The Ohio State University

Land Use Change and Integrated Modeling for Sustainability Analysis

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"Seeking sustainable pathways for land use in Latin-America"
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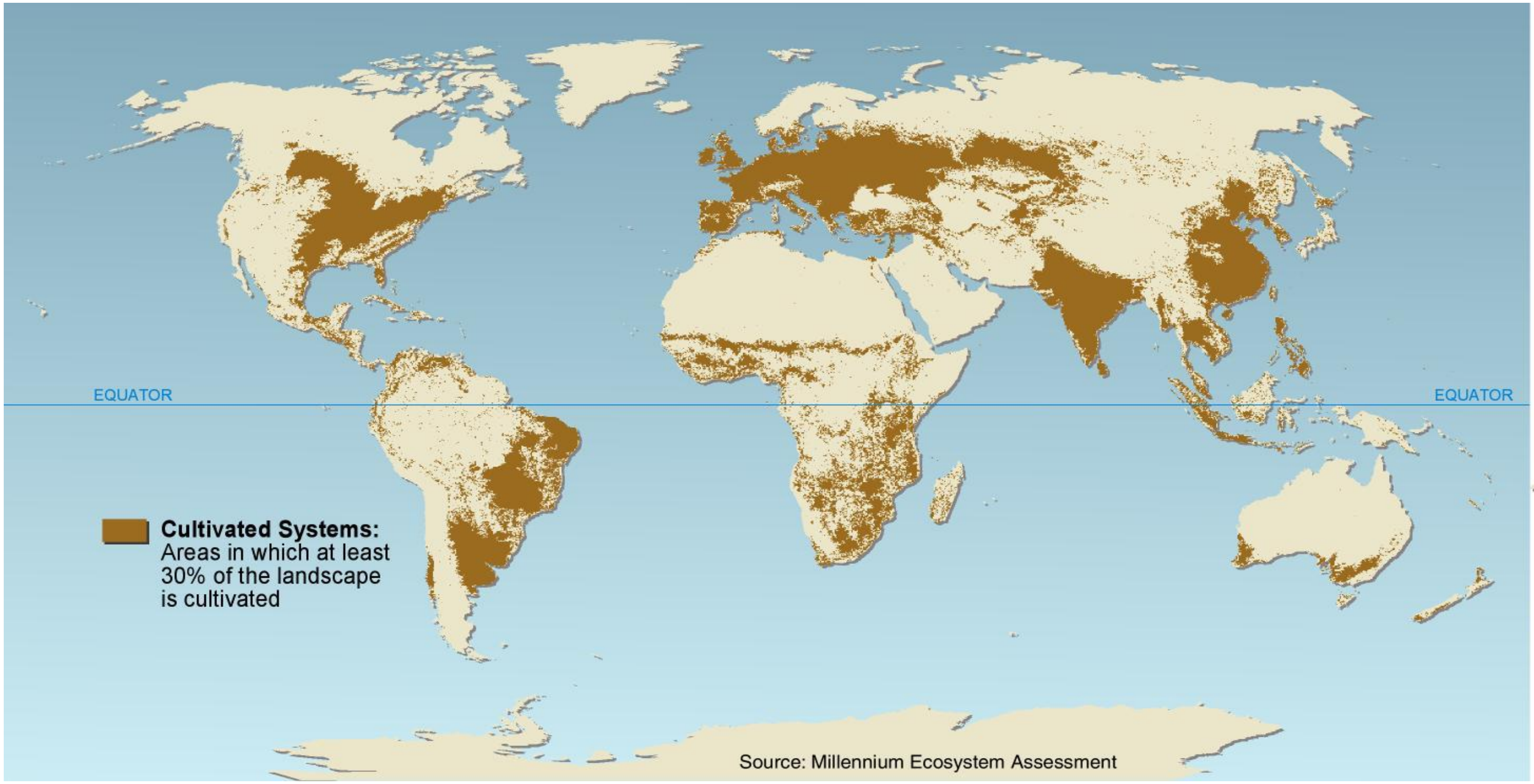
Land use: The ultimate human-environment interaction

Over 50% of the ice-free surface of the Earth has incurred significant human-induced land-cover change

- Land-climate interactions
- Water quantity and quality
- Biotic diversity, ecosystem function, and trade-offs among ecosystem services
- Food and fiber production
- Energy and carbon (sequestration)
- Urbanization, infrastructure, and the built environment

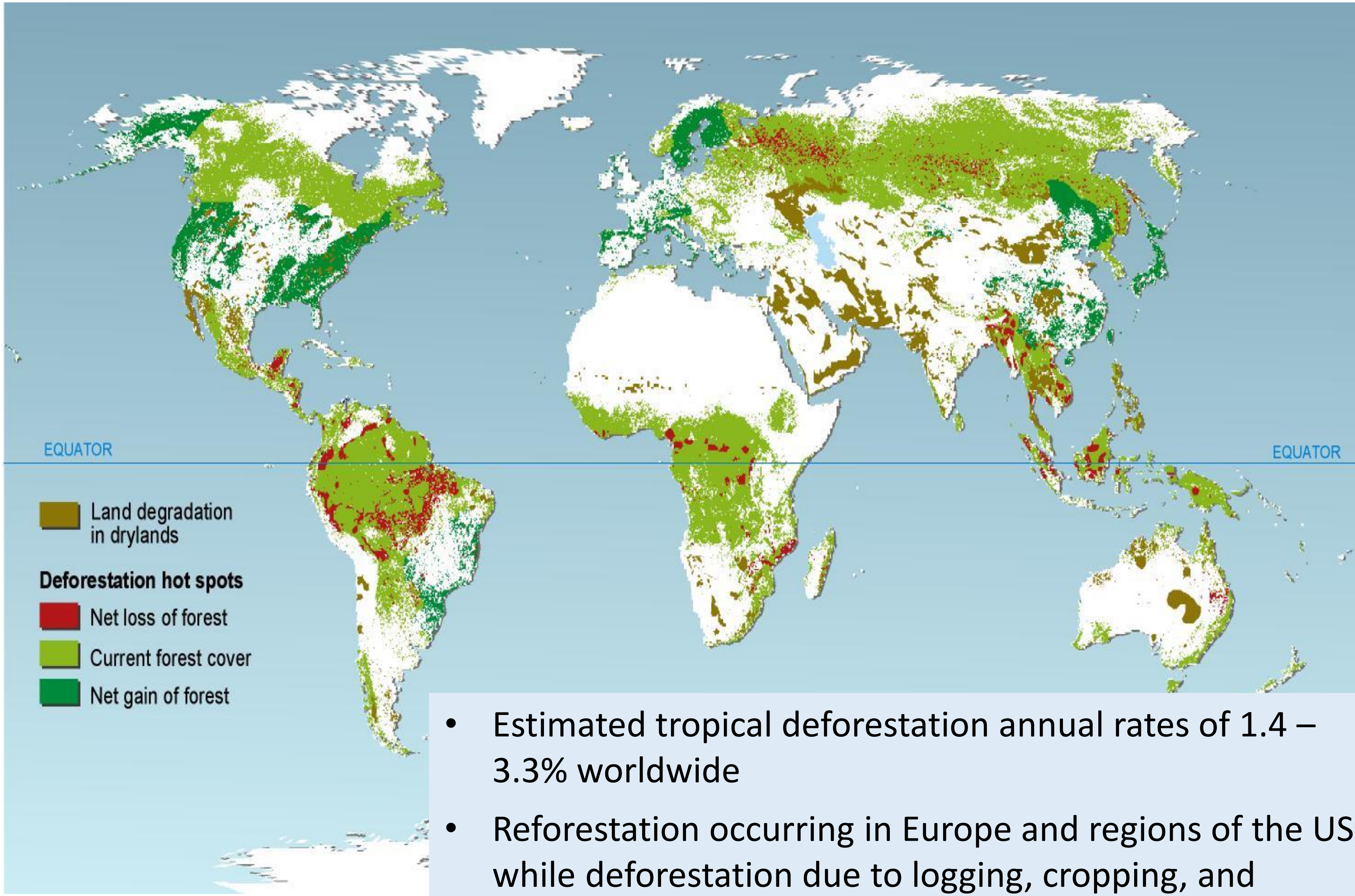
Agricultural Land Cover



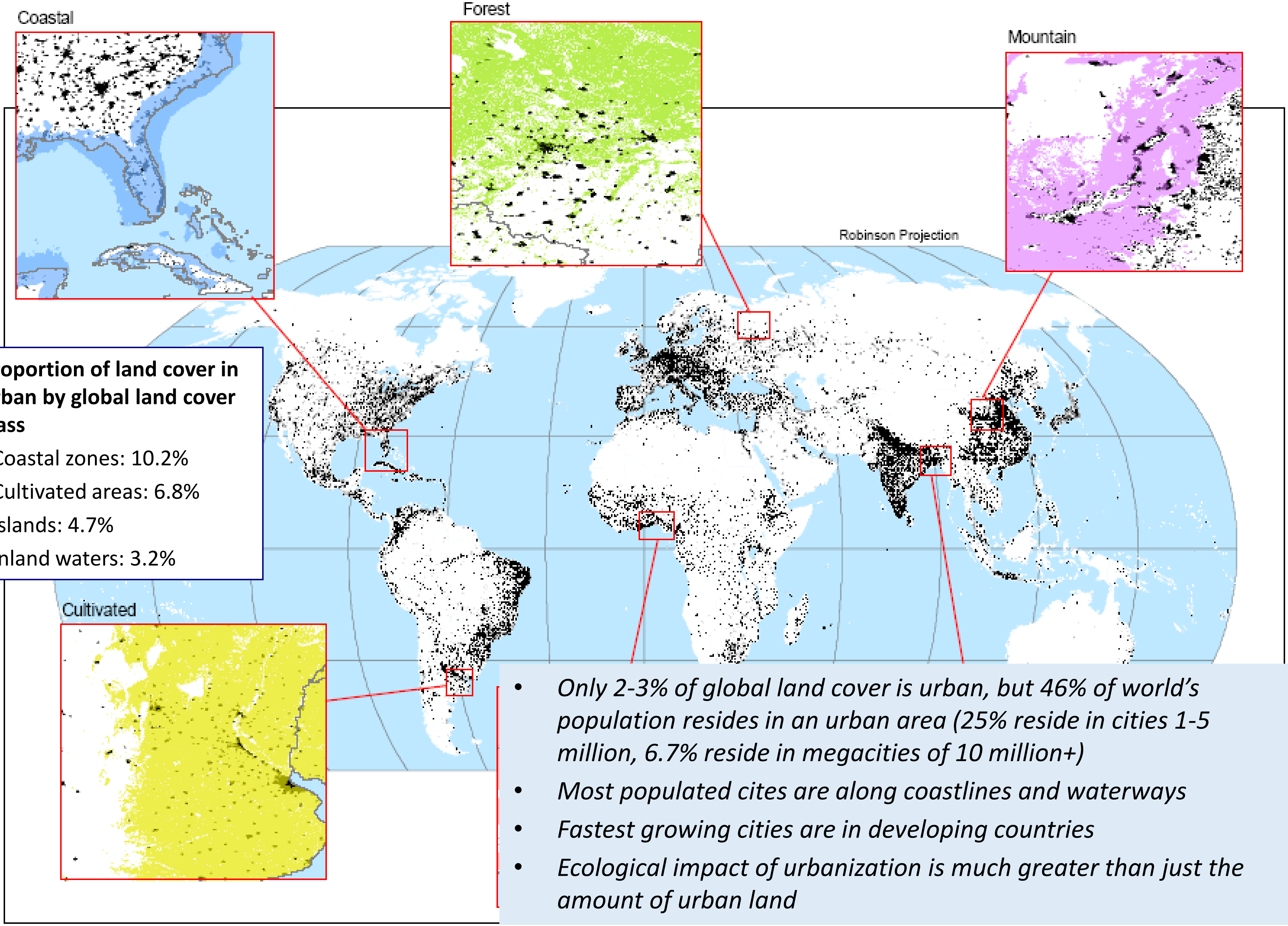
Cultivated Systems in 2000 cover 25% of Earth's terrestrial surface

- More land was converted to cropland in the 30 years after 1950 than in the 150 years between 1700 and 1850
- Cropland is 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

Deforestation Hot Spots



- Estimated tropical deforestation annual rates of 1.4 – 3.3% worldwide
- Reforestation occurring in Europe and regions of the US, while deforestation due to logging, cropping, and livestock grazing is occurring in tropical regions



Proportion of land cover in urban by global land cover class

- Coastal zones: 10.2%
- Cultivated areas: 6.8%
- Islands: 4.7%
- Inland waters: 3.2%

- *Only 2-3% of global land cover is urban, but 46% of world's population resides in an urban area (25% reside in cities 1-5 million, 6.7% reside in megacities of 10 million+)*
- *Most populated cites are along coastlines and waterways*
- *Fastest growing cities are in developing countries*
- *Ecological impact of urbanization is much greater than just the amount of urban land*

Urban Areas (UA)
UA within Coastal
UA within Cultivated
UA within Forest
UA within Dryland
UA within Mountain
UA within Inland Water

Urban Extents: Settlements Greater Than 5000 Persons

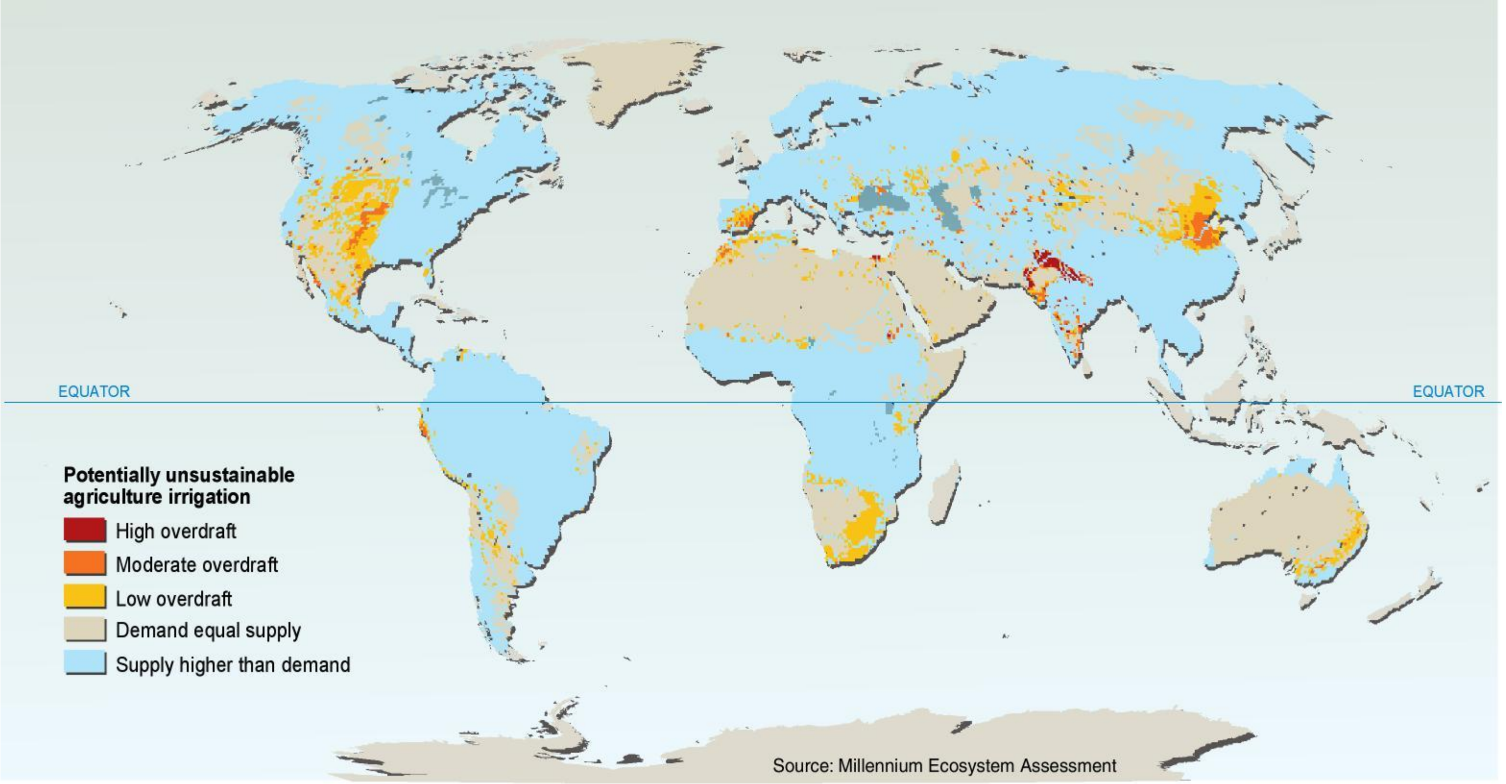
Call-outs show urban areas overlayed by ecosystems.

NOTE: Urban areas not drawn to scale. They are boldened here so as to be visable on a global map. Refer to Table 22.4 for estimates of urban land area.

Data Sources: Global Rural-Urban Mapping Project version 1, beta.sedac.ciesin.columbia.edu/gpw; Millennium Ecosystem Assessment core database, http://maweb.org

Water

- 5 to possibly 25% of global freshwater use exceeds long-term accessible supplies (*low to medium certainty)*
- 15 - 35% of irrigation withdrawals exceed supply rates and are therefore unsustainable (*low to medium certainty)*



What is sustainable land use?

The Brundtland Commission Report, Our Common Future (1987) defined **sustainable development** as…

> "development that meets that needs of the present without compromising the ability of future generations to meet their own needs …. At a minimum, sustainable development must not endanger the natural systems that support life on earth."

…requires making trade-offs between resource use now and in the future

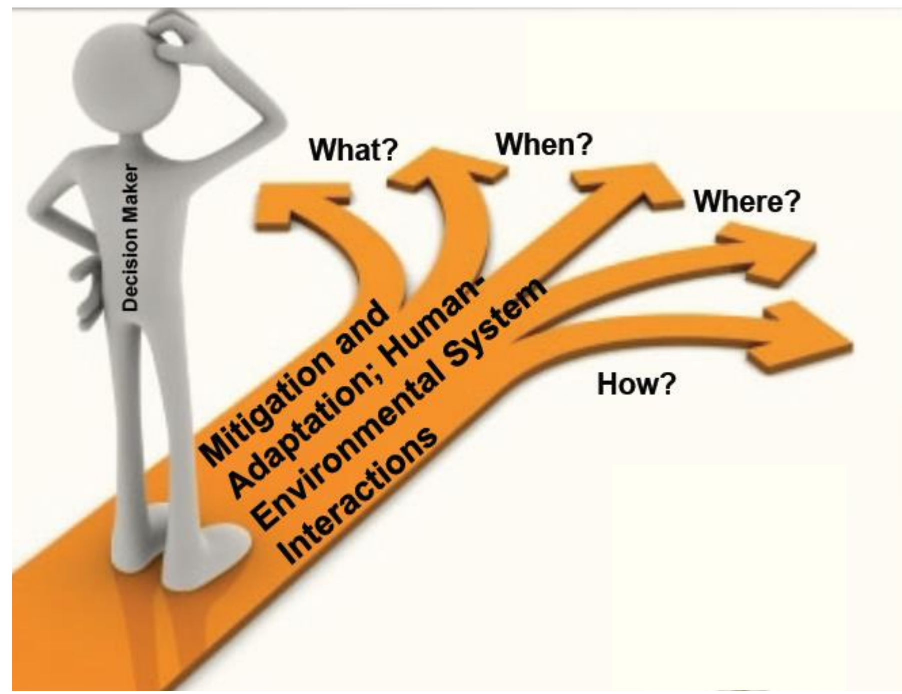
How can we assess future trade-offs in a world of uncertainty?

Population Growth?
Migration?
GDP?

Energy Costs?
Non-Energy Costs?
Availability?
Technological Change?

Climate Change?
Ecological Degradation?

Political leaders?
Natural resource conflicts?



Adapted from: Richard Moss (2014), Joint Global Change Research Institute

Predicting the future is risky business

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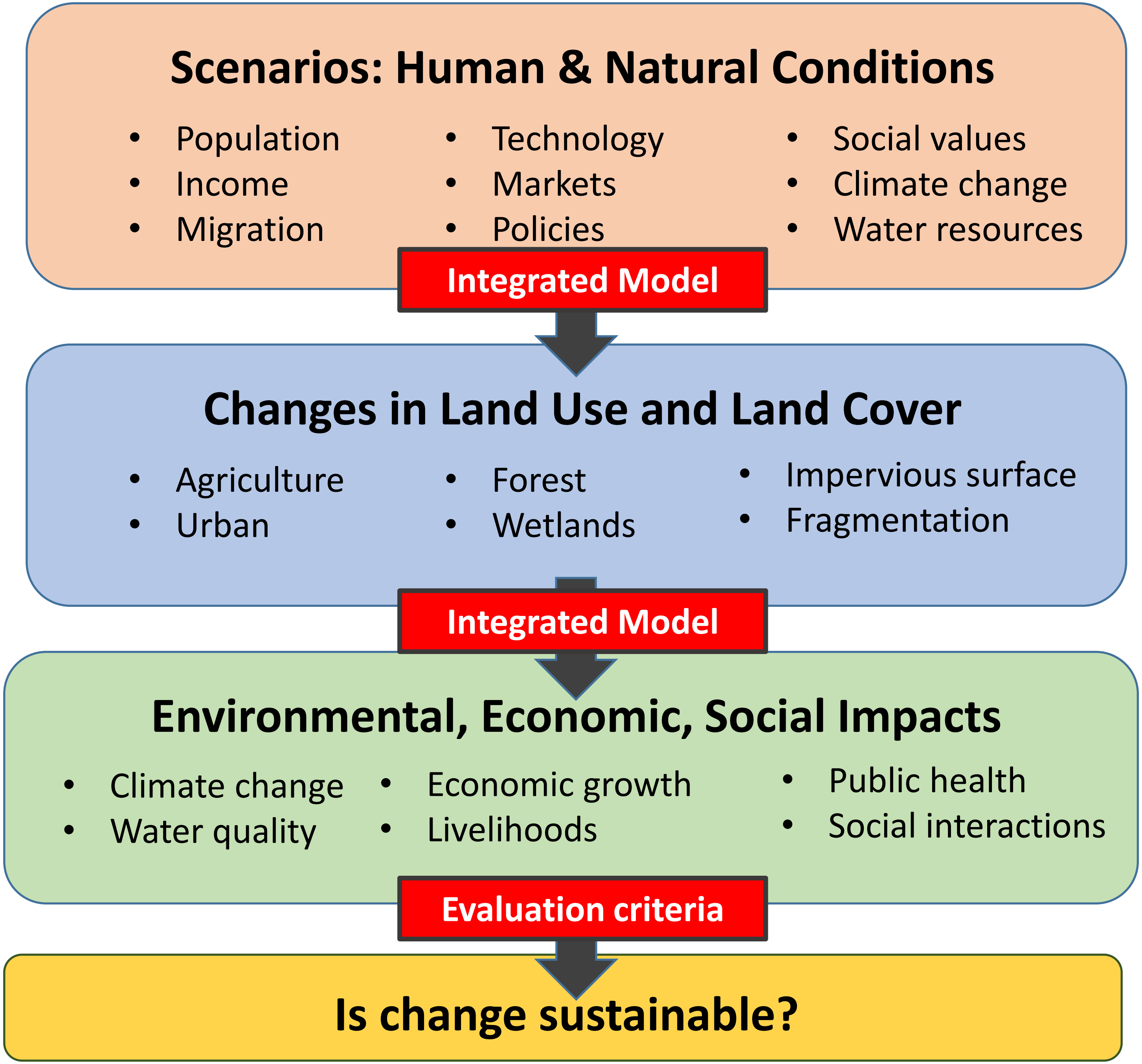
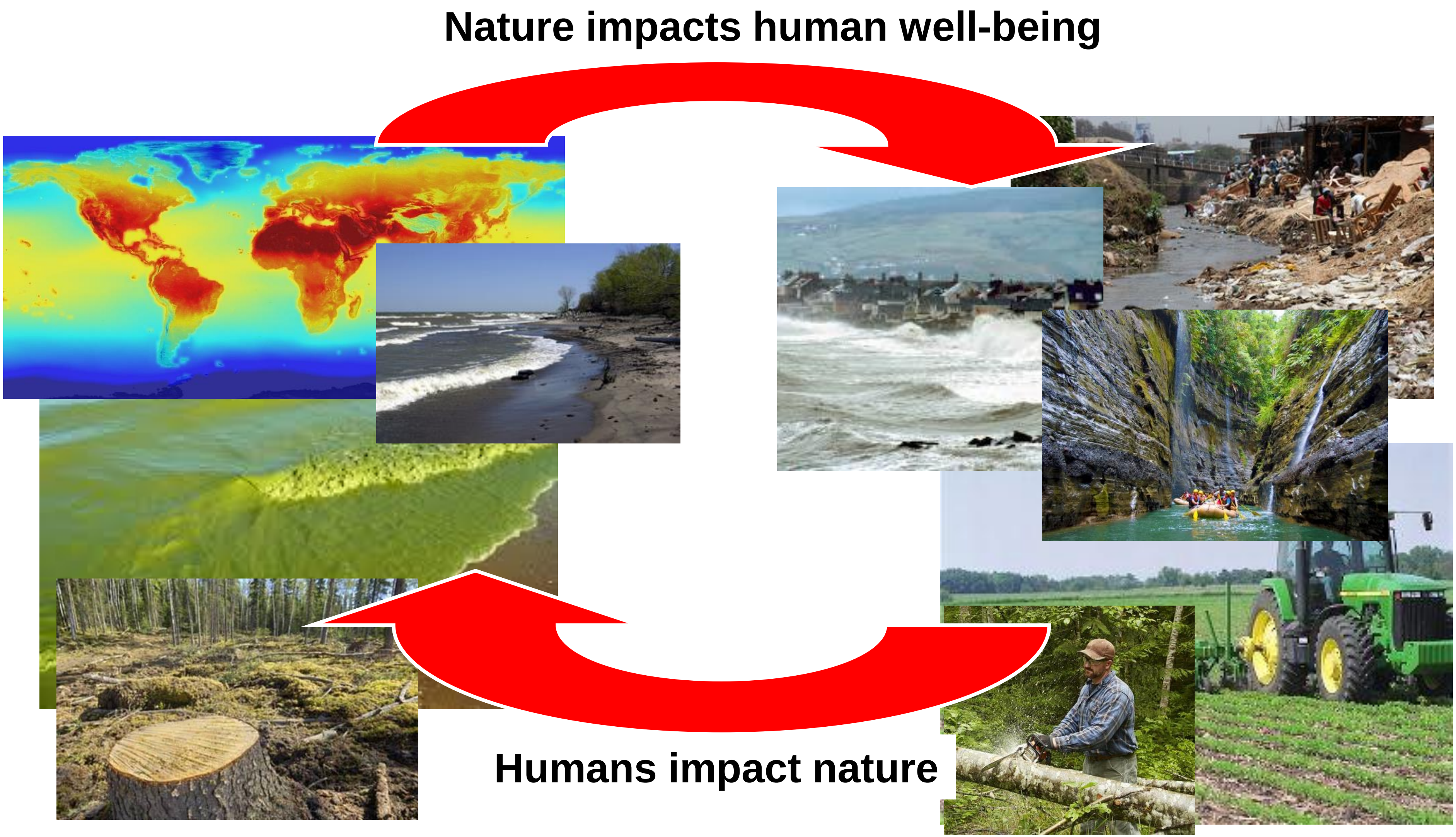

Scenarios: Human & Natural Conditions
Population
Income
Migration
Technology
Markets
Policies
Social values
Climate change
Water resources
Integrated Model
Changes in Land Use and Land Cover
Agriculture
Urban
Forest
Wetlands
Impervious surface
Fragmentation
Integrated Model
Environmental, Economic, Social Impacts
Climate change
Water quality
Economic growth
Livelihoods
Public health
Social interactions
Evaluation criteria
Is change sustainable?

Integrated models: Represent interactions between humans and natural systems



Assessing sustainability: Weak versus strong sustainability

- Weakly sustainable: does change generate non-decreasing total wealth over time?

$$\Delta W_t = \text{Value of } \Delta \textbf{ produced} \text{ capital}_t\ (v_{PC} \bullet \Delta\, PC_t) + \text{Value of } \Delta \textbf{ natural} \text{ capital}_t\ (v_{NC} \bullet \Delta\, NC_t) + \text{Value of } \Delta \textbf{ human} \text{ capital}_t\ (v_{HC} \bullet \Delta\, HC_t) + \text{Value of } \Delta \textbf{ social} \text{ capital}_t\ (v_{SC} \bullet \Delta\, SC_t) \geq 0$$

- Strongly sustainable: are minimum critical natural capital stocks and flows?

$$NC_{i,t+1} = NC_{i,t} + \Delta\, NC_{i,t} \geq \overline{NC_i} \text{ for each critical NC stock or flow } i$$

Key aspect on integrated models: Modeling land use change

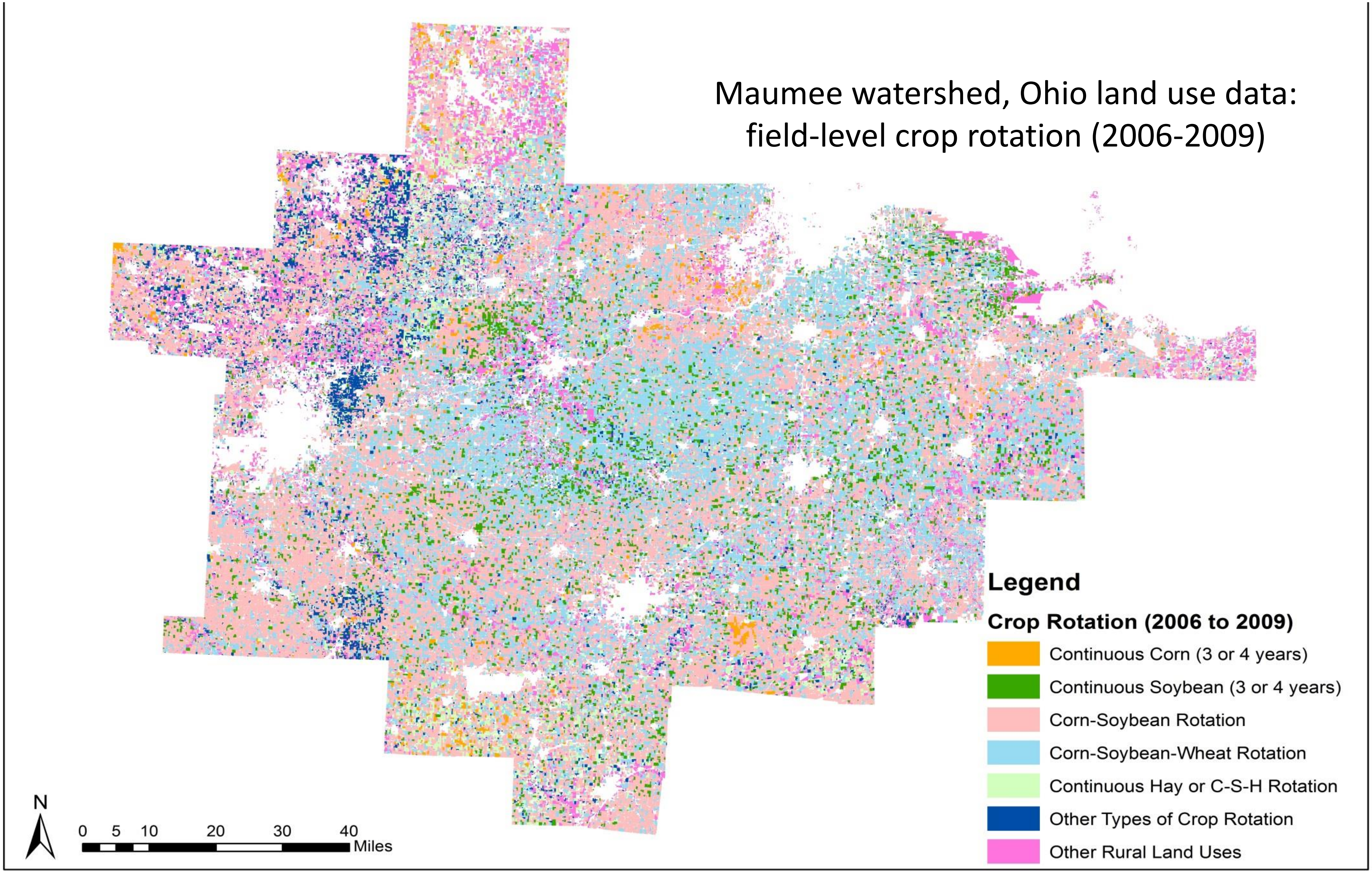
- **Land use conversion**: Discrete change from one land use category to another (example: forest to agriculture; agriculture to urban)

- **Land use modification**: changes that affect the character of the land without changing the classification (example: intensification of agriculture)

- **Land management change**: changes in the way in which land is managed, (example: fertilizer and pesticide use by farmers, zoning laws for urban development)

- **Land cover versus land use**

Land use change is the outcome of **human decision making**



Source: Common Land Unit boundaries overlaid with the Cropland Data Layer (USDA) , 2006-2012

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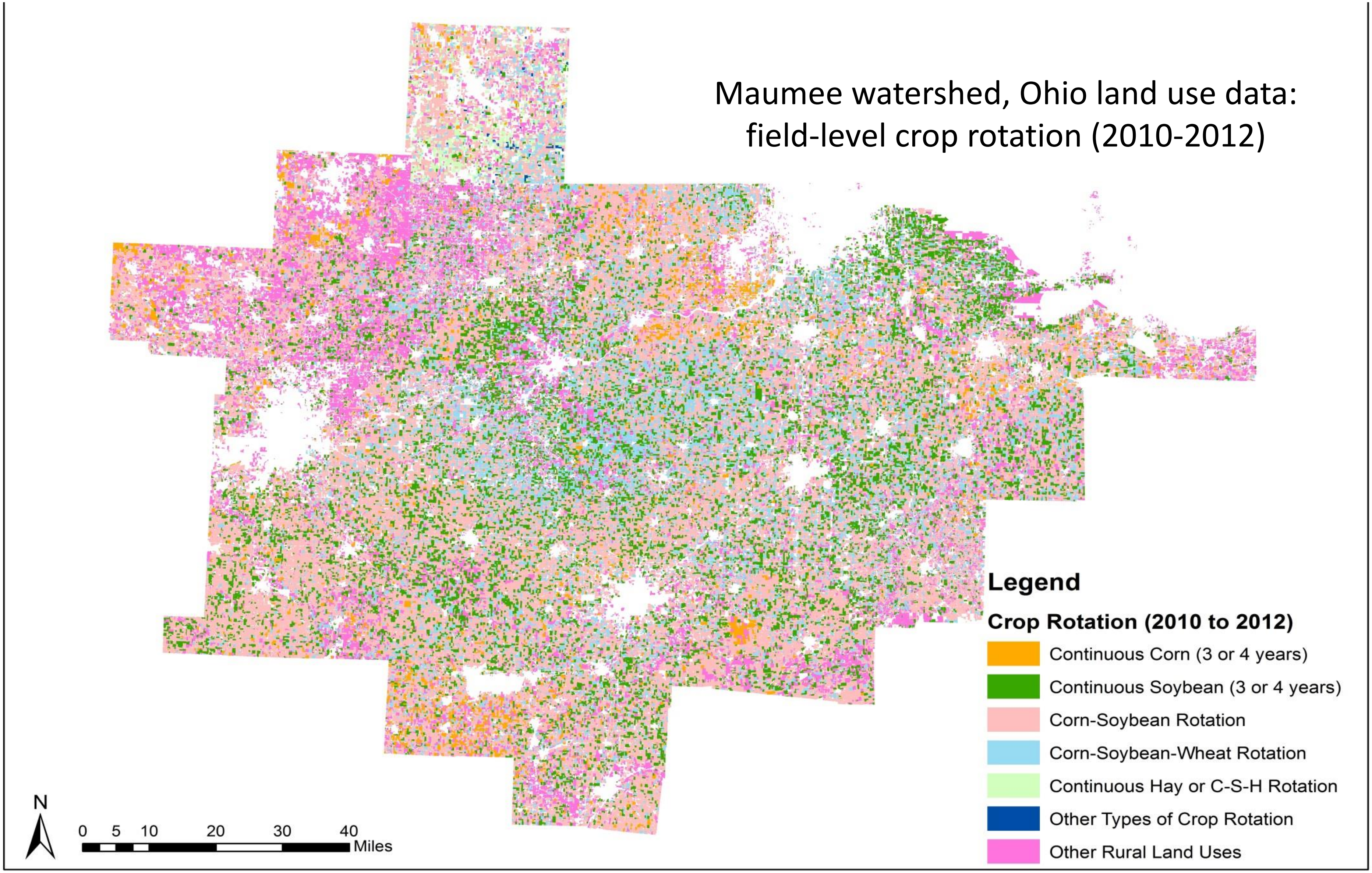

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Economic models of land use

- Models based on **individual decision making** (firms, households)
  - Land use decisions: landowner (e.g., farmer, developer)
  - Location decisions: firms and households
- Model solution: relates **individual-level decisions to aggregate outcomes of prices and land use pattern**
  - How do aggregate market-level outcomes—such as land prices, land use patterns—result from cumulative individual decisions and interactions?
  - How do aggregate/market outcomes influence individual decisions?

Individual development decision

Housing markets, urban land use pattern

Individual decision making agent

- Agents face constraints → necessitates trade-offs
  - Resource scarcity , other environmental constraints; income, time constraints; policy, legal constraints
  - Opportunity costs matter
- Agents make location and land use decisions to make themselves better off
  - Maximize expected profits or utility
- Agents consider benefits and costs of existing and alternative states in current **and future** periods
  - Uncertainty over future outcomes → expectations over ***future*** outcomes influence ***current*** decisions

Economic modeling challenges
(roughly in order of difficulty!)

1. **Identification:** Controlling for unobserved correlation and other sources of bias to isolate causal effect
2. **Prices and spatial equilibrium**: Accounting for price formation and feedbacks
3. **Data data data…**
4. **Non-economic behavior:** Accounting for heterogeneity in motivations, beliefs, decision-making rules
5. **Cross-scale integration:** Aggregating, downscaling, and modeling interactions across local-to-global scales
6. **Ecological dynamics:** Modeling coupled dynamics, nonlinearities and the value of resilience

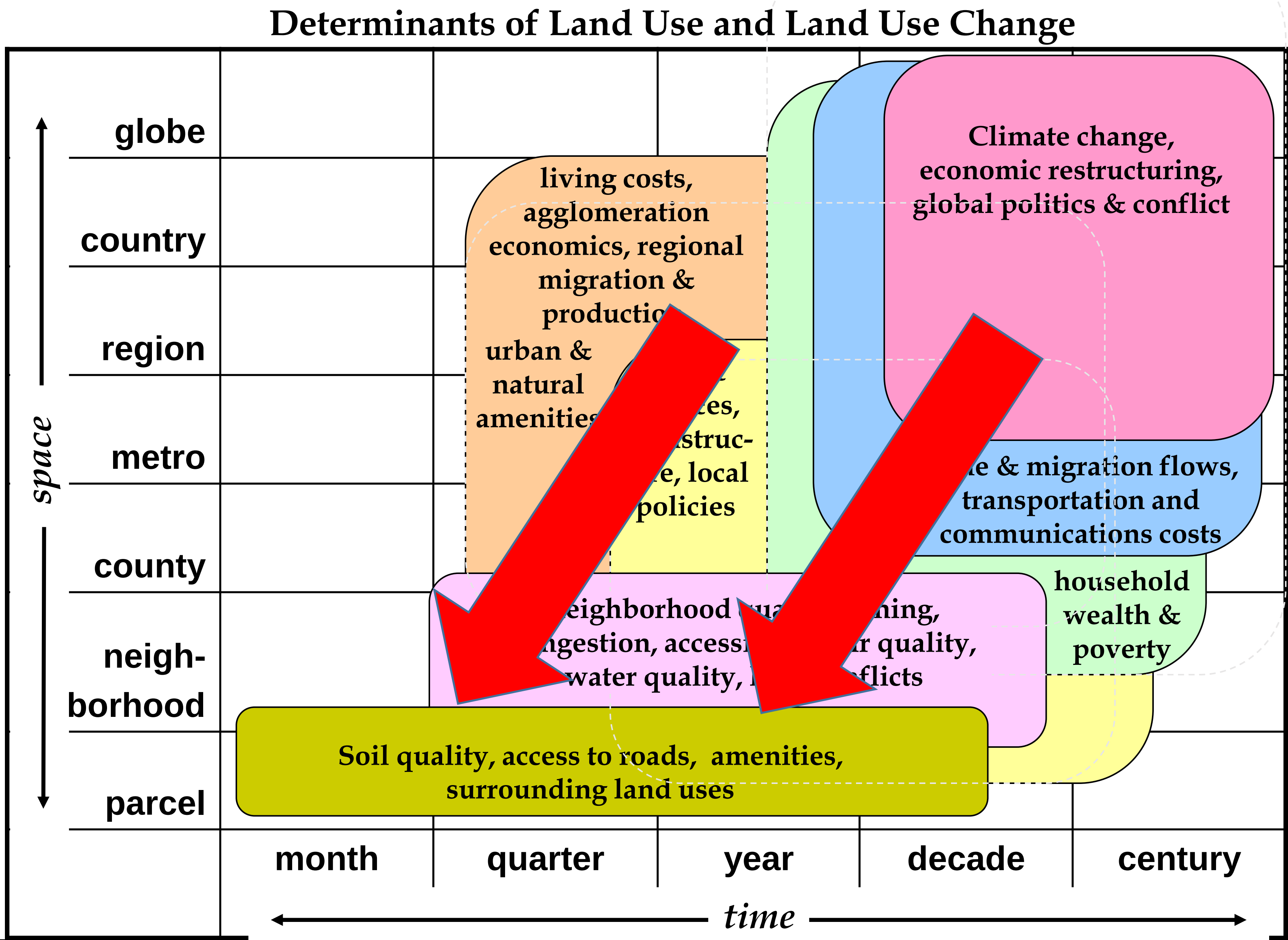
Challenge #4: Non-economic behavior

- Traditional economic models usually impose assumptions such as profit maximization rather than test them
- Differences in behavior are important – differences not only in preferences and expectations, but also in beliefs, motivations and decision making rules
- **Accounting for these behavioral differences is critical for scenarios** in which the goal is to predict land use responses to a change in policy

Example: Understanding heterogeneous farmer decision-making in Ohio

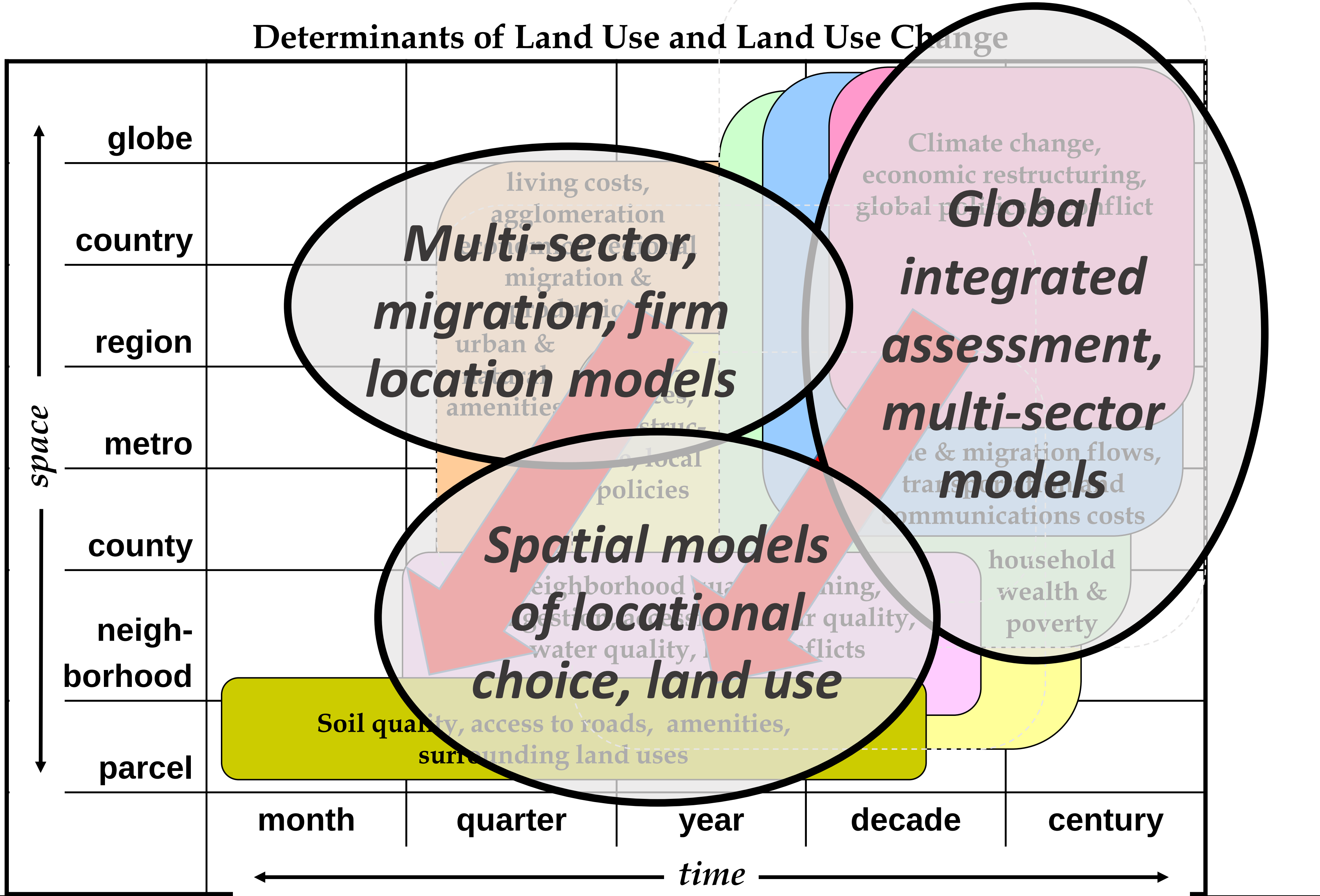
- All farmers want to maximize profits, but…
- When asked about primary farming goal, **80% chose non-economic motivations** such as environmental stewardship, family succession, and maintaining a rural lifestyle (Ferry and Wilson 2010)
- **Farmers' environmental stewardship** is a positive significant driver of farmers that adopt no-till (Konar et al. 2012) and filter strips (Howard and Roe 2013)
- **Farmer's perceived efficacy** matters (i.e., filter strip effectiveness in reducing runoff) matters more for "status quo" farmers versus farmers in "environmental stewardship" class (Howard and Roe 2013)

Challenge #5: Cross-scale integration



Source: Pickett et al. 2011

Challenge #5: Cross-scale integration



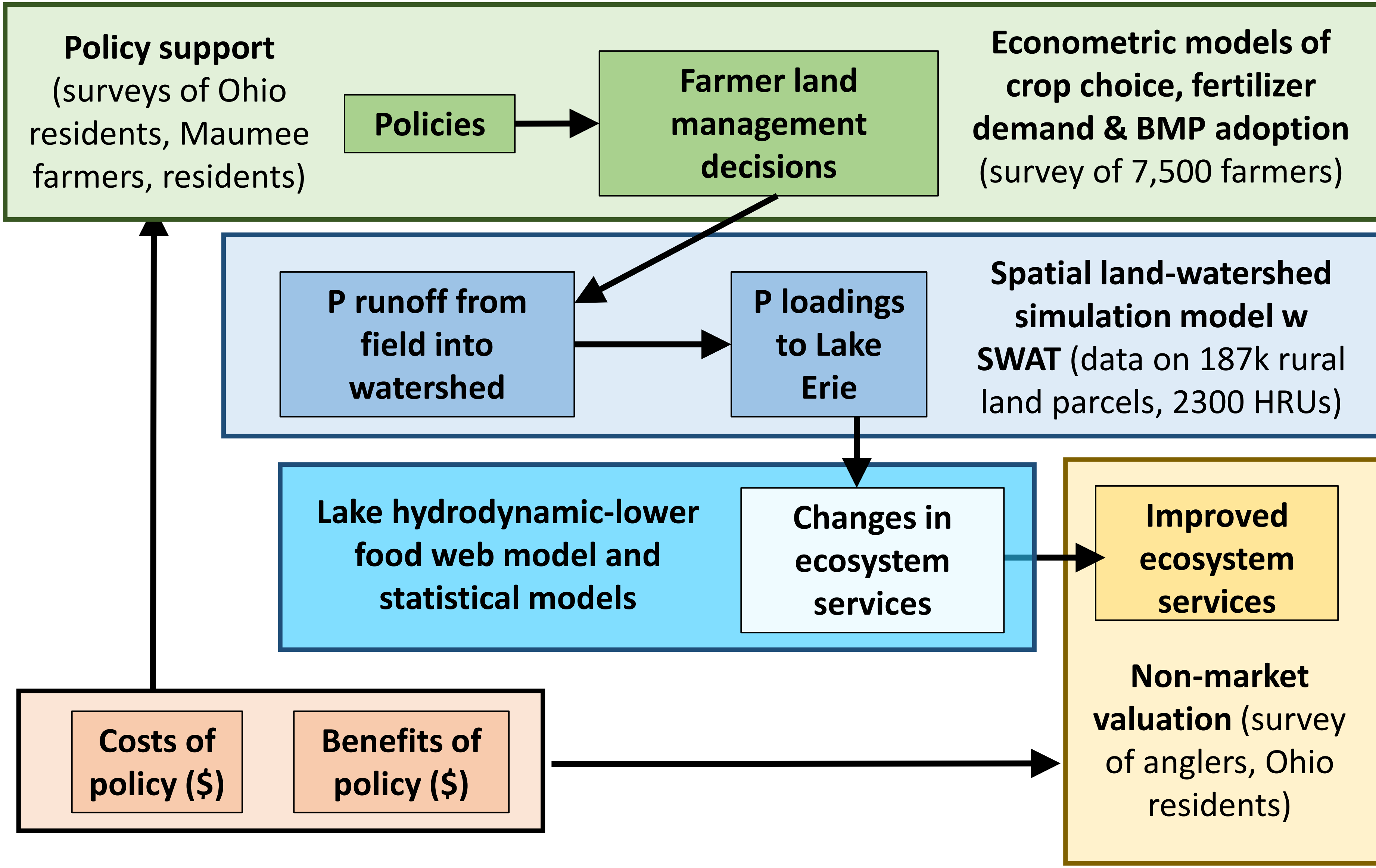
Challenge #6: Ecological dynamics

Ecosystems responses to climate change, habitat fragmentation and other impacts are often nonlinear; characterized by **thresholds and regime shifts**, e.g., fisheries collapse, lake eutrophication, species loss

Example: Lake Erie

- Land use in the watershed results in increases in sediment, nutrients (fertilizer and sewage) and pesticides
- Nutrient runoff leads to lake eutrophication (excessive plant growth)
- Results in "sudden" harmful algal blooms and dead zone

Lake Erie-land water integrated modeling



Conclusions

- This is a LOT of work – it will take a long time to fully address these challenges and we will never get everything "right" – **is it really WORTH IT?**

- **Policy decisions must be made** – better to make them with as much scientific input as possible!

- In the words of George Box (1987), one of the most influential statisticians of the 20th century, **"all models are wrong, but some are useful."**

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Thank you

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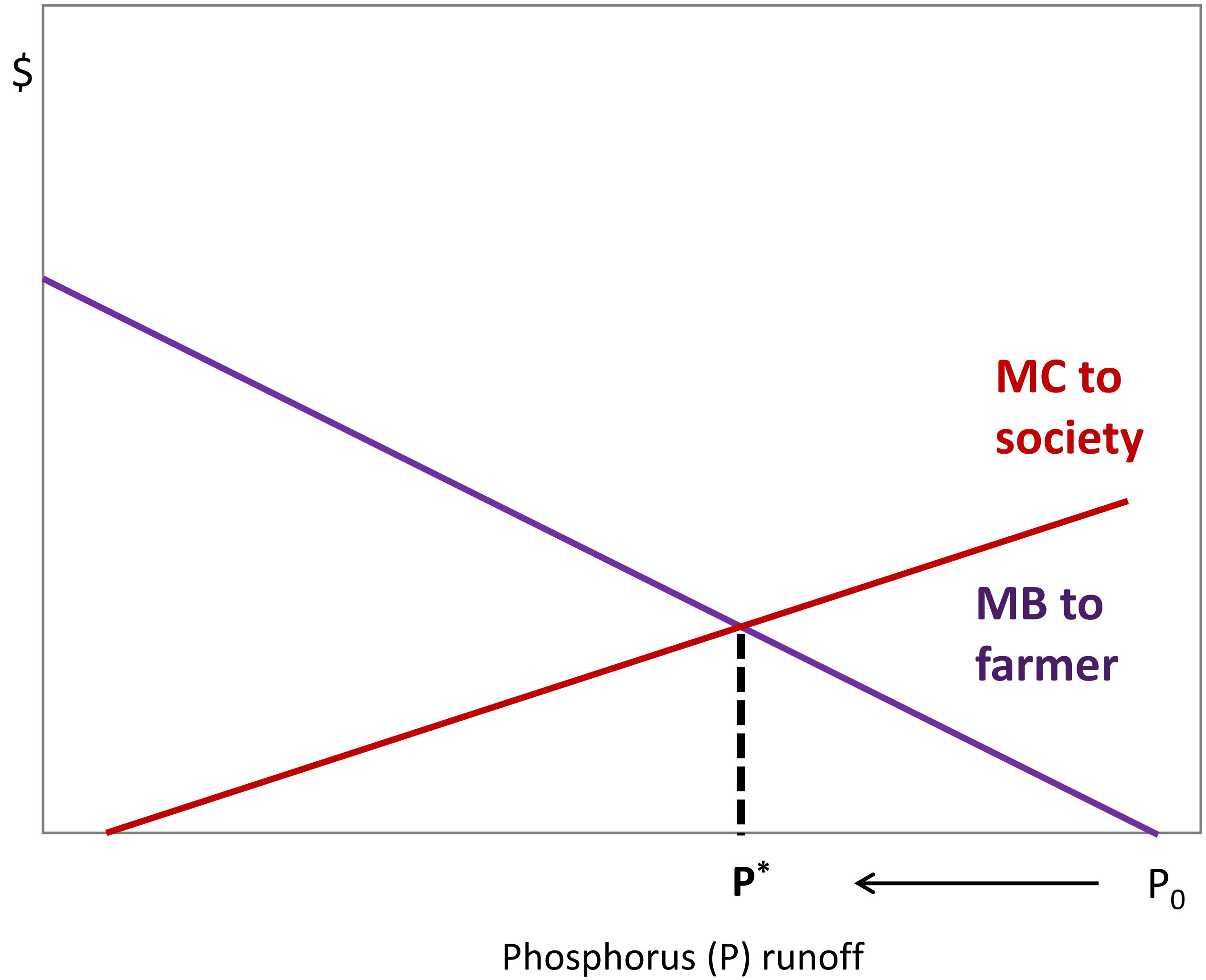
Conclusions

- Economists play a critical role in
  - Modeling human behavior
  - Designing incentives for individuals and businesses to provide ecosystem services
  - Valuing ecosystem services
- But economists can’t do it alone
  - Biophysical scientists: integrated models
  - Other social scientists: non-economic behaviors
  - Policy makers: what’s feasible

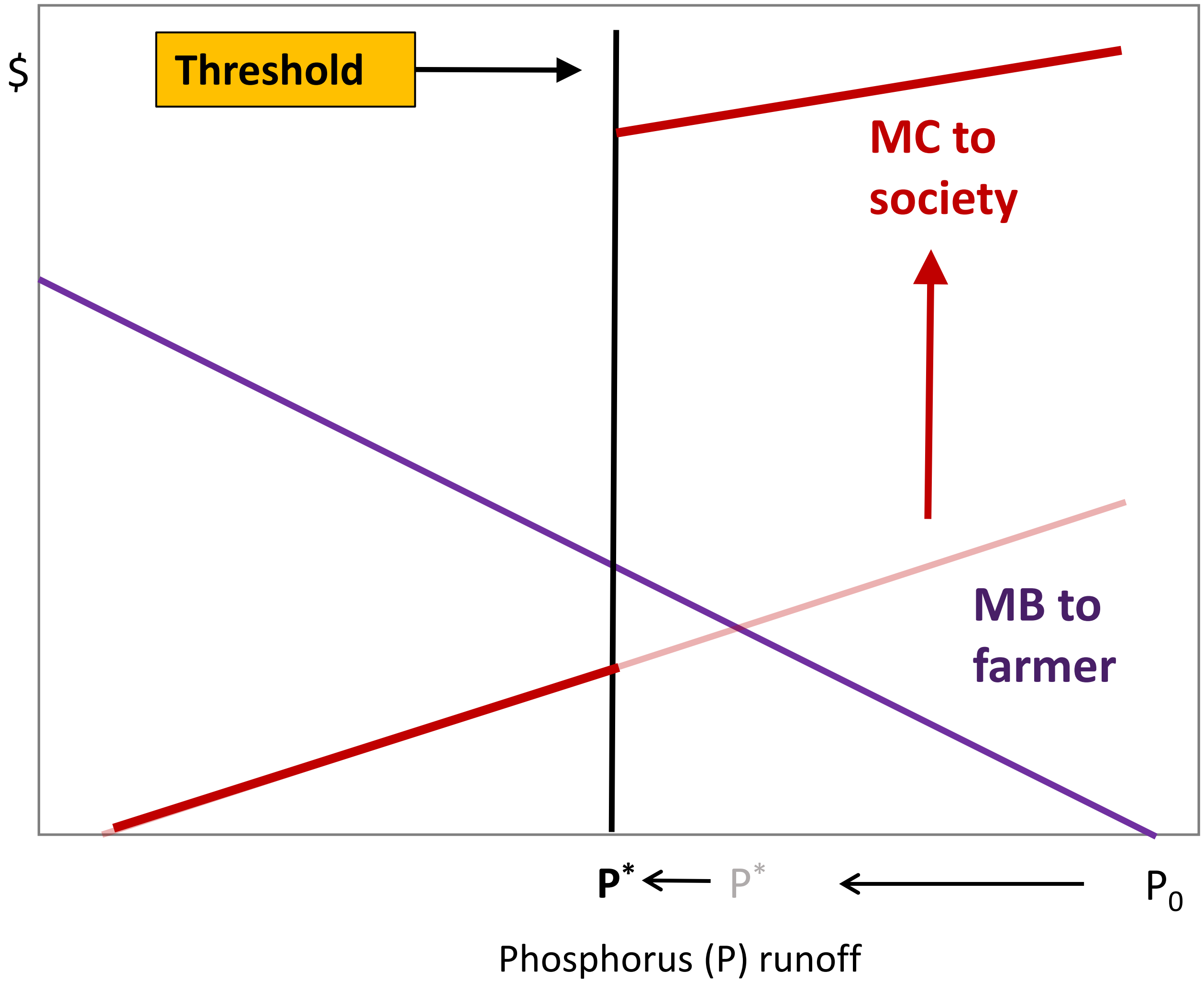
Trade-offs between P runoff and water quality

- **Farmer benefits** of P runoff = avoided cost of implementing BMP's (best management practices)
- **Social costs** of P runoff = foregone benefits of improved water quality



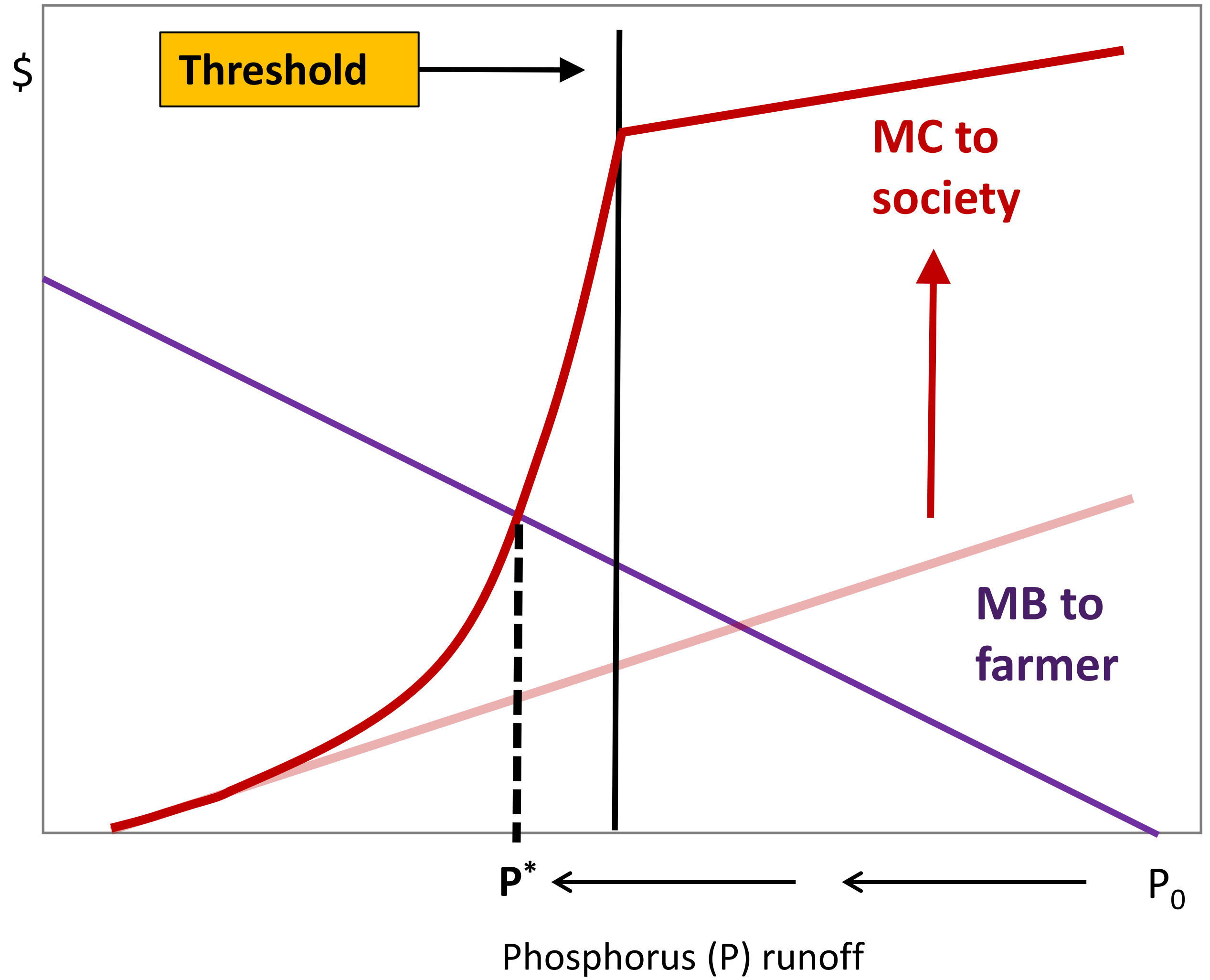
Trade-offs between P runoff and water quality

- **Farmer benefits** of P runoff = avoided cost of implementing BMP's (best management practices)
- **Social costs** of P runoff = foregone benefits of improved water quality
- **If the threshold were deterministic and we could perfectly control P, then the value of resilience = 0 for P < Threshold**



Trade-offs between P runoff and water quality

- **Farmer benefits** of P runoff = avoided cost of implementing BMP's (best management practices)
- **Social costs** of P runoff = foregone benefits of improved water quality
- **However, loss of resilience increases prob of regime shift → this cost is reflected in increasing MC curve as P approaches threshold**



Valuing Resilience (Gören-Mäler and Li 2010)

- Resilience can be regarded as one of society's productive capital stocks. **Value of resilience depends on**

1. **How a change in resilience alters the probability of a regime shift in a future time period** given initial level of resilience (requires projection of system dynamics in future time periods)
2. **Difference in intertemporal net social benefits** between state 1 (good) and state 2 (bad): NB_1 - NB_2