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Sustainability of Agro-Ecosystems: An Economist's Perspective

Wendong Zhang, Assistant Professor
Department of Economics, Iowa State University

Sustainable Agriculture Graduate Program Colloquium, Sep 14, 2016

Support provided by grants from the Ohio Sea Grant Program and the National Science Foundation Coupled Human and Natural Systems Program (GRT00022685)

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A Quick Introduction: Dr. Wendong Zhang

– Grown up in a rural county in NE China
– Attended college in Shanghai and Hong Kong
– Ph.D. in Ag Econ in 2015 from Ohio State
– 2012 summer intern at USDA-ERS on farm economy and farmland values
– Research and extension interests: land value, land ownership, agriculture and the environment, China Ag
– Leads ISU’s Iowa Land Value Survey as well as the Iowa Farmland Ownership and Tenure Survey

Outline of this Talk

- **Sustainability concepts**
  - Sustainable development
  - Weak vs. strong sustainability
- **Brief Introduction of two ongoing projects**
  - Land tenure and soil/water conservation
  - Economics of soil health
- **Integrated Modeling of Agricultural Landscapes and Ecosystem Services: The Lake Erie Coupled Human and Natural Systems Project (Focus of this Talk)**

Sustainability Science

- A **new scientific field** defined by the National Academy of Sciences that integrates across
  - Natural sciences
  - Social sciences
  - Engineering
  - Medicine
  - Public health

- Focus is on **integrated science for policy**

- Key research methods include **data analysis** and **integrated modeling** to conduct future scenarios

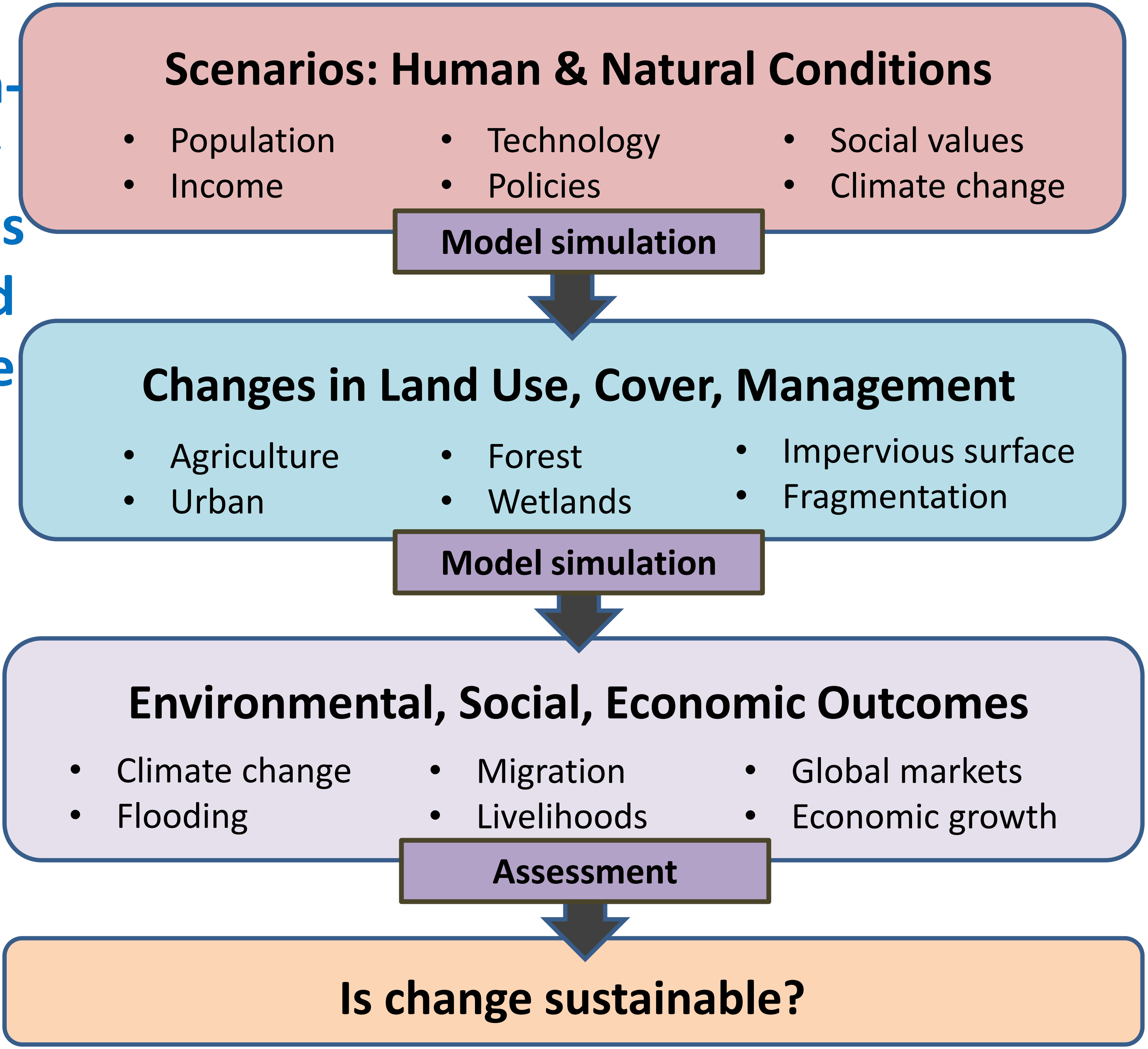
Sustainable Development…

“development that meets the 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.”

-- The Brundtland Commission Report, Our Common Future (1987)

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

Sustain-ability Analysis of Land Change



Two approaches: Weak versus strong sustainability

Weak sustainability

- Human well-being is dependent on its “productive base” = the total wealth of a society
- Total wealth = social value of all capital assets in society

W	=	**Total wealth**	=	Value of **produced** capital (PC)	+	Value of **natural** capital (NC)	+	Value of **human** capital (HC)	+	Value of **social** capital (SC)

Sustainability = non-decreasing total wealth over time

A society is sustainable if $W_{t+1} - W_t = \Delta W_t \geq 0$

Two approaches:
Weak versus strong sustainability

Strong sustainability

– Human well-being is subject to physical & ecological limits

– Sustainability = critical levels or flows of natural capital (NC) stocks are maintained over time:

- Minimum levels of ecosystem services, e.g., biodiversity, climate regulation, nutrient cycling, pollination, wetlands
- Maximum sustainable yields of renewable resources, e.g., fishing, deforestation
- Maximum rates of pollution, e.g., GHG emissions, nutrient run-off

A society is sustainable if $\boldsymbol{NC_{i,t+1} = NC_{i,t} + \Delta\, NC_{i,t} \geq \overline{NC_i}}$

for each critical NC stock or flow i

Project: Land Tenure and Conservation

- Funding: Iowa nutrient research center
- Timeline: 2016 fall – 2018 fall
- PIs: Wendong Zhang and Alejandro Plastina
- Goal: to enhance adoption of nutrient management practices and result in win-win situations for landowners and tenants.
- Approach: two state-wide surveys.
  - First, we add a special section on land tenure and conservation to state-mandated Iowa Farmland Ownership and Tenure survey.
  - Second, we also conduct a similar but separate survey among tenants in Iowa.

Project: Land Tenure and Conservation

- What is the most effective and acceptable economic incentive for landowners and tenants to adopt alternative conservation practices?
  - What is the willingness-to-pay by landowners for each nutrient management practice, and what is the willingness-to-accept needed by tenants to invest?
  - Rent reduction?
  - Longer leases?
  - Estate, income and land tax credits?

Project: Land Tenure and Conservation

- Heterogeneous impacts? Owner-operator, sentimental owners, absentee owners
- What additional economic incentives are needed to encourage adoption of longer-term structural conservation practices vs. annual practices (e.g., cover crops, reduced tillage)?
  - with high initial investment costs and low maintenance costs (e.g., conservation drainage, grass waterways, bioreactors and wetlands)
- Would landowners or tenants prioritize conservation adoption on low-productivity field or least productive areas of fields?

Project: Economics of Soil Health

Lit Review: a conceptual model of soil health

The McConnell model is expressed as

$$\int_0^T e^{-rt}[pg(t)f(s, x, z) - cz]\, dt + R[x(T)]\, e^{-rT} \tag{4}$$

subject to

$$\dot{x}(t) = k - s(t) \tag{5}$$

$$x(0) = x_0 \tag{6}$$

where $g(t)f(s, x, z) =$ output

$s(t) =$ soil loss
$x(t) =$ soil depth
$z(t) =$ index of variable inputs
$g(t) =$ neutral technical change
$c =$ variable input cost
$r =$ farmer's discount rate
$p =$ per unit output price
$R =$ resale value of farm
$k =$ exogenous addition to soil base

It is assumed that *soil loss*, $s(t)$, or farming more intensively in period t impacts positively on output but at a decreasing rate so $f_s \geq 0$ and $f_{ss} \leq 0$. The *depth of soil*, $x(t)$, also has a beneficial effect on output, but at some point additional depth adds nothing to productivity. Hence, $f_x \geq 0$ and $f_{xx} \leq 0$.

Source: Kenneth McConnell, University of Maryland

We model harvest as $h(s, x) = qs^{1/2}x^{1/2}$, where q is a catchability coefficient and x is a measure of effort. This generalized Schaefer specification of harvest has the attractive feature of diminishing returns to fish stock and effort. Assume

$$W = mh - cx, \tag{13}$$

$$F = \dot{s} = rs(1 - s/k) - h, \tag{14}$$

where the market price is $m = 10$, cost of effort is $c = 10$, the stock follows logistic growth with an intrinsic growth rate $r = 0.5$ and carrying capacity $k = 1{,}000$. We assume $\delta = 0.05$. Formally, the social planner's problem, replicating the outcome of a dynamically efficient market, is expressed as

$$\max_{x(t)} \int_0^{\infty} e^{-\delta}\left(mqs^{1/2}x^{1/2} - cx\right)dt$$

$$\text{subject to } \dot{s} = rs\left(1 - \frac{s}{k}\right) - qs^{1/2}x^{1/2}.$$

The current value Hamiltonian for this problem is

$$H = mqs^{1/2}x^{1/2} - cx + p(rs\left(1 - \frac{s}{k}\right) - qs^{1/2}x^{1/2}),$$

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Integrated Modeling of Agricultural Landscapes and Ecosystem Services: The Lake Erie Coupled Human and Natural Systems Project

Support provided by grants from the Ohio Sea Grant Program and the National Science Foundation Coupled Human and Natural Systems Program (GRT00022685)

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Lake Erie coupled human-natural systems research project

Jay Martin, Ohio State (PI)	
Noel Aloysius, Ohio State	Elena Irwin, Ohio State
Elizabeth Burnett, Ohio State	Stuart Ludsin, Ohio State
Na Chen, Ohio State	Erik Nisbit, Ohio State
Carlo DeMarchi, Case Western R. U	Brian Roe, Ohio State
Marie Gildow, AEP	Eric Toman, Ohio State
Alexander Heeren, Ohio State	Robyn Wilson, Ohio State
Greg Howard, East Carolina U	Wendong Zhang, Iowa St

Funding from NSF Coupled Human and Natural Systems Program (GRT00022685) and the Ohio Sea Grant Program

Ohio Sea Grant College Program

Project Website: http://ohioseagrant.osu.edu/maumeebay


Detroit
Windsor
Maumee Bay
Toledo
Lake Erie
Cleveland
N
25 miles
40km
Image: NOAA

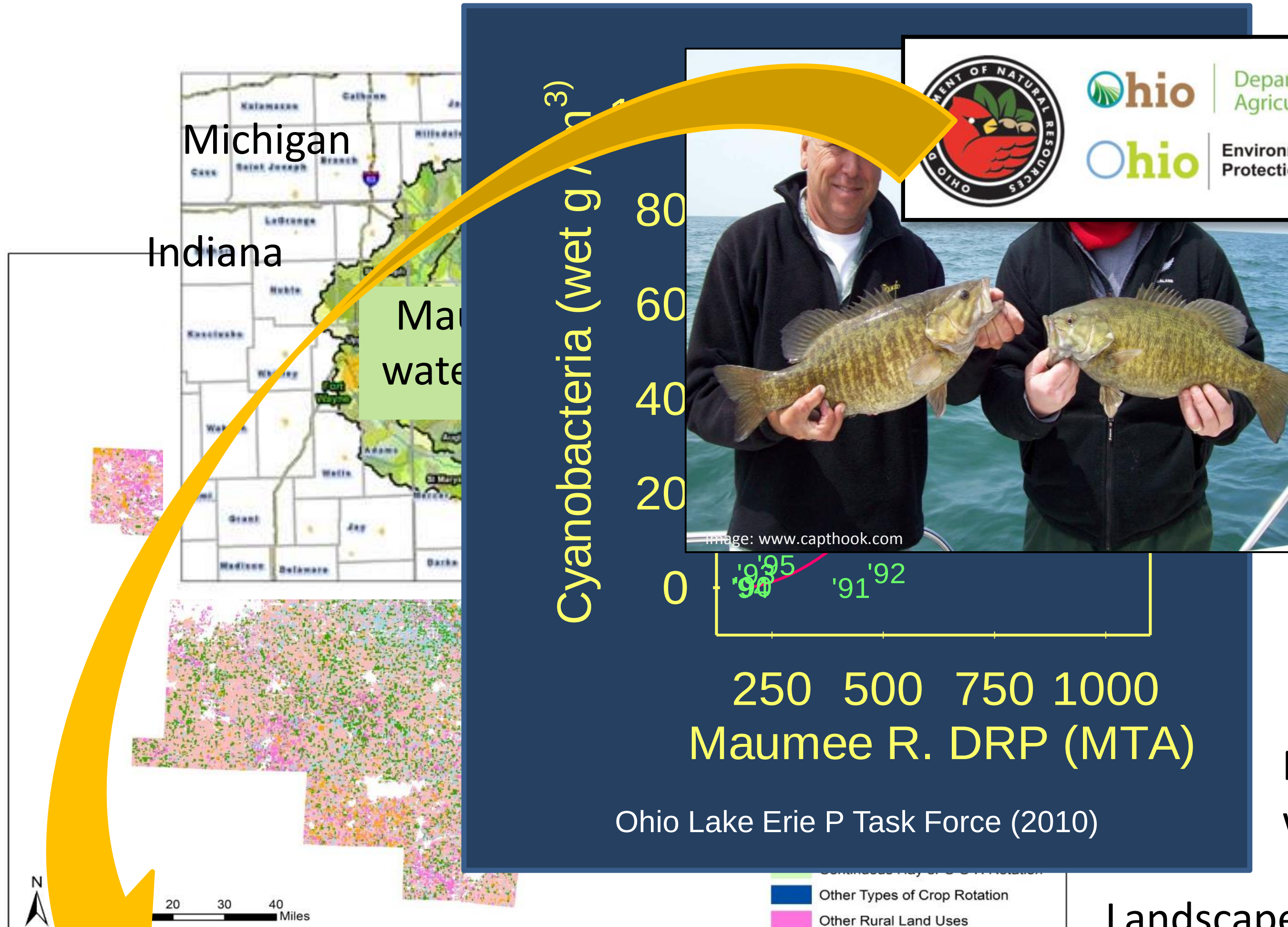

Point Pelee,
August 19, 2011


New York Times,
August 2014






A Complex, Coupled Human-Natural System



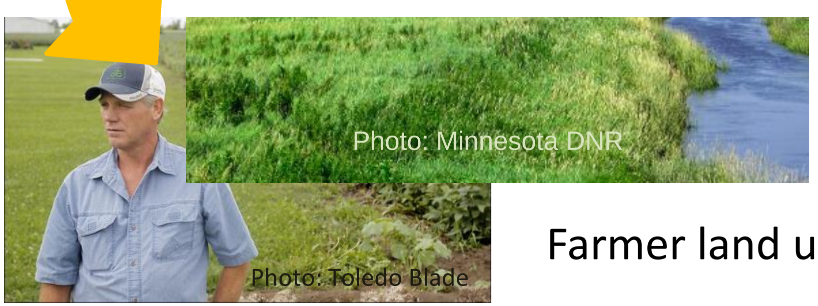
Lake & land management policies

Lake Erie ecosystem services

Concentration of toxic algae in Lake Erie

Phosphorus loadings from watershed to Lake Erie

Landscape change: Cumulative land use and runoff from all fields



Fertilizer runoff from field to waterway

Farmer land use & management decisions

From an economics viewpoint

Reducing excess P to improve Lake Erie water quality implies…

Challenges of quantifying benefits and costs

- **Lack of markets**
  - Many ecosystem services are public goods → no price
  - Pollution is an externality → no price
- **Complex ecosystem dynamics**
  - Threshold effects in terms of algal blooms, hypoxia
- **Complex social processes**
  - Human impacts are generated by the cumulative actions of many autonomous individuals
  - Humans respond (or don't) to changes in ecosystem services and policies, sometimes in unanticipated ways
- **Many trade-offs that need to be quantified**
  - Many types of economic activities generate benefits and costs
  - Many types of ecosystem services are impacted

Lake Erie coupled human-natural systems project

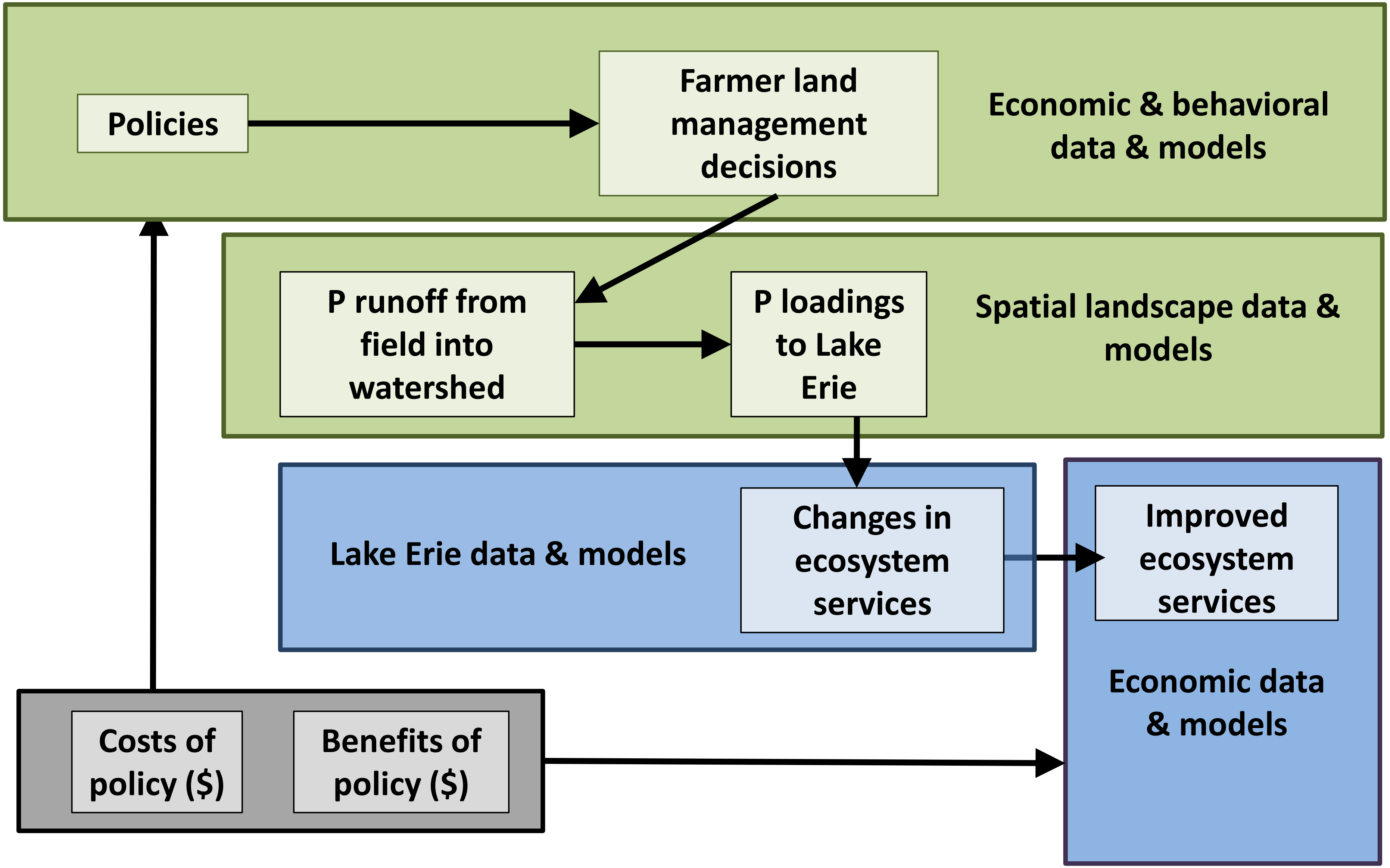
Main research questions

1) What are the costs and benefits of reducing phosphorus (P) (specifically, soluble P) loadings to Lake Erie?

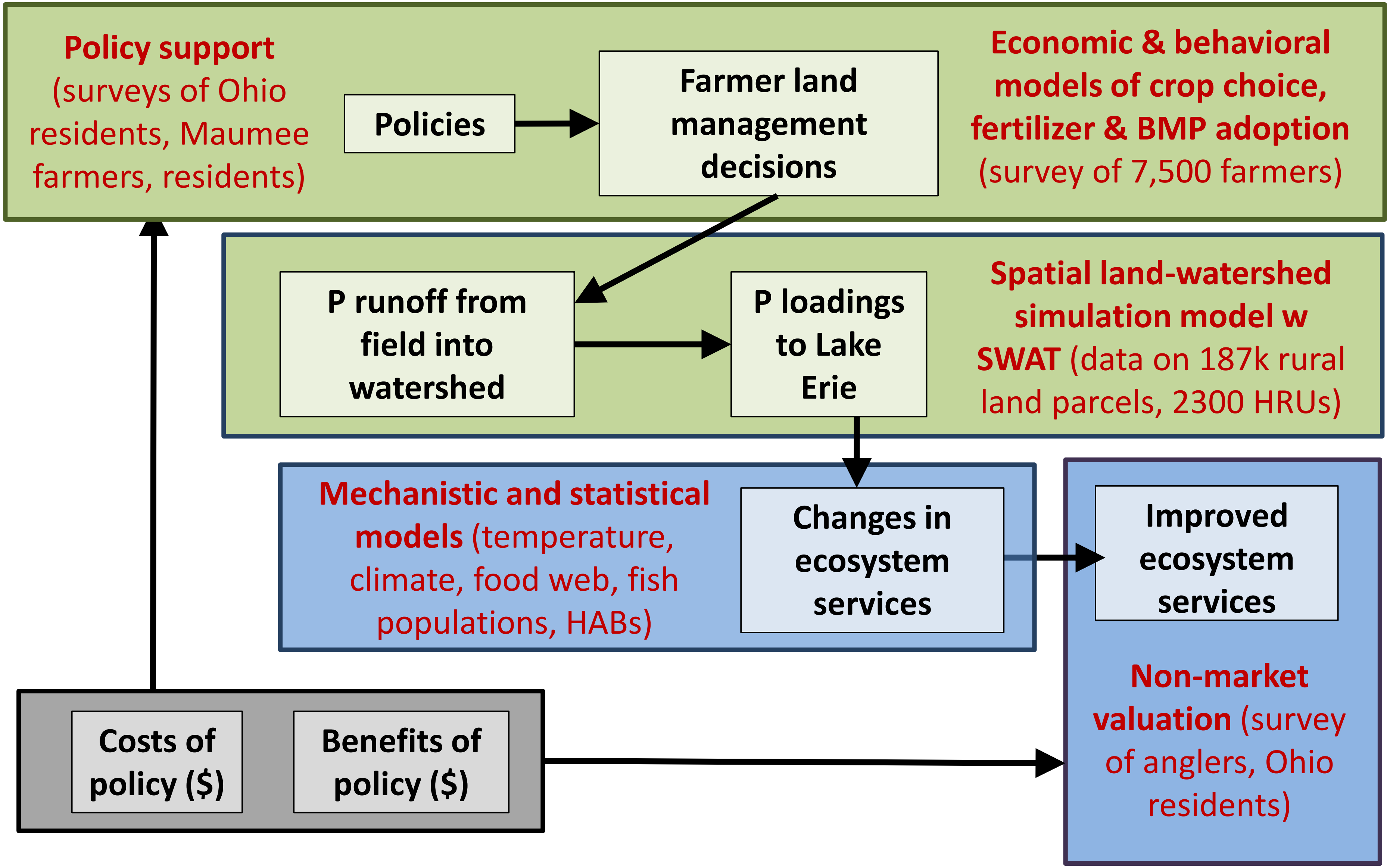
2) Which incentives are the most effective for reducing phosphorus runoff from farm fields?

3) What policies have the most public support?

How can we determine the "optimal amount" of phosphorus (P) loadings?

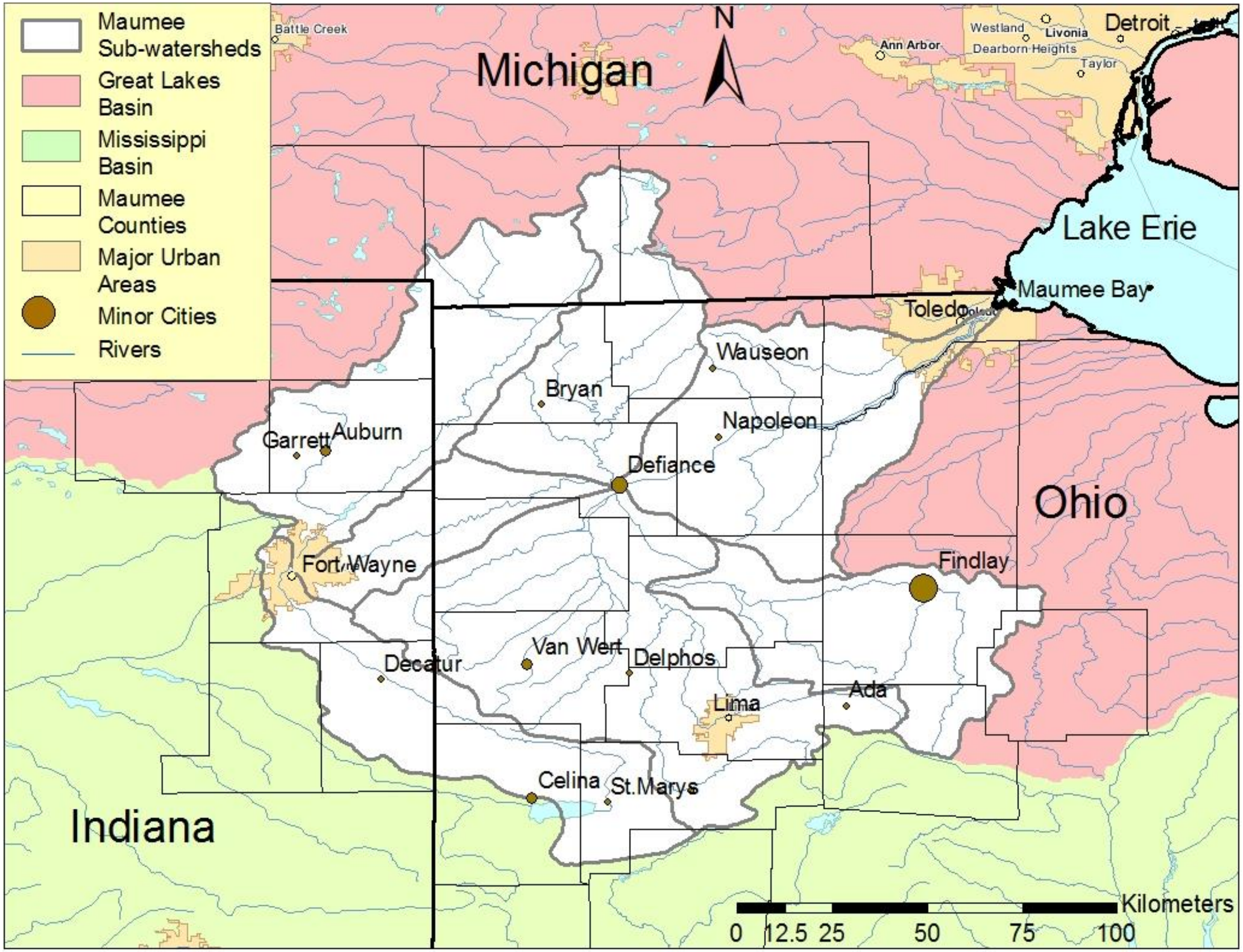


Data and integrated modeling needs



Maumee Watershed

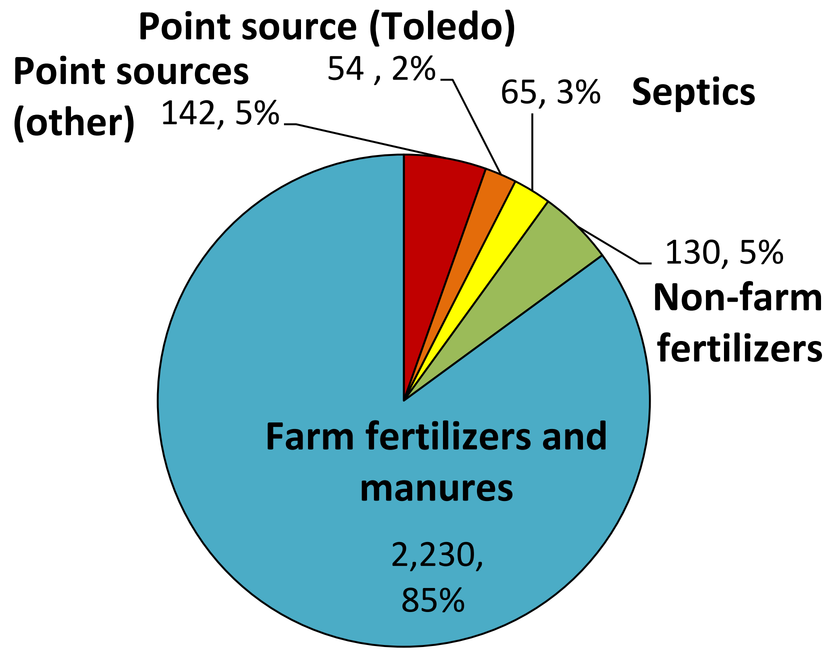
Largest in Great Lakes~17,000km^2, 85% agriculture



Why Focus on Agricultural Sources?

We estimated 85% of P delivered by the Maumee comes from agriculture.

Estimated P **Delivery** from the Maumee River to Lake Erie (*t/y*)



Delivery of Farm Fertilizers & Manures =

Average Load to Lake Erie (2620 t/y) –

Toledo WWTP (54 t/y) –

Other Point Sources (142 t/y) –

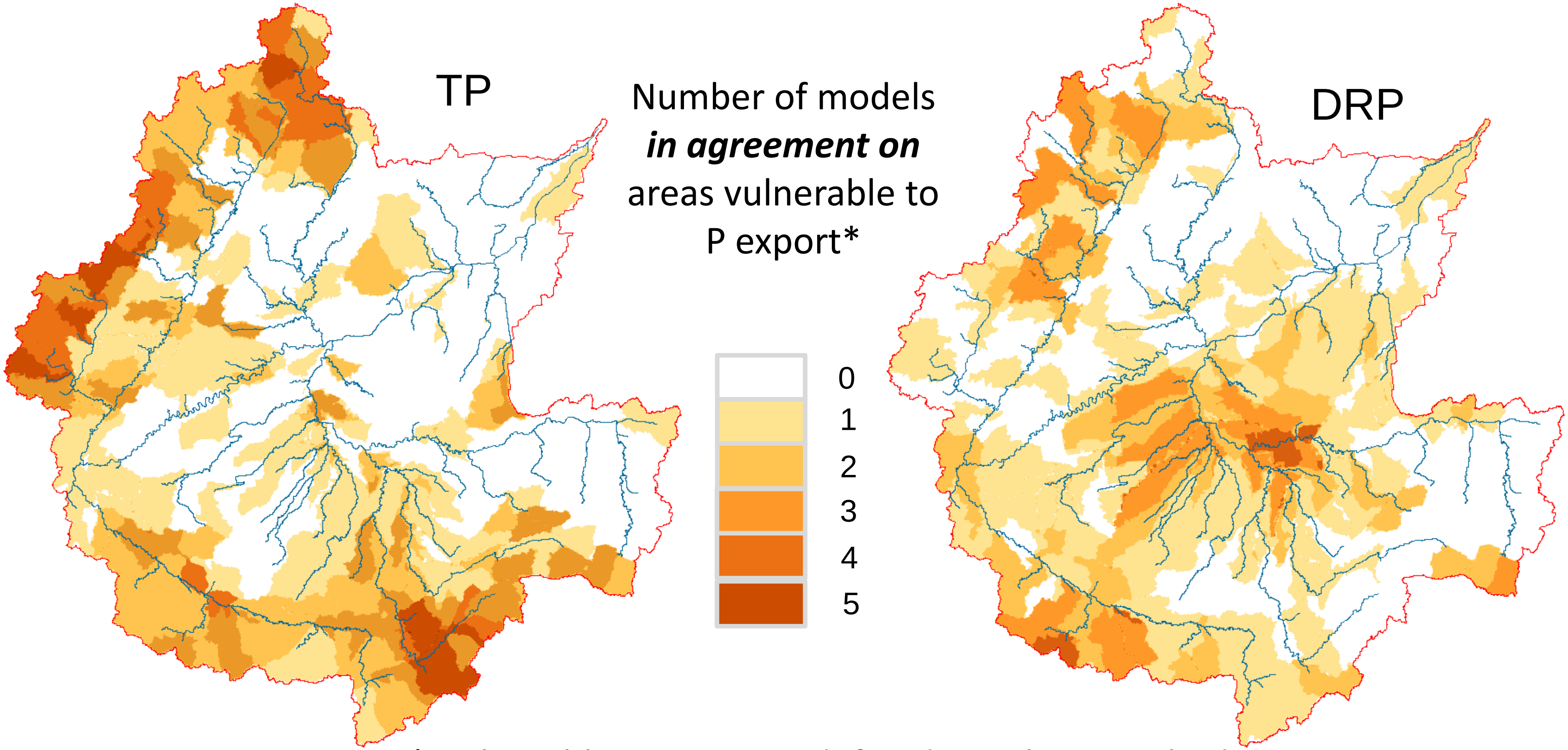
Non-farm Fertilizers (130 t/y) –

0.39 * Septics (65 t/y)

= ~ ***2230 t/y***

Jay Martin, OSU

Hot Spots of Total and Dissolved Phosphorus Loadings into Lake Erie



* Vulnerable areas were defined as sub-watersheds contributing the 20% highest area-weighted P load. These areas are more vulnerable to P losses if untreated by conservation practices.

Economic and behavioral models of farmers' crop choice and land management decisions

Robyn Wilson[1], Elizabeth Burnett[1], Wendong Zhang[2], Brian Roe[3], Greg Howard[4], Elena Irwin[3]

[1]School of Environment and Natural Resources, Ohio State University

[2]Department of Economics, Iowa State University

[3]Department of Agricultural, Environmental and Development Economics, Ohio State University

[4]Department of Economics, East Carolina University

What did we do?

- Conducted three mail surveys of corn and soybean farmers living in the WLEB
  - 2011 – Maumee (OH counties)
  - 2014 – Maumee (IN, MI, OH counties)
  - 2016 – Maumee and Sandusky (entire WLEB)
- Response rate: ~35-43%
- Goals
  - Identify baseline adoption of recommended practices
  - Model likely future adoption to inform policy and outreach

Our Farmers

- 98% Male
- Average age of 58 (range 18 to 96)
- 50% HS diploma, 48% at least some college
- 67% 3rd generation, 22% 2nd, 10% 1st
- Average acres: 211 corn/236 soybeans

- *Our sample may over-represent older, more experienced farmers with income over $50K*
- *But they have larger environmental impact*

What are farmers doing?*

	2011	2014	2017	Potential Future*	The Need**
Cover crops	8%	17%	22%	60%	58%
Avoiding winter application	25%	49%	56%	85%	--
Avoiding fall application	25%	30%	--	--	--
Delaying broadcasting	--	36%	39%	86%	--
Fertilizer placement	--	33%	39%	68%	50%
Rates based on testing	46%	52%	63%	92%	--

*2017 self-reported behavior + those reporting likely adoption

**Based on multi-modeling scenarios to achieve a 40% reduction in total P, assuming 78% adoption of filter strips

Robyn Wilson, OSU

Predictors of BMP Adoption

Recommended BMPs are more likely to be adopted among farmers with greater education, farm income, and acreage

These farmers perceive greater control over nutrient loss, are more willing to take risks, have a greater belief in the efficacy of recommended BMPs, perceive greater responsibility over water quality, and have a greater conservationist identity

Phosphorus fertilizer application model

(Wendong Zhang and Elena Irwin, 2015)

- **Research question:** How sensitive are farmers to the price of P fertilizer? How much would a change in the price alter their application rate, profit and phosphorus runoff?
- **Statistical model** estimates the farmer's rate of phosphorus application on a given field as a function of:
  - Type of crop grown on field
  - Land management practices implemented on field
  - Fertilizer prices paid by farmer
  - Land characteristics of field
  - Farmer characteristics
- **Model results** in terms of predicted price elasticity of fertilizer demand
  - Given an increase in price, how much will farmer reduce fertilizer application?

Estimated P fertilizer elasticity

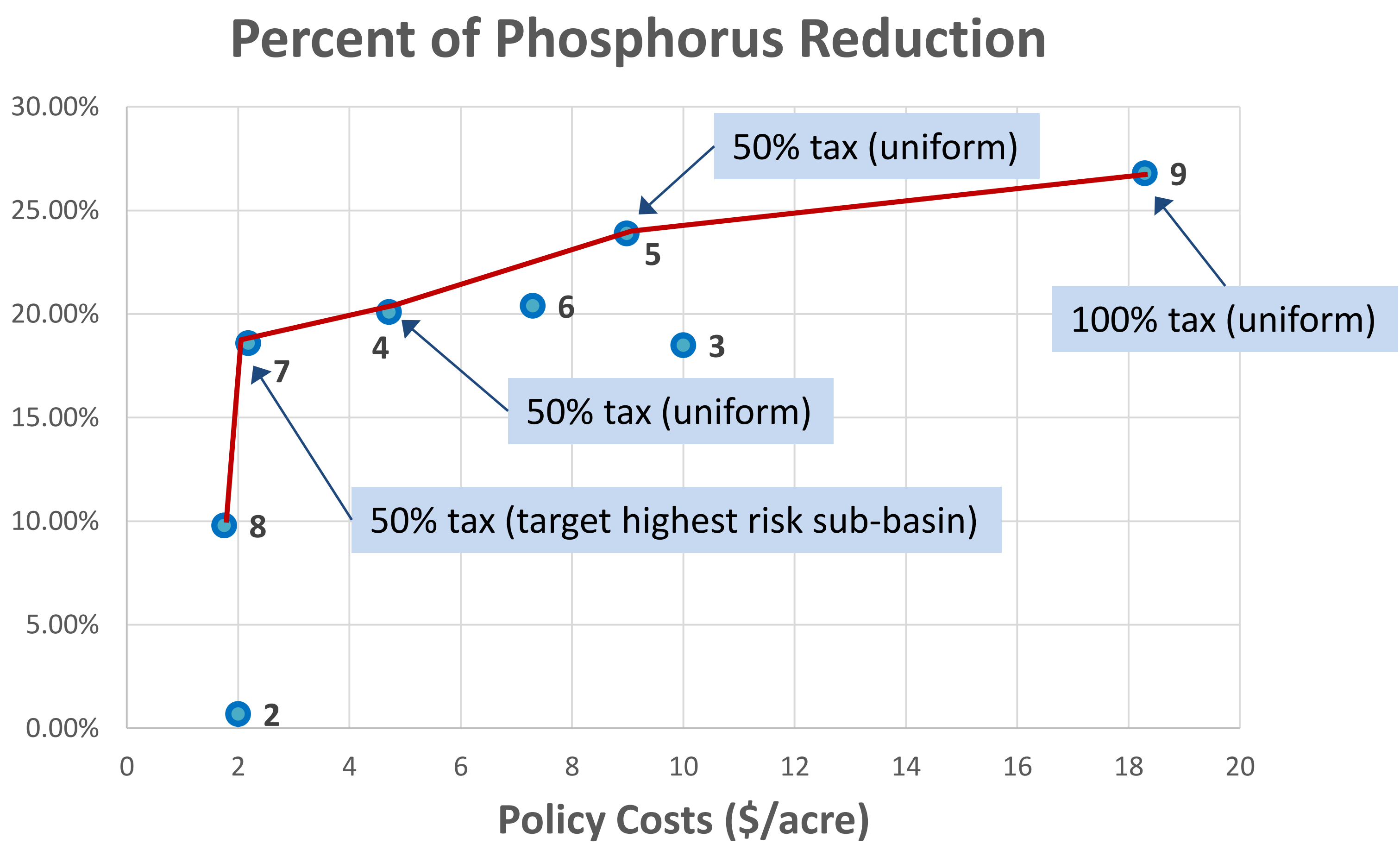
Question: How much will farmers reduce the amount of P fertilizer they apply over a two year period, given a 100% increase in fertilizer price?

	Corn crops	Soybean crops
Mean estimate	-38.8%	-48.8%
Farmer slightly familiar w 4Rs	-37.1%	-48.8%
Farmer very familiar w 4Rs	-53.6%	-48.8%
Average soil quality of field	-40.8%	-51.3%

Results

- Farmers are relatively price insensitive → reduce P fertilizer by less % than a given % price increase
- Farmers with environmental stewardship have higher price elasticity
- Soil quality and P are substitutes

Trade-off frontier: Percent of P input rate reduction (lbs/acre vs. cost of policy ($/ acre)

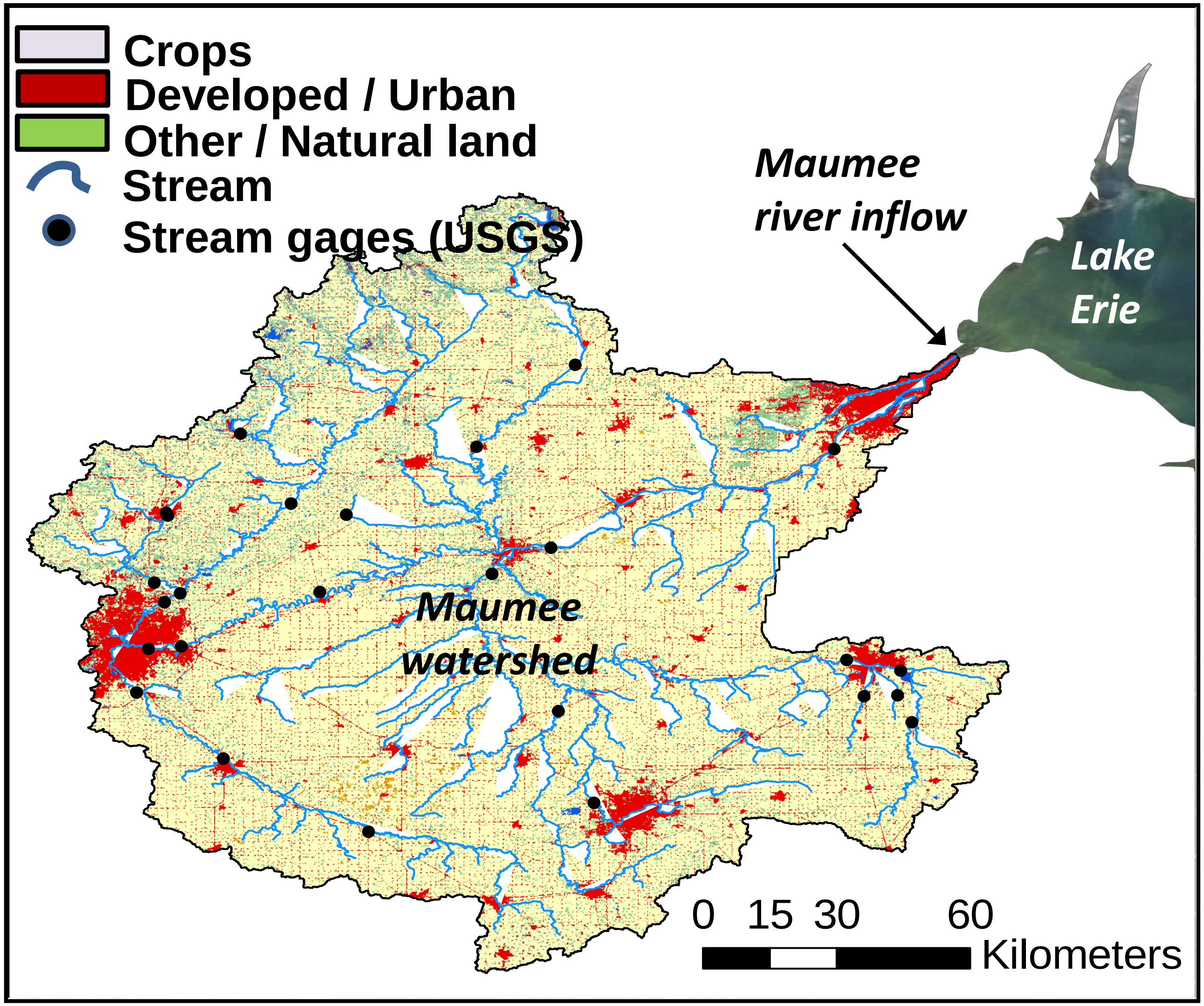


Spatial landscape model to simulate nutrient loadings from watershed to Lake Erie using Soil and Water Assessment Tool (SWAT) Model

Noel Aloysius[1,3], Marie Gildow[1,2], Jay Martin[1] and Stuart Ludsin[3]

[1]Department of Food, Agricultural and Biological Engineering
[2]presently at American Electric Power
[3]Department of Evolution, Ecology and Organismal Biology

Question: How do changes in agricultural management practices alter P loadings to Lake Erie?



Jay Martin, OSU

Management practices

Management practice	Abbreviation
Fertilizer placement/Injection into ground	Place
50% P application reduction	50% P
Spring application	Spr. App
Fall application	Fall App
Cover crop (cereal rye)	Cover
Continuous no-till	No-till
Continuous corn	Corn
Winter wheat rotation	Wheat
Vegetative filter strips	Filter

Vegetated filter strip

Winter cover crop

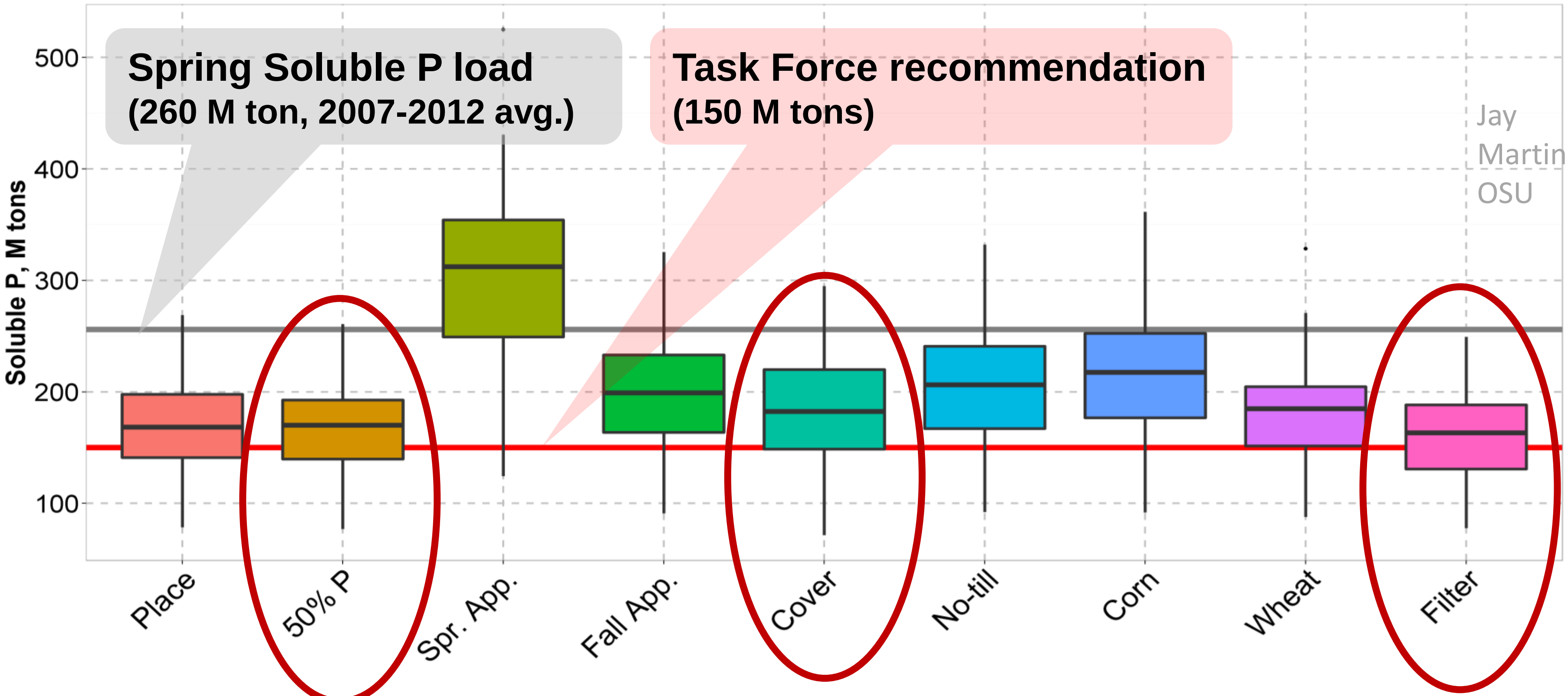
Nutrient management

Conservation tillage

Jay Martin

OSU

Changes in spring soluble P loadings
(M tons, 2005-2014)



50% reduction in application of P could potentially achieve target – but how can we achieve this and at what cost? Farmer model shows that the tax needed to achieve this may be too high; multiple policies are needed

Back to the question: **which policies will lead to more sustainable outcome?**

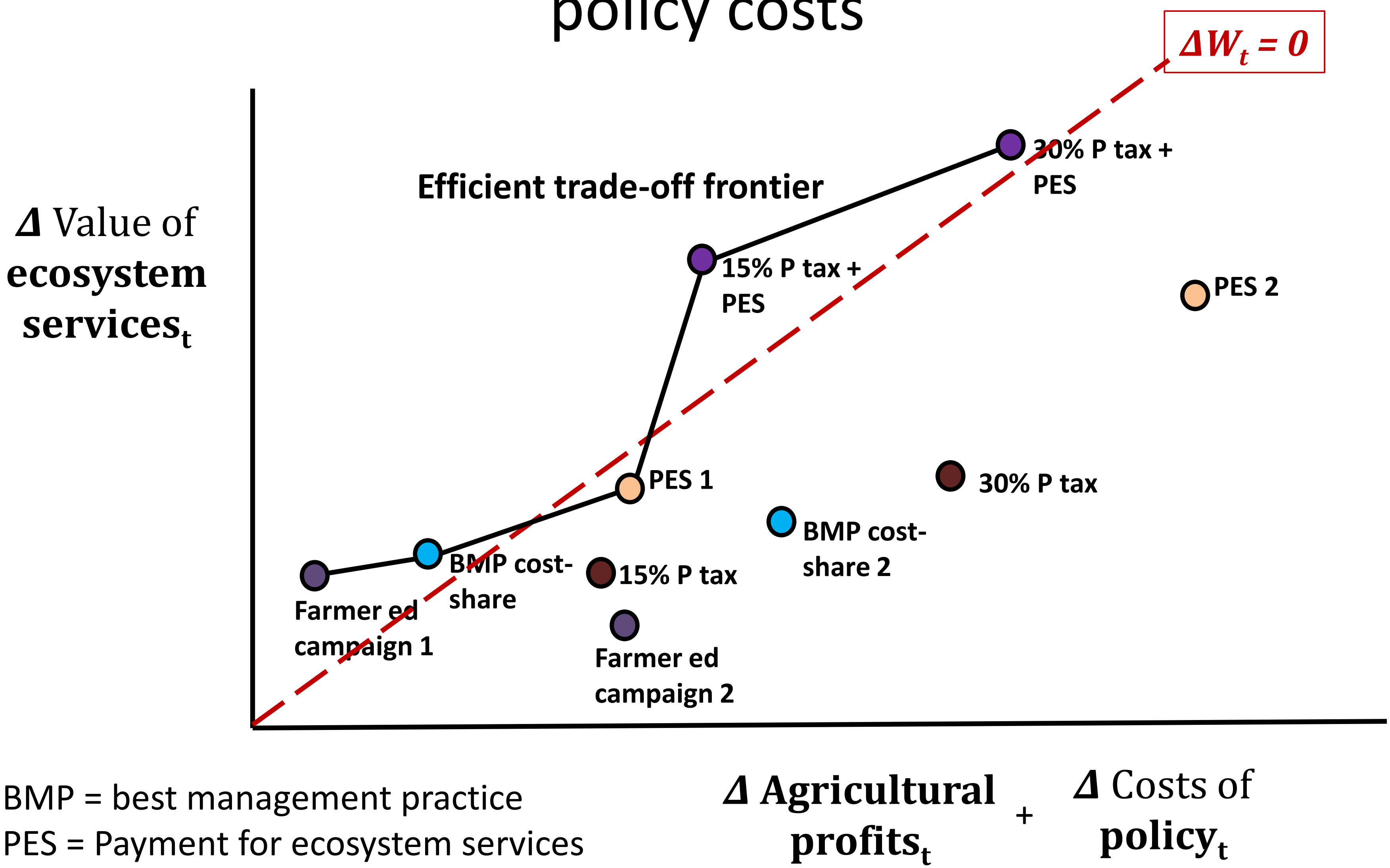
Weak sustainability: Does policy change generate non-decreasing total wealth over time?

$$\Delta W_t = \Delta \text{ Value of } \textbf{produced} \text{ capital}_t + \Delta \text{ Value of } \textbf{natural} \text{ capital}_t + \Delta \text{ Value of } \textbf{human} \text{ capital}_t + \Delta \text{ Value of } \textbf{social} \text{ capital}_t \geq 0$$

$$\Delta W_t = \Delta \text{ Value of } \textbf{produced} \text{ capital}_t + \Delta \text{ Value of } \textbf{natural} \text{ capital}_t + \Delta \text{ Value of } \textbf{institutional} \text{ capital}_t \geq 0$$

$$\Delta W_t = \Delta \textbf{ Agricultural profits}_t + \Delta \text{ Value of } \textbf{ecosystem services}_t + \Delta \text{ Costs of } \textbf{policy}_t \geq 0$$

Trade-off frontier to compare multiple policies: Ecosystem service benefits versus economic and policy costs



BMP = best management practice

PES = Payment for ecosystem services

Back to the question: **which policies will lead to more sustainable outcome?**

Strong sustainability: Does policy change maintain minimum critical natural capital stocks and flows?

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

$$P\,Flow_{t+1} = P\,Flow_t + \Delta\, P\,Flow_t \leq \overline{P\,Flow}$$

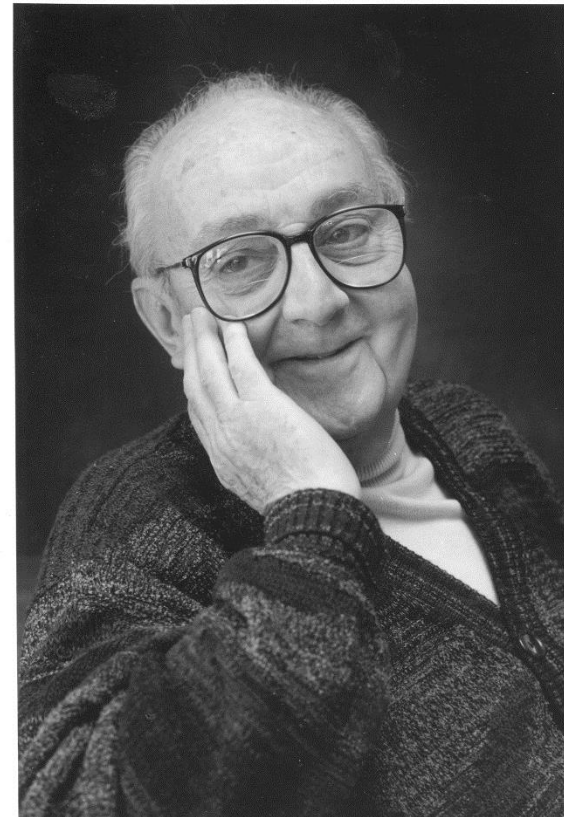
specifies a maximum limit for P run-off in given year

$$\Delta\, P\,Flow_{min} = P\,Flow_t - \overline{P\,Flow}$$

specifies minimum reduction in P run-off needed to meet limit

Conclusion

- Goal is to help stakeholders **understand trade-offs (costs and benefits) of different policy options**
- Integrated modeling that links **human changes** (farmer decisions) with **landscape and ecosystem changes** (ecosystem services) is critical for this analysis
- Be sure to balance **maintaining your discipline core** and effectively **collaborating with people outside your disciplines in a team**



"Essentially all models are wrong, but some are useful." – George Box

Thank You!

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