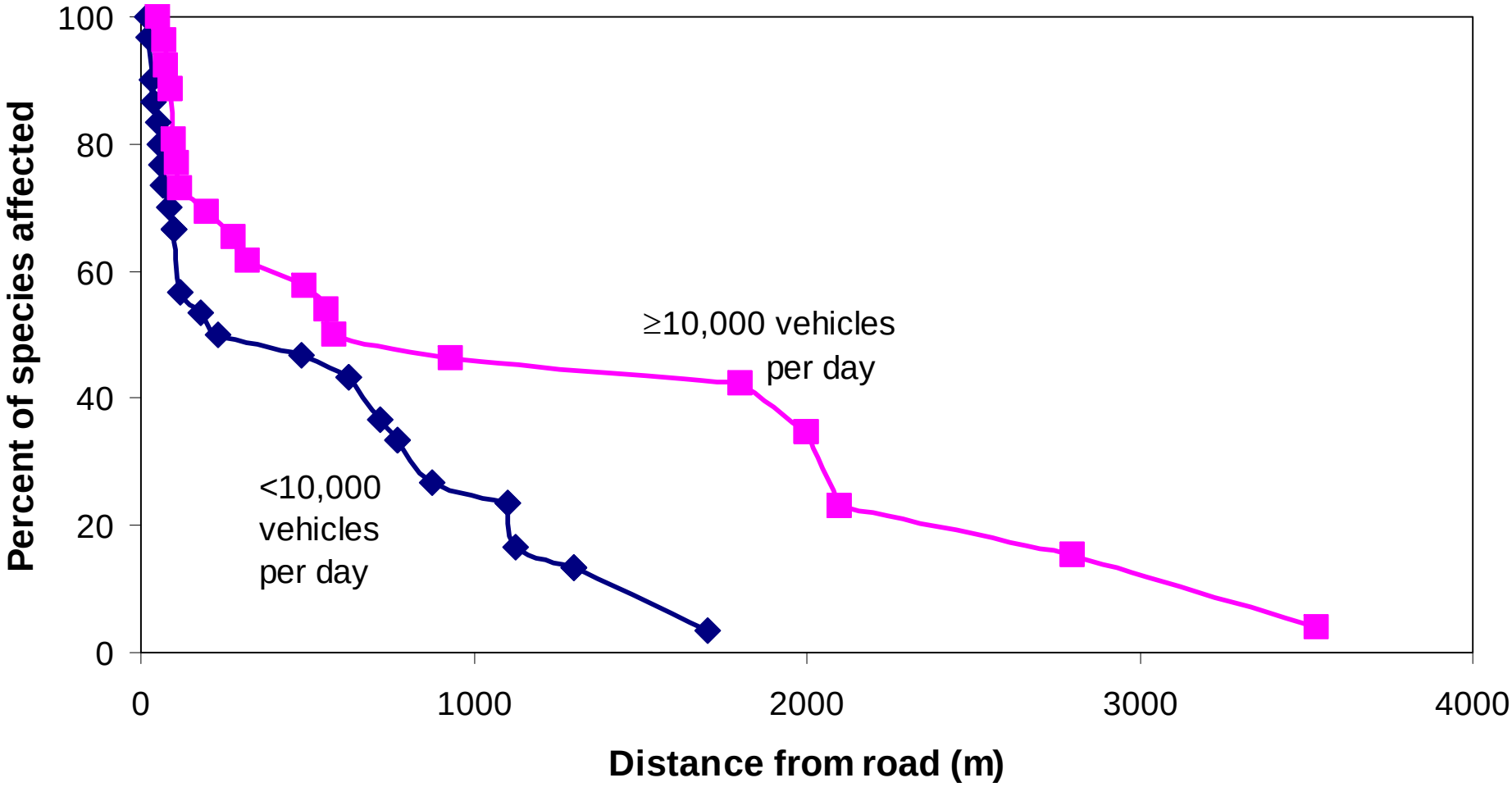
Proposed Road Plans for RSim Region

- Governor's Road Improvement Program (GRIP):
  - to widen two-lane roads
  - to attract economic development by improving the state's highway network

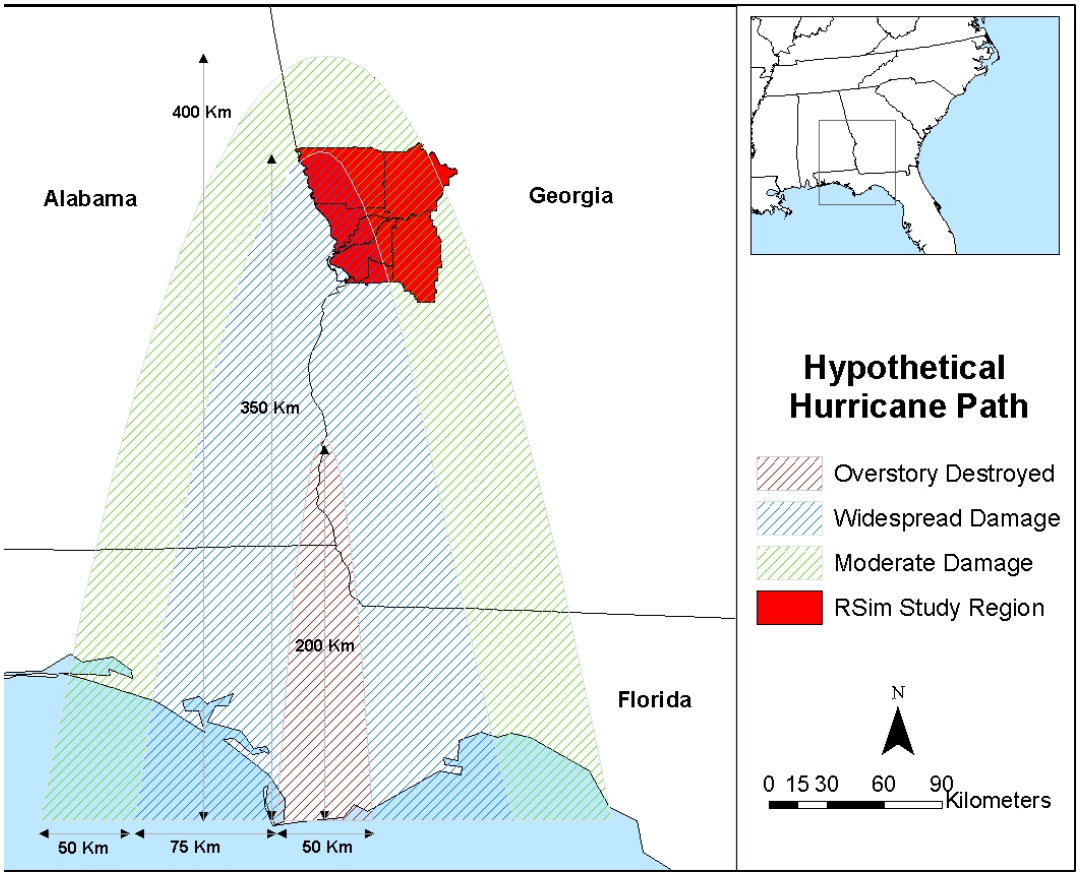




Distances from roads at which avian densities are reduced



Hurricane Scenario



Extent , depth, and impact of hurricane path from the coast is similar to that of Hurricane Hugo on the South Carolina coast (Conner 1998).

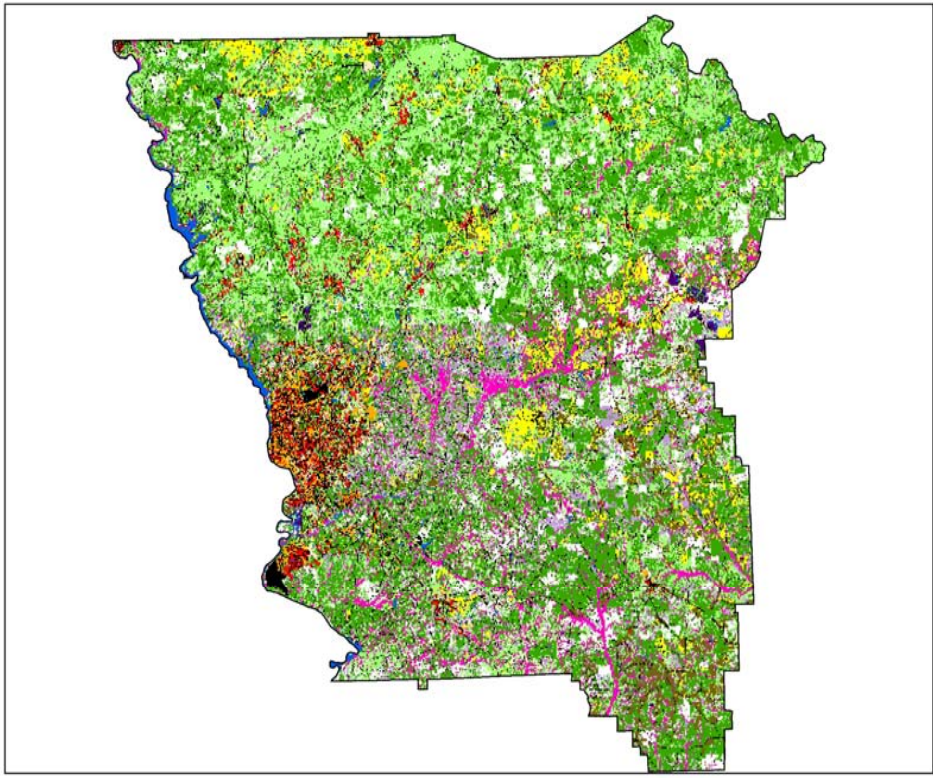
Hypothetical hurricane damage

- **Overstory destroyed** – 100% of the forest landcover is destroyed and converted to clearcut/sparse landcover
- **Widespread damage** - 50% of the forest landcover is destroyed and converted to clearcut/sparse landcover
- **Moderate damage** - 25% of the forest landcover is destroyed and converted to clearcut/sparse landcover

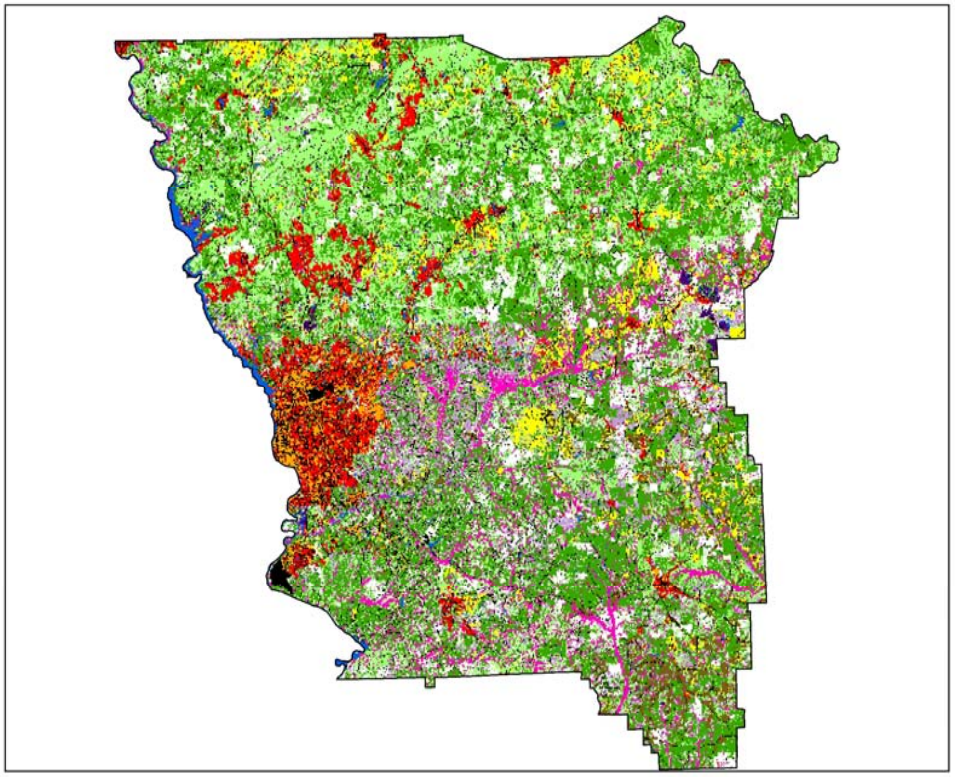
Ten years after the hurricane damage, the original forest

Projected Growth along Roads

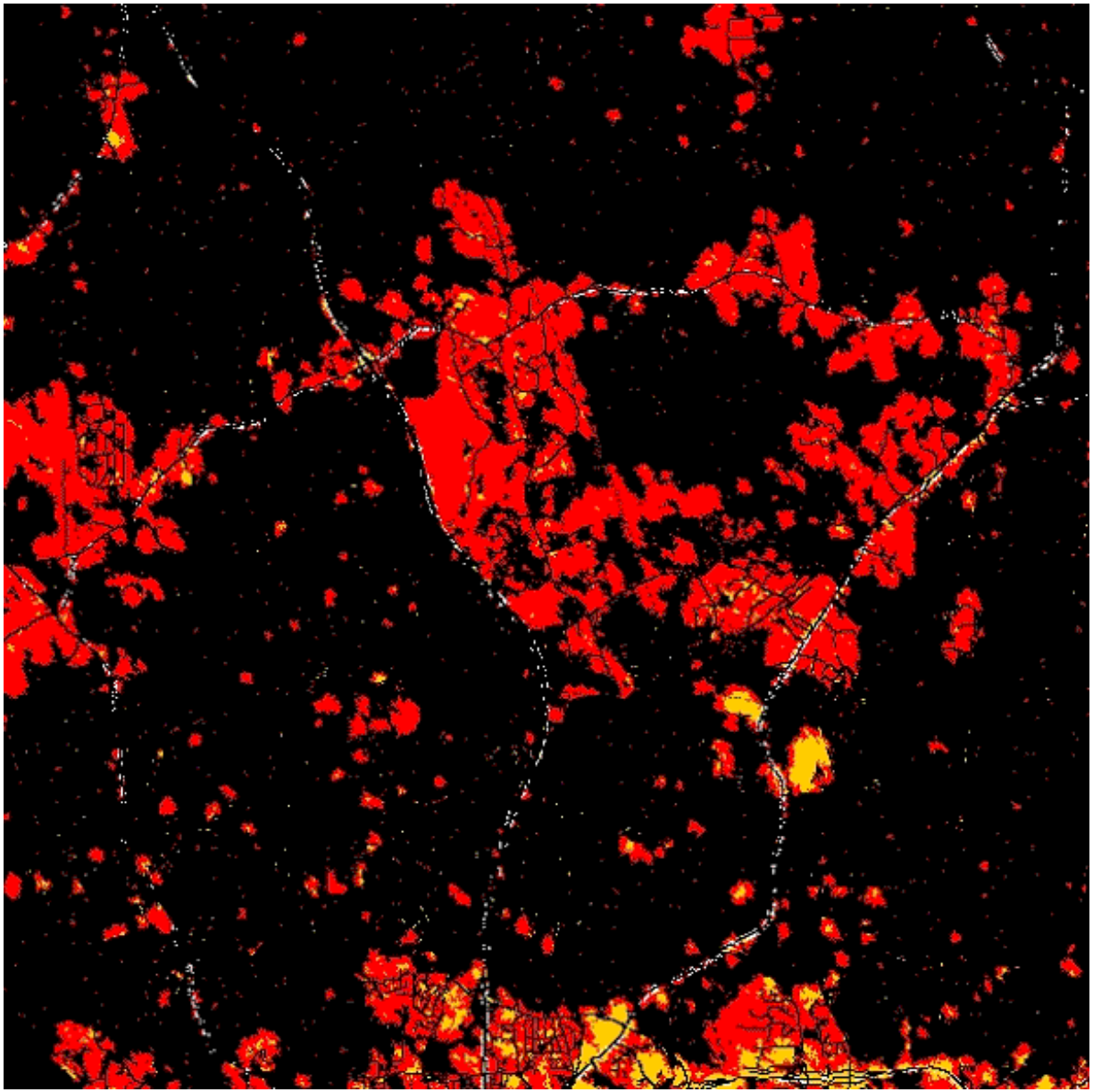
1998



Projected



Changes to Columbus area are primarily attributed to low-intensity urban growth



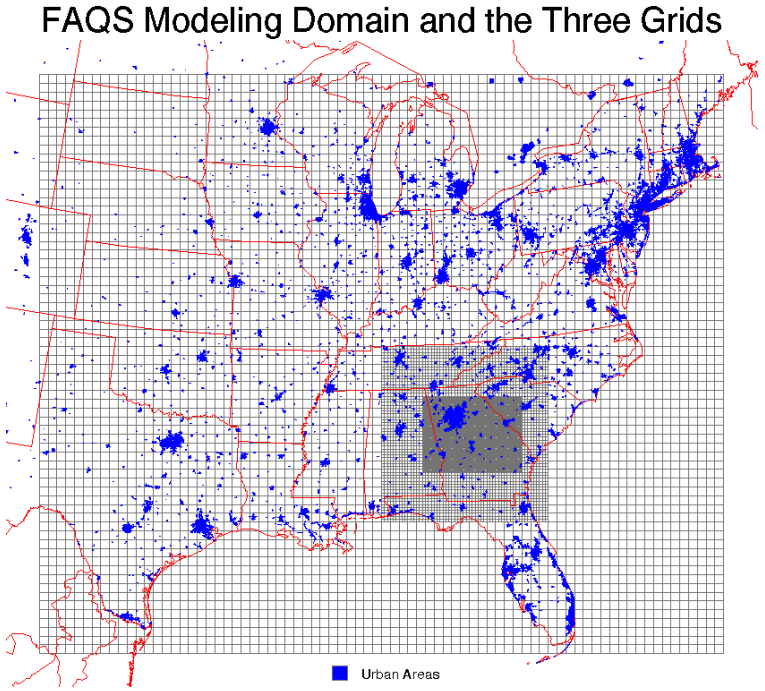
= low-intensity urban

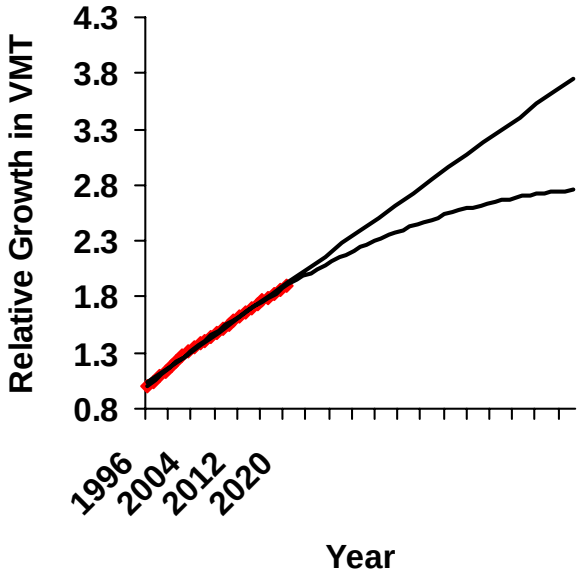
= high-intensity urban

= road growth

The RSim Air Quality Module Challenge:

- More Variables
  - Because of short deadlines mandated by the Clean Air Act, most air quality models do not address
    - long-term changes such as land or resource use
    - consequences associated with other concerns (e.g. noise, water, habitat).
- Simpler Codes & Faster Execution
  - Air quality models must solve hundreds of chemical reactions across thousands of grids in seconds. A simulation day may require hours of processing time. RSim will require simulations be completed ~immediately.
- Longer Forecasts
  - In the near term, one can assume inertia in infrastructure, activities, and technologies (e.g. roads, industrial processes, travel behavior).
  - At longer time scales, the same infrastructure, activities, and technologies are susceptible to change, which is difficult to forecast.





RSim: Changes in Ozone Air Quality

Georgia Institute of Technology

$$ozone_t = ozone_{2000} + \frac{\partial(ozone)}{\partial(source)} \Delta source_{t-2000}$$

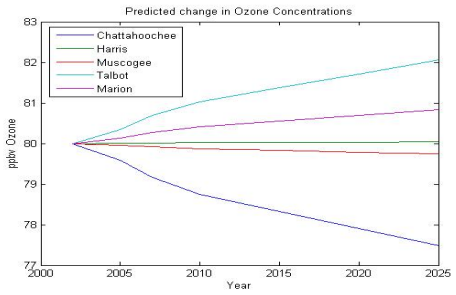
ozone in future year

ozone in base year with known emissions

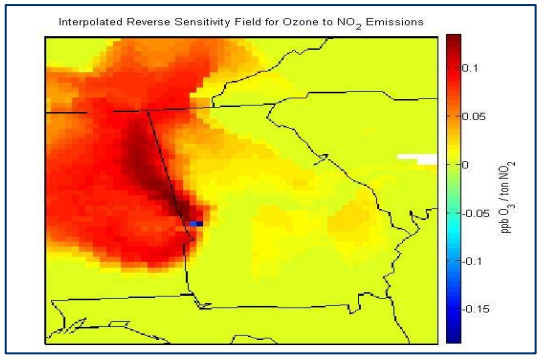
sensitivity coefficient

Change in emissions from base year to future year (scenario and user specified)

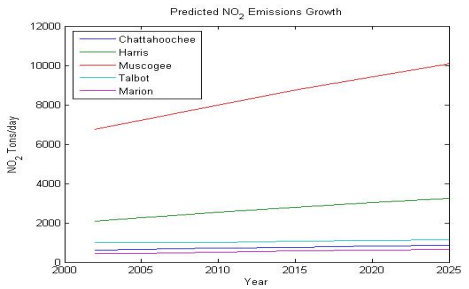
Air Quality Impact ($\Delta\chi$)



Transformation (P)

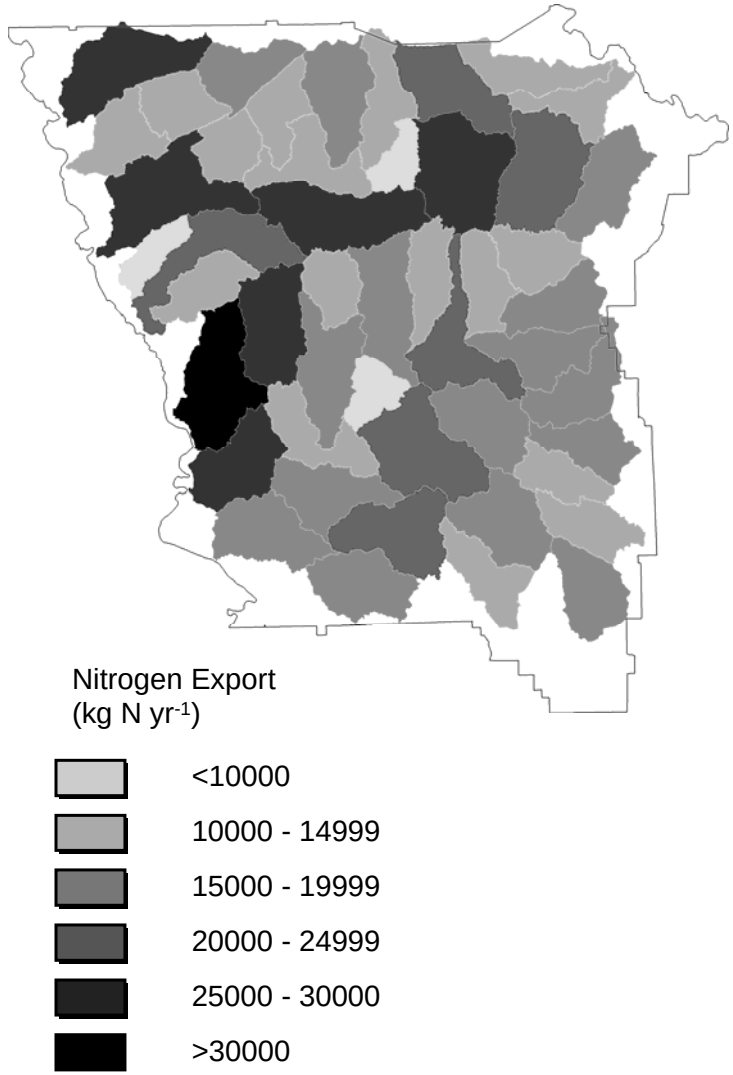


Emissions Change (ΔE)

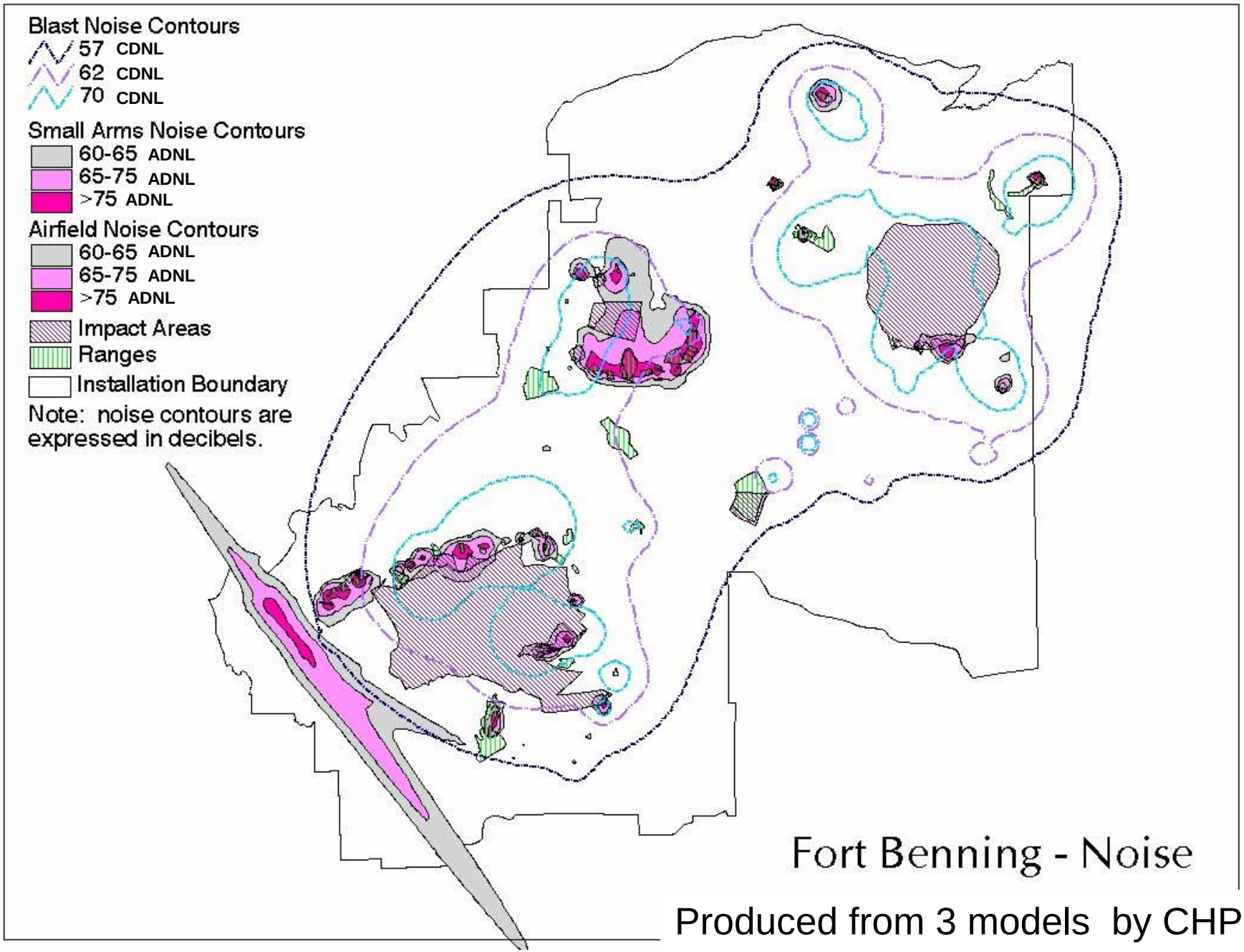


Annual N and P Export From Watersheds

- There are 48 watersheds (12-digit HUCs) within the RSIM region (≈3573 km^2)
- Used export coefficients for different land covers from NCSU WATERSHEDSS Pollutant Budget Estimation Form
- Calculated annual N and P loads based on 1998 land cover map
- Regional N load (238 kg km^{-2} yr^{-1}) was in the lower range reported for US rivers (177 to 518 kg N km^{-2} yr^{-1})
- Regional P loads (42 kg km^{-2} yr^{-1}) agree well with reports for other US rivers
- Urbanization and commercial development have the potential to alter future N and P exports from affected watersheds within the RSIM region



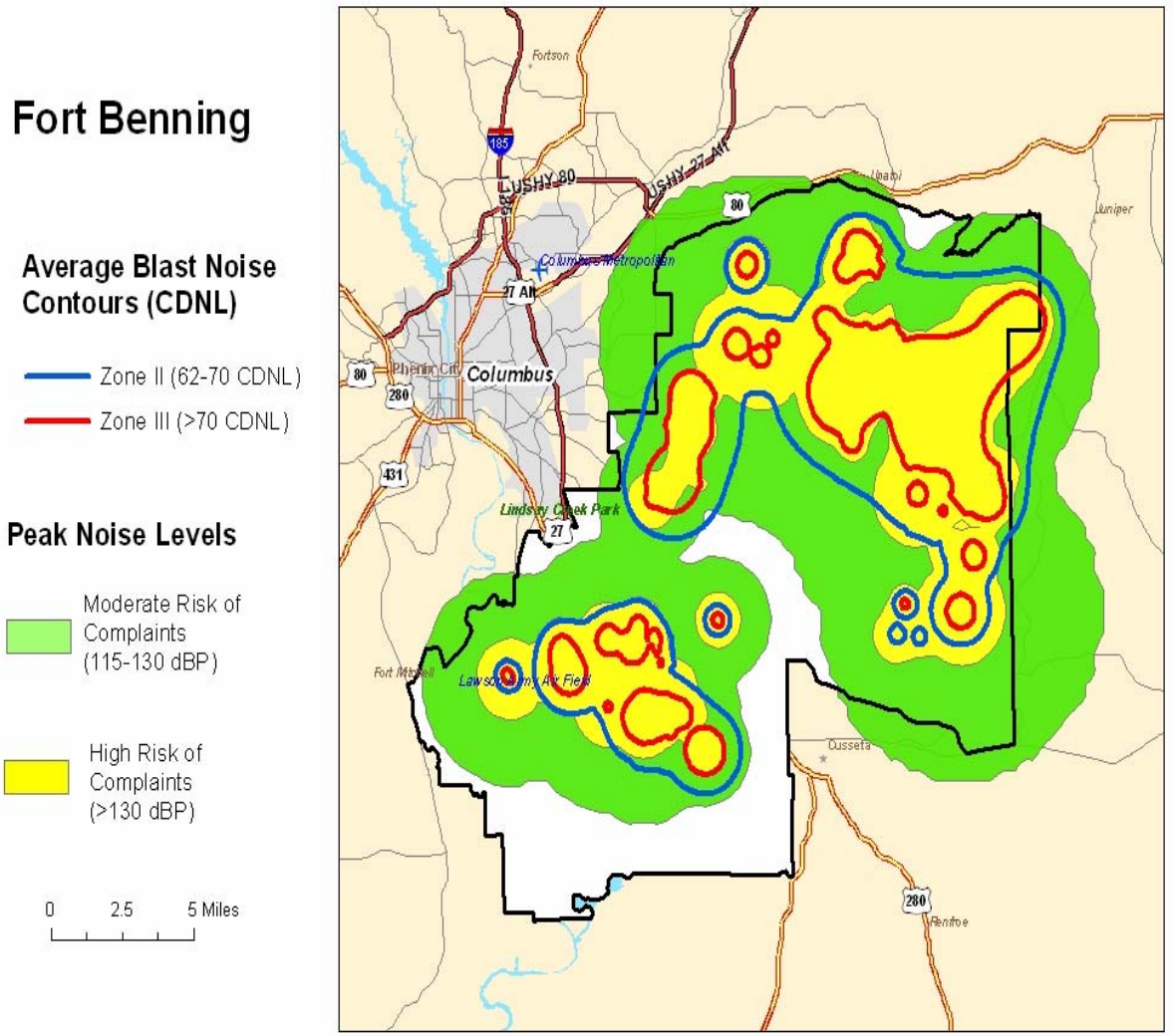
Model Component: Noise



Produced from 3 models by CHPPM

Determining noise effects on wildlife

- Have peak noise levels
  - Isoclines and grid values
  - More related to animal responses
- Will analyze effects of peak noise on gopher tortoise
  - Based on
    - Measured thresholds
    - GIS correlations
  - Example effects
    - Immobilization
    - Avoidance
    - Acoustic threshold shift
- Challenges
  - Units (exposure vs effects)
  - Monitoring
  - Few effects data, mostly no effects levels
  - No inter-species extrapolation methods
  - Few data on individual training events
  - Correlations of noise with habitat variables



Model Component: Focal Species and Communities

Data on species occurrence and potential for occurrence:
- *Fort Benning
- *The Nature Conservancy
- *Soil data

Data on habitat:
- *Fort Benning: ECMI and LCTA
- *EPA's Southeastern Ecological Framework (SEF)
- * Longleaf Pine Alliance

Scenario constraints

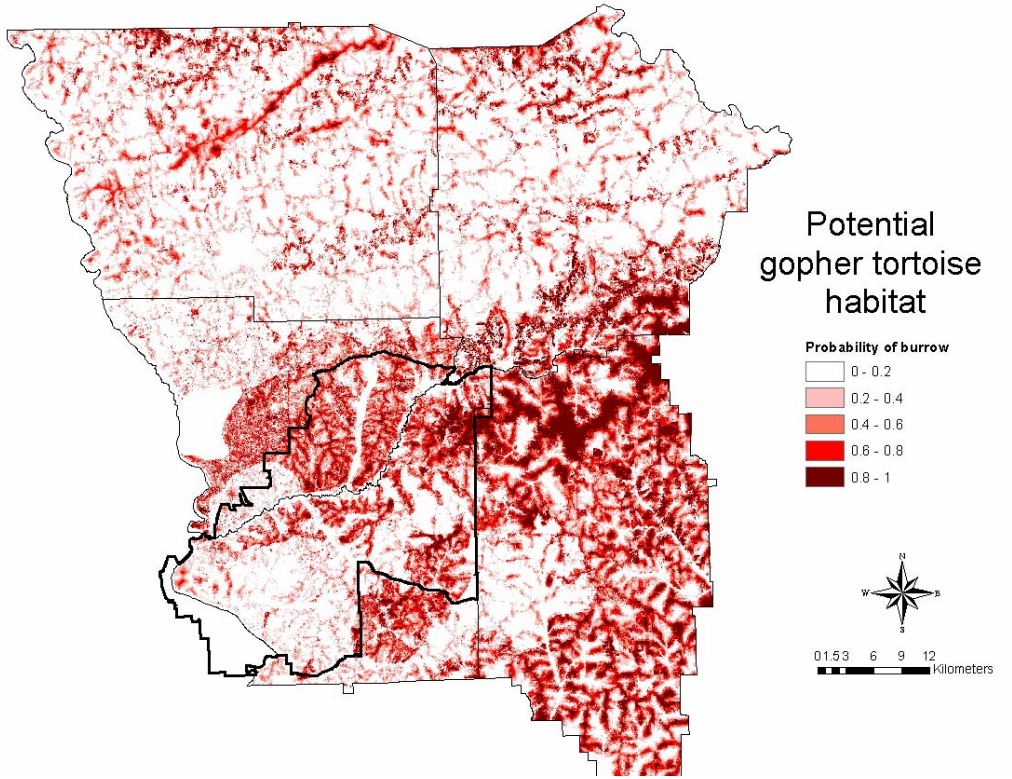
Models of species presence and habitat availability

Constraints from other factors:
- *Noise
- *Water or nutrients
- *Air

Species and habitat effects

Gopher Tortoise Habitat Model

- Well documented gopher tortoise burrows within Fort Benning were used to develop a habitat model for the five county region
- The parameters considered for the model are landcover, soil, distance to roads, distance to soils and slope
- Model has been field tested and analysis is “in press” in peer reviewed literature



Baskaran, L.M., V.H. Dale, R. A. Efroymson, and W. Birkhead. In press. Habitat modeling within a regional context: An example using Gopher Tortoise. American Midland Naturalist.

Results from projection of gopher tortoise burrows

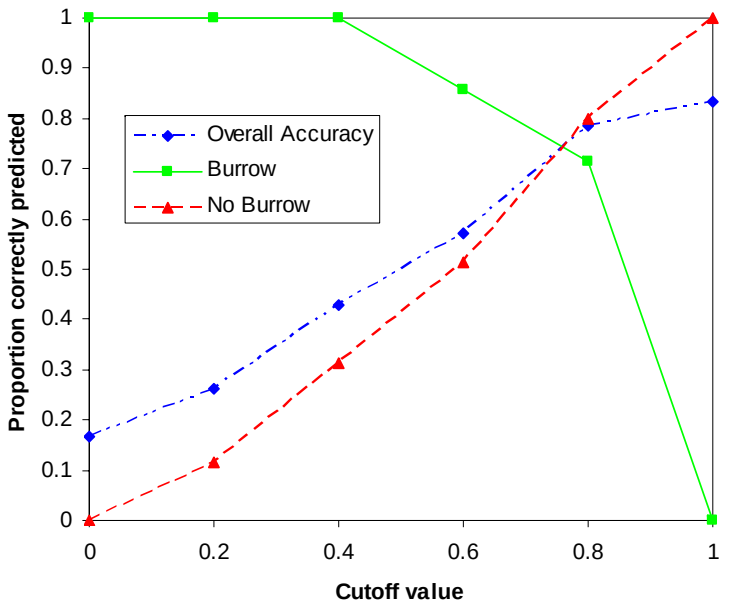
- The probability of finding a burrow
  - Decreases
    - As the clay percentage in the top soil layer increases.
    - As the distance from the road increases.
  - Increases
    - When the land cover is a
      - clear-cut/sparse region*
      - pasture*
      - transportation cover
      - utility swath
      - deciduous, evergreen or mixed forest
      - row crop
    - As the distance to streams increases.

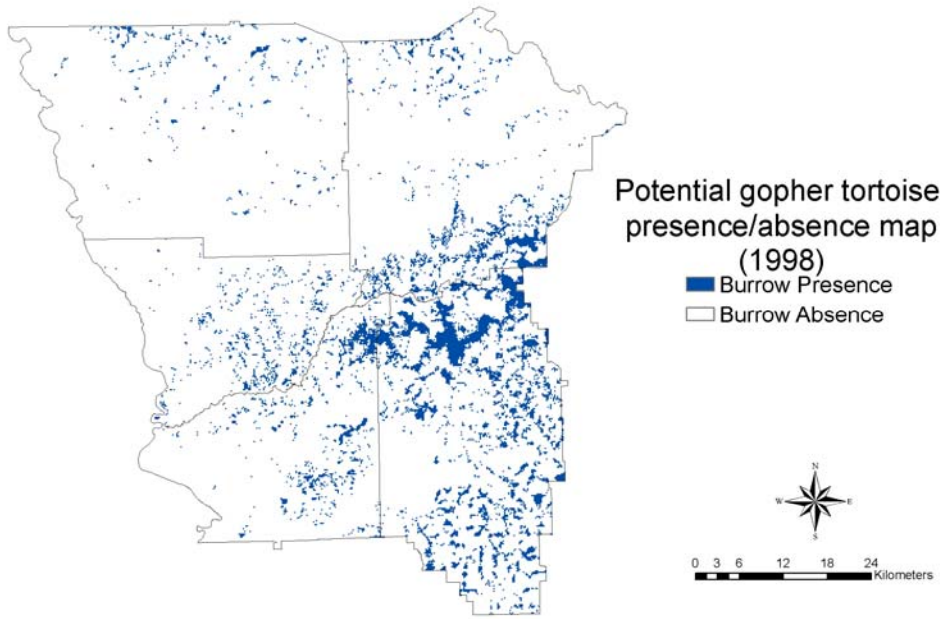
* = Most important

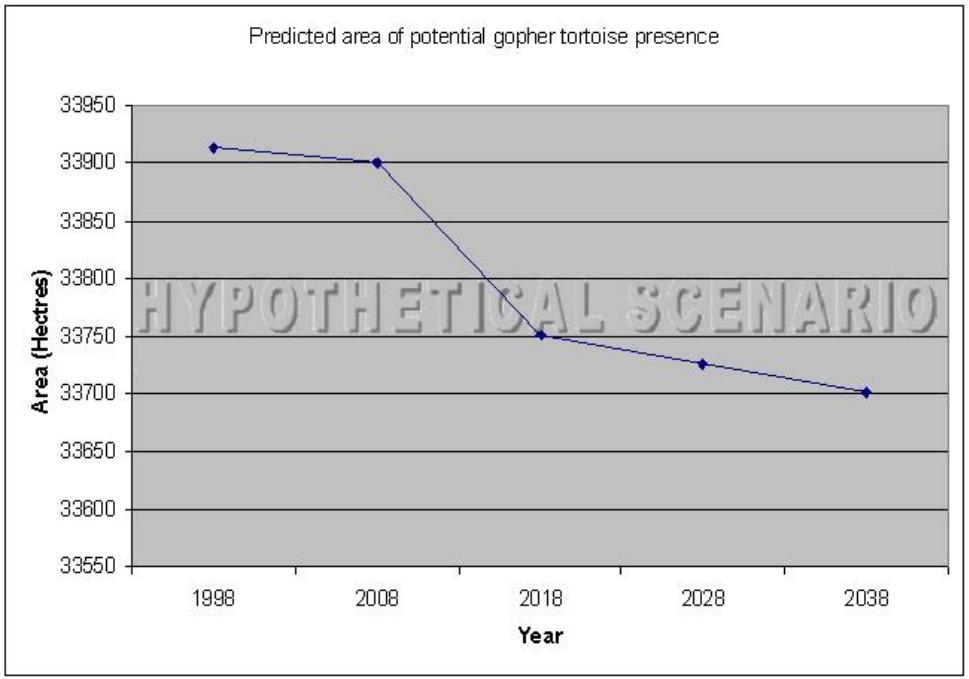
Relating gopher tortoise model to RSim (Regional Simulator)

- Choose from scenarios in RSim:
  - Population growth
  - Road improvement plan
  - The Digital Multipurpose Range Complex (DMPRC) in Fort Benning
- Feed land-cover change caused by each scenario into the gopher tortoise model
- Identify locations with a change in the probability of supporting gopher tortoise burrows

Cut off probability value affects prediction error







Example Ecological Outputs of RSim

- Stability of population of red-cockaded woodpecker (RCW) based on number of territories
- Map of RCW clusters where temporary flushing from nest may occur
- Area of otherwise suitable gopher tortoise habitat that is unsuitable due to small patch size
- Map of gopher tortoise burrows that may be abandoned following land cover change
- Buffer areas around roads likely to have low abundances of particular songbirds
- Map of vegetation predicted to have >20% reduced yield because of ozone exposure

Stressors that cross military-civilian boundaries

Activity	Stressor	Mil	Civil
Urban development	Loss and frag of habitat, alteration of hydrology, alteration of nutrients, heat, light, nonnative veg	X	X
Road development	Noise, loss of habitat, altered hydrology, visual stressor	X	X
Logging	Loss and frag of habitat	X	X
Agriculture	Nutrients		X
Prescribed burns	Loss and frag of habitat, air pollutants	X	X
Wildfires	Loss and frag of habitat, air pollutants	X	X
Troop training	Changes in veg from trampling, particulates in air, sedimentation, noise	X	
Tracked vehicles	Erosion, sedimentation, altered hydrology, noise	X	
Aircraft overflight	Noise, visual stressor, air movement (rotor wash) from takeoff/landing	X	X
Release of smokes, obscurants	Metals, chlorinated hydrocarbons, oils	X	
Explosions	Noise, erosion	X	

Encroachment Issues relevant to military mission (GAO 2002)

- Military compliance with endangered species legislation
- Application of environmental statutes to unexploded ordnance and munitions
  - Competition for radio frequency spectrum
  - Required consultation with regulators on activities potentially affecting protected marine resources
  - Competition for airspace
- Application of the Clean Air Act to base-generated air pollution
- Application of noise abatement rules to training and testing activities
- Urban growth around military installations

(• = being addressed by this effort)

Efroymson, R.A., V.H. Dale, L.M. Baskaran, M, Chang, M. Aldridge, and M. Berry. 20005. Planning transboundary ecological risk assessments at military installations. *Human and Ecological Risk Assessment* 11:1193-1215.

RSim is:

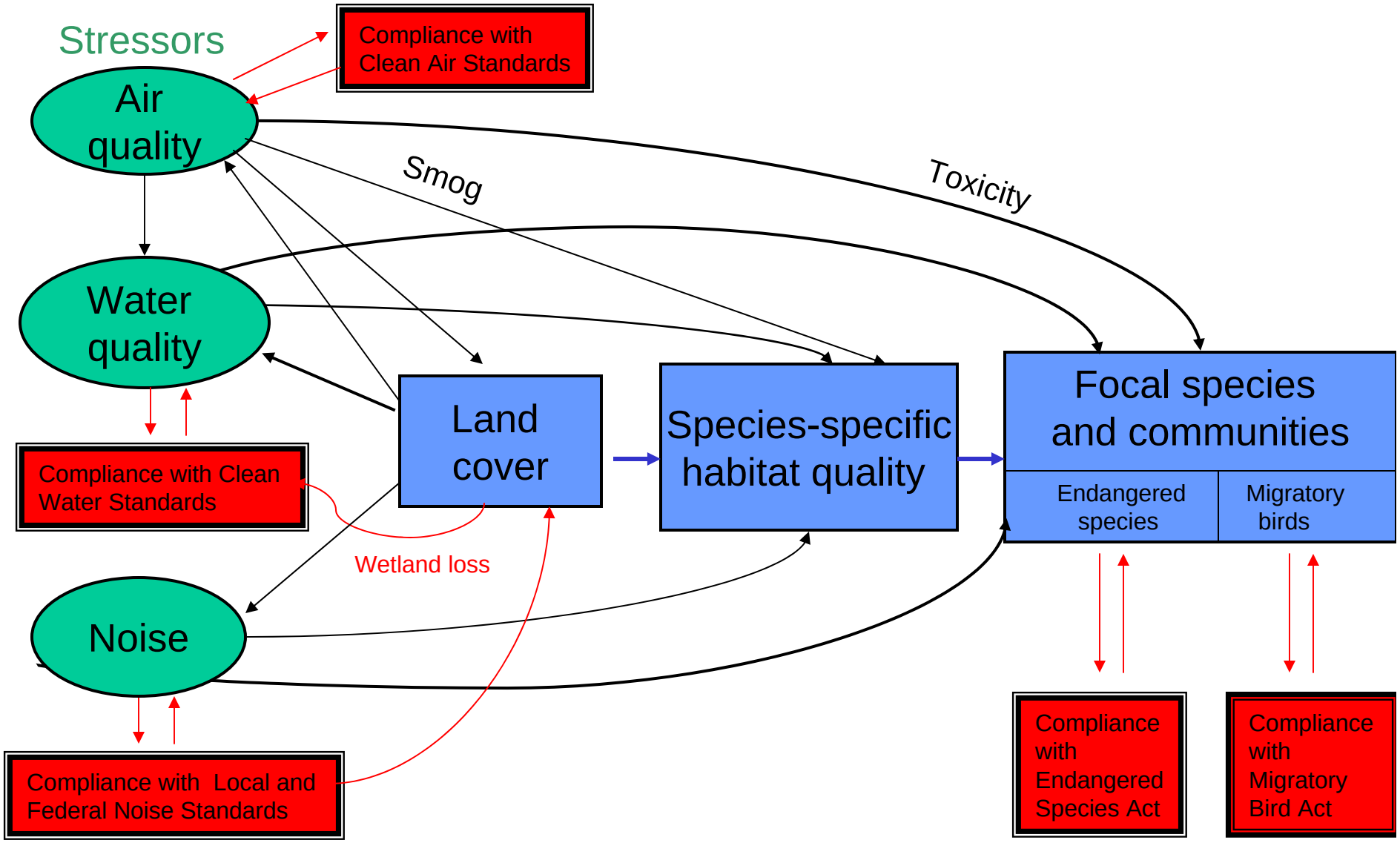
Innovative Science

- Scales: RSim integrates processes that operate on different temporal and spatial scales
- Feedbacks: RSim incorporates feedbacks between different aspects of the environment that operate at different scales
- Optimization: RSim considers several criteria at the same time dealing with air, water, noise and species.
- RSim incorporates advances within each module (air, water, noise and species).
- RSim provides a regional perspective

Accomplishments

- RSim implemented for five-county region of west central Georgia
- Four scenarios of RSim
  - Human population growth
  - New roads
  - New military range
  - Hurricane
- Components of RSim developed
  - Noise
    - Maps of military-induced noise
    - Noise levels for alternative locations of the Digital Multipurpose Range at Fort Benning
    - Estimates of off-installation areas of human annoyance, based on noise
  - Air
    - Estimates of future air concentrations for the 5-county area.
  - Water
    - Potential excess nitrogen and phosphorus modeled for the 5-county area
  - Species and their habitats
    - Estimates of clusters of red-cockaded woodpecker:
    - Location of sites suitable for gopher tortoise burrows
- Census data for region analyzed to calibrate urban growth in RSim
- Risk thresholds for various stressors have been obtained.
- The planning phase of a risk assessment framework for transboundary ecological risk assessment at military installations has been developed
- Meetings with decision makers in region helped to focus effort
- The RSim graphical user interface developed
- Review of “live” version of RSim

Interactions of RSim with Environmental Laws and Regulations



RSim can be a scoping tool for the National Environmental Policy Act (NEPA)

Lessons

- Resource managers are limited by models that do not consider the major factors necessary to promote sustainability.
- Modeling, understanding, and managing for effects of land-use change on several sectors (air, water, noise, and habitat) requires attention to the spatial and temporal scale at which each sector operates.
- Simulation models offer a cost effective and efficient means to explore potential outcomes of resource management and land use.