Protecting Watershed Ecosystems Through Targeted Local Land Use Policies

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Question:

What do you think are the most important goals for local land use planning and regulations?

According to Local Planners

- Posted the same question to county land use planners in five western states (CA, OR, WA, ID, NV).
- Protecting water quality, wildlife habitat, and resource lands (farmland and forest land) were among the most frequently cited goals.

Two Issues

- Which land use policies are most effective in achieving the environmental goals?
- Can land use policies be better targeted to improve their environmental performance?
- In this paper, we attempt to address these issues by conducting an empirical analysis, focusing on four western states (OR, WA, CA, ID).

These Issues Are Important

- Land use is arguably the most pervasive socioeconomic force driving the degradation of ecosystems.
  - Agricultural runoff has been identified as a leading cause of water pollution in both inland and coastal waters.
  - Drainage of wetlands and irrigation water diversions have brought many wildlife species to the verge of extinction.
  - Urban development has been linked to water pollution, air pollution, and loss of wildlife habitat.

The Environmental Effects Depend on Land Use Policies

- **Some Land Use policies directly affect land use**
  - Zoning ordinances
  - Transfer of development rights
  - Critical habitat designation
- **Others affect land use indirectly**
  - Open space designation can affect both the pace and pattern of land development by creating spatial externalities (Irwin and Bockstael 2002; 2004; Wu and Plantinga, 2003).
  - Incentive-based policies, such as development impact fees or reforestation payments, affect land use by changing the relative returns to alternative land uses.

Objectives

- To evaluate the effect of alternative land use policies on watershed ecosystem services through their impacts on land use in four western states (CA, ID, OR, WA).
  - Are the impacts of land use policies uniform across watersheds?
  - Can the land use policies be targeted to improve their environmental performance?

Related Literature

- Many natural sciences studies have examined the effect of land use changes on water quality and ecosystem services, but most take land use as given, do not examine how land use is affected by economics and policies.
- Many economic studies have examined land use decisions, but most do not examine how those decisions affect water quality and ecosystems.
- Some studies have explored the linkages between policies and water quality, but most are at the farm or watershed level.
- Several have explored the linkages at the regional level, but none, to our knowledge, has examined the effect of local land use policies.

Contribution

- To use linked models of land use and watersheds to evaluate the impacts of local land use policies on selected watershed indicators, with a focus on the potential for targeting such policies.

Approaches

- Estimate an econometric model of land use choice to predict landowners' responses to policies.
- Estimate a set of physical models to examine the effect of land use on watershed ecosystem indicators.
- Combine the models to simulate the policy impacts on watershed ecosystem indicators.

The Land Use Model

- Predicts land use choices at individual NRI sites under different prices and policy scenarios
- Based on a random utility model
- A landowner's utility from land use *k* on parcel *i* in year *t*, $U_{ikt,}$ is divided into a mean and a random error term:

$$U_{ikt} = \boldsymbol{\beta}_k'\mathbf{v}_{ikt} + \varepsilon_{ikt}$$

- $(\beta_k' v_{ikt)})$ is a function of the current net returns to the land use, the expected growth of the net return, and the uncertainty surrounding the return, and local land use regulations (Capozza and Li. 1994).
- $\text{Prob}_{ikt}=\text{Prob}(\boldsymbol{\beta}_k'\mathbf{v}_{ikt} + \varepsilon_{ikt} \geq \boldsymbol{\beta}_l'\mathbf{v}_{ilt} + \varepsilon_{ilt,}$ for any l).

Watershed Health Indicators

- *Conventional ambient water pollution:* number of surface water samples in a watershed with concentrations of one or more of four conventional water pollutants (phosphorus, ammonia, dissolved oxygen, pH) exceeding the national reference levels.
- *Toxic ambient water pollution:* number of surface water samples in a watershed with concentrations of one or more of four toxic pollutants (copper, nickel, zinc, chromium) exceeding the national chronic levels.
- *Species-at-risk:* number of aquatic and wetland species (plants and animals) at risk of extinction in a given watershed.

The Models of Watershed Health Indicators

- The indicators are "event counts", which are usually estimated using the Poisson model.
- The Poisson model has a restrictive equidispersion property: (i.e., $E(y) = V(y)$)
- Negative binomial (NB) models suggested by Cameron and Trivedi (1998) overcomes this limitation.
- The watershed indicator models are specified as NB2 models:

$$\ln(CONVWQ_i) = \ln N_i^c + \beta_0 + \beta_1 l_i^c + \beta_2 p_i^c + \beta_3 d_i^c + \varepsilon_i^c$$
$$\ln(TOXICWQ_i) = \ln N_i^t + \theta_0 + \theta_1 l_i^t + \theta_2 p_i^t + \theta_3 d_i^t + \varepsilon_i^t$$
$$\ln(SPERISK_i) = \delta_0 + \delta_1 l_i^s + \delta_2 p_i^s + \delta_3 d_i^s + \varepsilon_i^s$$

N: total number of samples
l: land use variables
p: physical characteristics of watersheds
d: spatial dummies
$\text{Exp}(\varepsilon) \sim$ Gamma distributed

Table A1. The Causes and Effects of Impaired Conventional Ambient Water Quality

Causes	*References*	*Effects*	*References*
Cultural (excessive) eutrophication:			
• Discharge of organic waste, treated and untreated sewage • Nutrient loading caused by urban and agricultural runoff	Carpenter et al. 1998 Faurie et al. 2001 Laws 1993 Ryszkowski 2002 Schindler 1977 Schnoor 1996	• Increased growth of algae (algal blooms), aquatic weeds, and other phytoplankton • Increased water turbidity • Wide fluctuations of dissolved oxygen concentration causing hypoxic or anoxic conditions • Changes in species composition and biomass, loss in faunal and floral diversity • Adverse effects on aesthetic and recreational values	Brouwer et al. 1991 Carpenter et al. 1998 Faurie et al. 2001 Laws 1993 Mason 1977 Sayer et al. 1999 Schindler 1990, 1994 Schnoor 1996 Seehausen et al. 1997 Smith 1998 Ryszkowski 2002 Vitousek et al. 1997
• Agricultural practices (e.g., fertilizer and chemical application rates, crop management practices), and topographic and hydrological characteristics	Anderson et al. 1985 Barbash et al. 2001 De Roo 1980 Gilliam and Hoyt 1987 Kellogg et al. 1992 Smith et al. 1987 Wu et al. 1997 Wu and Babcock 1999		
Dissolved oxygen depletion:			
• Abiotic factors (incl. temperature and atmospheric pressure) • Biotic factors (incl. photosynthesis of plants and planktonic algae)	Faurie et al. 2001	• Oxygen shortages leading to fish kills and changes in aquatic biodiversity	Carpenter et al. 1998 Smith 1998
• Organic waste, incl. domestic, farm, and industrial effluents, or urban runoff	Alloway 1995 Deaton and Winebrake 2000 Fergusson 1982		
Acidification:			
• Atmospheric nitrogen deposition	Vitousek et al. 1997	• Disruption of the nitrogen cycle in freshwater ecosystems	Vitousek et al. 1997
		• Decreased faunal and floral diversity	Schindler 1988, 1990, 1994

Table A2. The Causes and Effects of Impaired Toxic Ambient Water Quality

Causes	*References*	*Effects*	*References*
• **Metal mining**, incl. ore extraction, smelting, and processing • **Industrial processes** (e.g., metallurgy, electronics, electrical manufacturing, petroleum refining, or chemical industry) Contamination may occur by: - Emission of aerosols and dusts and consequent atmospheric deposition - Discharge of effluents into water ways - Creation of waste dumps in which metals become corroded and leached in the underlying soil • **Domestic uses**, sewage, urban runoff, and traffic	Fergusson 1982 Keyes 1976 McGowen and Basta 2001 Alloway 1995 Fergusson 1982 Stephenson 1987 Alloway 1995 Fergusson 1982	• **Contamination of sediments** in aquatic environments (metallic pollution is highly persistent in time)	Erichsen Jones 1958 Hare et al. 1994 Tessier et al. 1993 Welsh and Denny 1980
		• **Bioaccumulation** of metallic contaminants in aquatic organisms	Handy and Eddy 1990 Laws 1993 Novotny and Olem 1994 Skidmore 1964 Van der Zanden and Rasmussen 1996 Walker 1990
• **Intensive agriculture** (e.g., impurities in fertilizers, sewage sludge, manures from intensive hog and poultry production, pesticides)	Alloway 1995		

Table A3. The Causes and Mechanisms of Changes in Aquatic Biodiversity

Causes	*References*	*Mechanisms*	*References*
Conventional water pollution:			
• Excessive eutrophication and its ramifications, e.g. - Algal blooms creating generally uninhabitable environment, with some bloom-forming species being toxic - Oxygen shortages caused by senescence and decomposition of nuisance plants • Acidification	Carpenter et al. 1998 Ryszkowski 2002 Sayer et al. 1999 Schindler 1990, 1994 Schnoor 1996 Seehausen et al. 1997 Smith 1998 Vitousek et al. 1997 Schindler 1990, 1994	• Changes in species composition and biomass of aquatic fauna and flora caused by: - Dominance of a few highly competitive species tolerant of high nutrient concentrations - Reduced habitat heterogeneity - Higher competition and predation	Brown 1987 Carpenter et al. 1998 Deaton and Winebrake 2000 Laws 1993 Mason 1977 Sayer et al. 1999 Smith 1998
Toxic water pollution:			
• Toxicity of a compound varies across species, the individuals, their age, life history, and various environmental conditions such as pollutant concentration (chronic vs. acute), dissolved oxygen levels, water hardness and pH.	Handy and Eddy 1990 Laws 1993 Skidmore 1964 Watras and Bloom 1992	• Changes in morphology, physiology, body biochemistry, behavior, and reproduction	Handy and Eddy 1990 Laws 1993 Skidmore 1964 Waldichuk 1979
		• Fish kills and increased stress	Skidmore 1964
		• Reduction in photosynthesis	Laws 1993
		• More complex response (additive, synergistic, or antagonistic effects) may occur due to simultaneous exposure to several to metallic contaminants	Skidmore 1964

Table A3. The Causes and Mechanisms of Changes in Aquatic Biodiversity – cont.

Habitat alterations:

• Changes in physical condition of aquatic habitats, incl. water temperature, water currents, depth of the water column, turbidity, area of open water, sediment type and particle size, organic content of sediments	Faurie et al. 2001 Hedrick 1984	• Changes in species composition and population abundance in aquatic ecosystems	Faurie et al. 2001 Ehrlich and Ehrlich 1981 Harding et al. 1998
• Blockage of migratory /dispersal routes by dams	Angermeier 1995	• Isolation of populations caused by habitat alterations (e.g., dam construction) can indirectly affect extinction rates of other species (e.g., non-migratory fish)	Angermeier 1995 Winston et al. 1991
• Changes in riparian conditions	Raphael and Bisson 2003 Wipfli et al. 2002		
• Location versus size of suitable habitat (e.g., fragmentation, connectedness)	Bockstael 1996 Lamberson et al. 1992 Montgomery et al. 1994	• Disruption of wildlife interactions, changing wildlife populations and communities	Rottenborn 1999
• Disturbances associated with urban development, incl. noise, human presence, exotic species, habitat fragmentation	Rottenborn 1999	• Decline in species richness along the urban-rural gradient, with the lowest richness usually found in the urban core	Czech et al. 2000 McKinney 2002
• Importance of the land use - ecosystem linkage at the regional or national scales - Land use, incl. logging, grazing, mining, industrial activities, fertilizer use, urban development - Cumulative damage to aquatic habitats caused by human land use - Regional versus local land-use pattern	Czech et al. 2000 Ehrlich and Ehrlich 1981 Frissell 1993 Harding et al. 1998 Malmqvist and Rundle 2002 Rivard et al. 2000		

Data for Estimating the Land Use Model

- Land use
  - 1982, 1987, 1992, and 1997 Natural Resources Inventories (NRI)
  - Agricultural land (crop and pasture land), range land, forest, urban and built up land, and other.
- County-level land use regulations
  - Our survey of county land use planners in 5 western states
  - Four categories: Incentive-Based Policies, Property Acquisition Policies, Development Guidelines, and Zoning Ordinances
  - Regulation index for each category reflecting both the number of regulations and the perceived effectiveness by the land use planner
- Net returns to alternative land uses
  - Estimated using data from various sources, including data compiled by Plantinga and Lubowsky, USDA, the Bureau of Economic Analysis, and U.S. Census Bureau.

Data for the Watershed Indicator Models

- Watershed health indicators
  - EPA's Index of Watershed Indicators
  - The two water quality indicators are measured by the EPA as the total number of samples exceeding a certain threshold over the 1990-1998 period.
  - The number of species at risk indicator is measured only for 1996.
  - The unit of observation for these variables is a watershed
- Land use, physical characteristics
  - For the water quality models, we aggregate the parcel-level land use data to the watershed level and average over 1987, 1992, and 1997.
  - For the species-at-risk model, we include land use variables for 1992.
  - Data on the characteristics of the watersheds come from NRI, US Geological Survey, and other sources.

Results: The Land Use Model

- Overall, the model performs well.
- The model correctly predicts land use choice for 60.8% of observations.
- To further validate the model, we estimated it with data from the first three periods (1982, 1987, 1992), used the model to project total acreages in each land use in 1997, and compared actual and predicted outcomes using Theil's Inequality Coefficients.
- Theil's ICs range from 0.007 to 0.17, which indicates good predictive performance.

Table 2. Estimates of Marginal Effects for the Multinomial Logit Model of Land Use Choice

Variable	*Agriculture*	*Range*	*Forest*	*Urban*	*Other*
Constant	-0.1076***	-0.1216***	-0.0506***	-0.0315***	0.3112***
Ag. Returns	0.0031***	-0.0005***	-0.0003***	-0.0001***	-0.0022***
Expected Growth of Ag. Returns[a]	0.1163	-0.0184	-0.0110	-0.0040	-0.0830
Range Returns	-0.0127***	0.1178***	-0.0118***	-0.0042***	-0.0890***
Expected Growth of Range Returns[a]	0.0050*	-0.0465*	0.0047*	0.0017*	0.0352*
Forest Returns	-0.0968***	-0.1499***	0.9569***	-0.0323***	-0.6779***
Expected Growth of Forest Returns[a]	-0.000	0.0014	-0.0091	0.0003	0.0064
Variance Growth of Forest Returns[a]	0.0010***	0.0016***	-0.0101***	0.0003***	0.0072***
Urban Returns	-0.0003***	-0.0005***	-0.0003***	0.0032***	-0.0022***
Expected Growth of Urban Returns	0.0031***	0.0048***	0.0029***	-0.0321***	0.0214***
Variance Growth of Urban Returns	0.0218***	0.0337***	0.0203***	-0.2281***	0.1524***
Incentive-Based Policies	0.0035	-0.0158***	0.0402***	-0.0084***	-0.0195***
Property Acquisition	-0.0593***	0.0753***	-0.1039***	-0.0033*	0.0912***
Development Guidelines	0.0910***	0.0472***	-0.0730***	0.0148***	-0.0800***
Zoning Policies	-0.0843***	-0.0227***	0.0505***	0.0001	0.0564***
Land Use Plan	0.0082***	0.0057***	-0.0305***	-0.0188***	0.0354***
Mandatory Review	0.0308***	-0.0195***	0.0881***	0.0082***	-0.1076***
High-Quality Land	0.1796***	0.0344***	0.0007	-0.0402***	-0.1744***
Weighted Distance Index[a]	0.0073*	0.0181***	0.0149***	0.0323***	-0.0725***
Distance Wilderness Park[a]	0.0354***	-0.0936***	0.2713***	-0.0292***	-0.1839***
Distance Urban Park[a]	0.1205***	0.0265***	-0.2696***	-0.1203***	0.2429***
Climatic Factor	0.0007***	0.0012***	-0.0004***	0.0002***	-0.0017***
Percentage of Federal Land	-1.6175***	-0.1859***	-0.7958***	-0.2282***	2.8275***

*, **, *** indicate significance at $\alpha = 10\%$, 5%, and 1%.

[a] Marginal effects are multiplied by 1000 to facilitate presentation. Observations: 512,201. % Correct Predictions: 60.8%

Results: The Land Use Model – cont.

- The own-return marginal effects are positive and significant and the cross-return effects are negative and significant.
- The expected growth of returns to urban and range land has a negative effect in their own equations, suggesting that higher expected growth of returns decrease the probability of choosing the land use at present.
- Counter intuitive, but theoretically possible.
  - When the growth expectation increases, the option value of not developing also increases, so that it may be worthwhile to postpone development even if the value of developed land has increased (Capozza and Li 1994).

Results: The Land Use Model – cont.

- The marginal effects of the land use regulation indices yield mixed results.
- Incentive-based policies and property acquisition programs have a negative and statistically significant effect on the probability of choosing urban land.
- On the other hand, zoning and development guidelines have positive effects on the probability of choosing urban land, although only the marginal effect of development guidelines is statistically significant.
- The insignificant effect of zoning may indicate that zoning affects the location, but not the total amount, of development.
- The positive effect of development guidelines is consistent with the notion that land use planning that preserves open space may spur additional development.

Results: The Watershed Indicator Models

- Many versions of models are estimated, results are generally consistent.

Land Use	*Conventional Water Quality*	*Toxic Water Quality*	*Species at Risk*
Constant	-2.718*** (< 0.0001)	-5.132*** (0.0017)	0.905*** (< 0.0001)
Urban Land	0.013* (0.0708)	0.034* (0.0745)	0.007* (0.0812)
Agricultural Land	0.018*** (0.0002)	0.002 (0.9225)	0.002 (0.4058)
Transportation Land		1.444** (0.0206)	0.301*** (0.0012)
Mining Land		0.4972* (0.0928)	0.113 (0.1054)
Other Land 1	0.012*** (0.0018)		
Other Land 2		0.039** (0.0286)	0.002 (0.4149)
Irrigated Land	1.67 E-04 (0.6245)	-0.0075* (0.0861)	-5.52 E-05 (0.7524)
Soil Loss due to Water Erosion	0.017 (0.7246)		
Soil Loss due to Wind Erosion	-0.021 (0.5743)		
Index of Soil Permeability	-0.124 (0.1368)		
Area of Water Bodies			-2.39 E-04 (0.7957)
Area of Wetlands			0.005*** (0.0057)
Total Land Area			1.80E-04*** (0.0048)
Observations	155	31	279
Deviance/DF	1.20	1.43	0.96
Pearson χ^2/DF	0.93	0.93	1.03

Table 3. Coefficient Estimates for the Watershed Health Indicator Models

Land Use	*Conventional Water Quality*	*Toxic Water Quality*	*Species at Risk*
Constant	-2.648***	-5.800***	-11.611***
Urban Land x LRR AB	0.002	0.066	
Urban Land x LRR C	0.014*	0.041**	
Urban Land x LRR DE	0.020	0.243*	
Ag. Land x LRR AB	0.015***	-0.011	
Ag. Land x LRR C	0.016***	0.060***	
Ag. Land x LRR DE	0.023***	-0.020	
TR x LRR AB		2.141**	
TR x LRR C		-1.674**	
TR x LRR DE		1.365**	
Min x LRR AB		-2.118	
Min x LRR C		0.585***	
Min x LRR DE		-11.066	
Urban Land x Div. 240			0.111***
Urban Land x Div. m240			-0.003
Urban Land x Div. 260			0.017***
Urban Land x Div. m260			0.004
Urban Land x Div. 320			-0.355**
Urban Land x Div. 330			0.361
Urban Land x Div. m330			0.025
Urban Land x Div. 340			0.039
TR92 x Div.240			1.00**
TR92 x Div.m240			0.364*
TR92 x Div.260			0.308**
TR92 x Div.m260			0.640***
TR92 x Div.320			2.011**
TR92 x Div.m330			-0.455*
TR92 x Div.340			0.171

Ag. Land x Div. 240			-0.064***
Ag. Land x Div. m240			-0.033***
Ag. Land x Div. 260			0.006
Ag. Land x Div. m260			-0.006
Ag. Land x Div. 320			-0.037**
Ag. Land x Div. 330			-0.037
Ag. Land x Div. m330			-0.006
Ag. Land x Div. 340			-0.029***
MIN92 x Div.240			-5.102***
MIN92 x Div.m240			0.984
MIN92 x Div.260			0.049
MIN92 x Div.m260			-0.331
MIN92 x Div.320			-0.035
MIN92 x Div.m330			-0.102
MIN92 x Div.340			0.152
USLE879297	0.033		
EIWIND879297	-0.008		
SOILPERM	-0.118		
WATERacres92			5.43E-07
WETLANDac97			-2.45E-06
IRRIGacres879297	0.000	-6.53E-06	-7.82E-7***
Other Land 1[a]	0.010**		
Other Land 2[b]		0.050***	-0.010***
Observations	155	31	279
Deviance/DF	1.2364	2.0195	1.0706
Pearson χ^2/DF	0.9558	1.5337	1.3045

*, **, *** indicate significance at $\alpha = 10\%$, 5%, and 1%, respectively.

[a]Other land 1 includes transportation, minor land (incl. mining land), CRP land, and federal land.

[b]Other land 2 includes minor land (excl. mining land), CRP land, and federal land.

Table 2. Estimated Coefficients for the Conventional and Toxic Water Quality Models with the NB2 Specification

	Conventional Water Quality Model				Toxic Water Quality Model			
	(1a) Basic Model		(1b) Alternative Model		(2a) Basic Model		(2b) Alternative Model	
Variables	Coefficient	St. Error	Coefficient	St. Error	Coefficient	St. Error	Coefficient	St. Error
Intercept	-2.0283***	0.2343	-2.8338***	0.1704	-2.2533***	0.5432	-4.0067***	0.3612
UR	0.0118***	0.0026			0.0077	0.0055		
TR	0.0293	0.0547	0.1168**	0.0534	0.4847***	0.1338	0.3084**	0.1276
CC	0.0120***	0.0018			-0.0044	0.0040		
NONCC	-0.0042	0.0085			-0.0297	0.0189		
PAST	0.0105***	0.0033			-0.0192***	0.0074		
RANG	0.0030	0.0022			0.0060	0.0054		
CRP	-0.0074	0.0164	0.0067	0.0165	0.0931**	0.0428	0.0490	0.0404
MINOR	0.0063	0.0043	0.0045	0.0048				
MIN					0.0771*	0.0446	0.0833*	0.0451
OMINOR					0.0031	0.0100	0.0068	0.0105
FED	-0.0010	0.0020	-0.0041**	0.0017	0.0075	0.0046	0.0080**	0.0038
POPDEN			0.0011***	0.0003			0.0007	0.0009
FERTUSE			1.87E-05	1.29E-05				
PESTUSE							0.0090	0.0205
IRRIGacres	4.55E-05	0.0002	0.0004*	0.0002	0.0006	0.0008	0.0005	0.0007
USLE	0.0059	0.0147	0.0233	0.0144	-0.0215	0.0298	-0.0204	0.0287
EIWIND	0.0071*	0.0039	0.0102**	0.0044	0.0198	0.0231	0.0198	0.0233
SOILPERM	0.0122	0.0202	-0.0232	0.0200	-0.1107**	0.0529	-0.0699	0.0489
Spatial Dummies								
Region A	-1.0548***	0.2092			-0.1969	0.8050	1.4202*	0.7515
Region B	-0.2282	0.2071	0.9348***	0.1785	-1.7410**	0.7247	0.0149	0.6589
Region C			1.0441***	0.2108			1.7400***	0.5257
Region D	-0.1524	0.1853	1.0157***	0.1441	-0.9701**	0.4440	0.8493**	0.3395
Region E	-0.3728**	0.1862	0.7692***	0.1422	0.0548	0.4326	1.7217***	0.3292
Region F	-0.2089	0.2241	1.2792***	0.1839	-1.6023***	0.5458	0.1675	0.4296
Region G	-0.2588	0.2207	0.9947***	0.1859	-1.2550**	0.5321	0.7425*	0.4229
Region H	-0.5266***	0.1964	0.8520***	0.1537	-1.6144***	0.4592	0.2986	0.3127
Region I	-0.7479***	0.2452	0.5604***	0.2157	-1.8632**	0.7395	-0.0697	0.6809
Region J	-0.5753**	0.2269	0.7808***	0.1824	-1.8120***	0.5402	-0.1876	0.4327
Region K	-0.4070**	0.2074	0.7393***	0.1550	-0.8486*	0.4859	0.6742*	0.3503
Region L	-0.5025**	0.2196	0.9896***	0.1697	-1.4709***	0.4532		
Region M	-0.3184	0.2056	1.2040***	0.1471	-1.2738***	0.4398	0.1721	0.2759
Region N	-0.5711***	0.2023	0.5746***	0.1380	-0.2660	0.4314	1.1134***	0.2527
Region O	-0.1898	0.2586	1.1123***	0.2255	-0.9566*	0.5520	0.5320	0.4422
Region P	-0.3155	0.1997	0.7999***	0.1388	0.0225	0.4424	1.6200***	0.2562

Table 3. Estimated Coefficients for the Species-at-Risk Model with the NB2 Specification

	Species-at-Risk Model			
	(3a) Basic Model		(3b) Alternative Model	
Variables	**Coefficient**	**St. Error**	**Coefficient**	**St. Error**
Intercept	**1.5207*** **	0.0979	**-0.3989**	0.3548
Endogenous Variables				
CONVWQ	**4.52E-05*** **	1.54E-05	**4.79E-05*** **	1.52E-05
TOXICWQ	**2.17E-04**	2.81E-04	**2.85E-04**	3.24E-04
Exogenous Variables				
STORAGE	**-3.91E-05**	5.54E-05	**-4.22E-05**	5.51E-05
WATERacres	**6.21E-04**	5.39E-04	**7.67E-04**	5.51E-04
WETLANDacres	**1.46E-04**	3.76E-04	**1.06E-04**	3.75E-04
LANDacres	**4.13E-04*** **	7.13E-05	**4.03E-04*** **	7.13E-05
Spatial Dummies				
Division 210	**-0.7437*** **	0.1491	**1.1844*** **	0.3661
Division M210	**-0.6372** **	0.2748	**1.2905*** **	0.4314
Division 220	**-0.0432**	0.0963	**1.8852*** **	0.3440
Division M220	**-0.0085**	0.1340	**1.9031*** **	0.3558
Division 230			**1.9158*** **	0.3513
Division M230	**-0.0062**	0.4377	**1.9193*** **	0.5483
Division 240	**-0.8800**	0.8474	**0.9963**	0.9190
Division 250	**-0.8494*** **	0.1310	**1.0763*** **	0.3520
Division 260	**0.2135**	0.3728	**2.3407*** **	0.5402
Division M260	**0.1480**	0.4190	**2.0709*** **	0.5319
Division 310	**-0.6352*** **	0.2251	**1.2910*** **	0.3947
Division M310	**-0.5105**	0.3527	**1.4242*** **	0.4699
Division 320	**-0.4595***	0.2436	**1.4750*** **	0.3988
Division 330	**-1.5923*** **	0.1921	**0.3399**	0.3743
Division M330	**-1.3573*** **	0.1729	**0.5716**	0.3671
Division 340	**-1.8586*** **	0.3323		
Division M340	ND	ND	ND	ND
Division 410	**-1.7944** **	0.8890	**-0.1689**	1.0075
Dispersion	**0.3820*** **	0.0309	**0.3782*** **	0.0308
Obs.	**614**		**611**	
Deviance/DF	**0.9846**		**0.9844**	
Pearson X2/DF	**1.1030**		**1.1011**	
Log Likelihood	**3526.9425**		**3534.2596**	

Results: The Watershed Models – cont.

- Agricultural and urban land uses are two major contributors of conventional water pollution.
- Agricultural, urban, transportation, and mining land uses are major contributors of toxic water pollution.
- Urban and transportation are two major land uses affecting the number of aquatic species at risk of extinction.

Simulation Procedures

- Use the land-use model to predict land use probabilities at each NRI site in 1997.
- Use NRI's x-factor to aggregate the predictions to the watershed level and calculate fraction of each watershed in urban, agricultural, and forest land.
- Feed predicted land use acreages into watershed models to calculate watershed health indicators.

Simulation Procedures – cont.

- First create a baseline by running the procedure using the sample value of the variables.
- Then estimate the policy effects by changing the policy variables in the land use models and feed the predicted land use into the watershed models and compare results with the baseline.
- Finally, examine whether the policy effects vary across watersheds with different land use mixes
  - Compare results for the 5% of watersheds with the highest and lowest proportions of urban, forest, and agricultural land.
  - Refer them as the most/least urban, agricultural, and forested.

Policy Scenarios

- Policies that discourage development (e.g., development impact fees)
  - decreased the returns to urban land by $2 (0.04%), $5 (0.1%), $10 (0.2%), and $500 (9.6%) per acre.
- Policies that preserve agricultural land (e.g., agr. subsidies)
  - increase returns to agriculture by $2 (1.3%), $5 (3.3%), $10 (6.7%), and $15 (10%) per acre.
- Reforestation policies (e.g., reforestation subsidies)
  - increase returns to forestry on land used for agriculture by $2 (10%), $5 (25%), and $10 (50%) per acre.
- Local land use regulations:
  - increase value of land use regulation indices.

Simulation Results 1

- Land use choices are insensitive to policies that attempt to change the relative returns to different land uses.

Table 4. Mean Percentage of Watershed in Each Land Use

Land Use Policy	*% of Watershed in Ag. Land*	*% of Watershed in Urban Land*	*% of Watershed in Forest Land*
Baseline	23.33%	5.12%	10.62%
Urban Returns			
↓Urban Returns by $2 (0.04%)	23.33%	5.12%	10.62%
↓Urban Returns by $5 (0.10%)	23.33%	5.12%	10.62%
↓Urban Returns by $10 (0.19%)	23.33%	5.12%	10.62%
↓Urban Returns by $500 (9.6%)	23.38%	4.90%	10.65%
Agriculture Returns			
↑ Ag. Returns by $2 (1.33%)	23.33%	5.12%	10.62%
↑ Ag. Returns by $5 (3.33%)	23.33%	5.12%	10.62%
↑ Ag. Returns by $10 (6.67%)	23.33%	5.12%	10.62%
↑ Ag. Returns by $15 (10%)	23.33%	5.12%	10.62%
Reforestation Payments on Ag. Land			
↑ Forest. Returns by $2 (10 %)	23.31%	5.12%	10.67%
↑ Forest. Returns by $5 (25%)	23.28%	5.11%	10.78%
↑ Forest. Returns by $10 (50%)	23.23%	5.10%	10.91%

Simulation Results 2

- Landowners do respond to some land use regulations.
  - The incentive-based land use policies, such as preferential property taxation, increase forest and agricultural land and decrease urban land.
  - When the index of incentive-based policies increased to the highest level found in the sample, urban land use decrease from 5.12.% to 4.28%, a 16% reduction.

Table 4. Mean Percentage of Watershed in Each Land Use

Land Use Policy	*% of Watershed in Ag. Land*	*% of Watershed in Urban Land*	*% of Watershed in Forest Land*
Baseline	23.33%	5.12%	10.62%
Incentive-Based Policies			
↑ Inc.-Based Index 5%	23.30%	5.10%	10.69%
↑ Inc.-Based Index 25%	23.22%	5.01%	10.99%
↑ Inc.-Based Index 50%	23.13%	4.92%	11.33%
↑ Inc.-Based Index to 1.0	22.34%	4.28%	14.10%
Property Acquisition			
↑ Prop.-Acq. Index 5%	23.35%	5.12%	10.53%
↑ Prop.-Acq. Index 25%	23.45%	5.11%	10.19%
↑ Prop.-Acq. Index 50%	23.59%	5.08%	9.79%
↑ Prop.-Acq. Index to 0.6	24.43%	4.99%	6.19%

Simulation Results 3

- Policies that attempt to change the relative returns to alternative land uses are ineffective in protecting watershed ecosystems in any type of watersheds.

Table 6. Mean Percentage Change in Toxic Water Pollution Relative to Baseline

Land Use Policy	*Most Urban Land*	*Least Urban Land*	*Most Ag. Land*	*Least Ag. Land*	*Most Forest Land*	*Least Forest Land*
Urban Returns						
↓Urban Returns by $2 (0.04%)	-0.01%	0.00%	0.00%	0.00%	-0.01%	0.00%
↓Urban Returns by $5 (0.10%)	-0.03%	-0.01%	-0.01%	-0.01%	-0.03%	-0.01%
↓Urban Returns by $10 (0.19%)	-0.06%	-0.01%	-0.02%	-0.02%	-0.05%	-0.02%
↓Urban Returns by $500 (9.6%)	-3.01%	-0.56%	-0.89%	-0.97%	-2.52%	-1.18%
Agriculture Returns						
↑ Ag. Returns by $2 (1.33%)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
↑ Ag. Returns by $5 (3.33%)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
↑ Ag. Returns by $10 (6.67%)	0.01%	0.00%	0.00%	0.00%	-0.01%	0.00%
↑ Ag. Returns by $15 (10%)	0.01%	0.00%	0.00%	0.00%	-0.01%	0.00%
Reforestation Payments on Ag. Land						
↑ Forest. Returns by $2 (10 %)	-0.23%	0.00%	-0.12%	0.00%	-0.03%	0.00%
↑ Forest. Returns by $5 (25%)	-0.58%	0.00%	-0.30%	0.00%	-0.07%	0.00%
↑ Forest. Returns by $10 (50%)	-1.17%	0.01%	-0.60%	0.00%	-0.14%	0.00%

Table 7. Mean Percentage Change in the Number of Species at Risk Relative to Baseline –

Land Use Policy	*Most Urban Land*	*Least Urban Land*	*Most Ag. Land*	*Least Ag. Land*	*Most Forest Land*	*Least Forest Land*
Urban Returns						
↓Urban Returns by $2 (0.04%)	0.00%	0.00%	0.00%	0.00%	-0.01%	0.00%
↓Urban Returns by $5 (0.10%)	-0.01%	0.00%	-0.01%	0.01%	-0.02%	0.01%
↓Urban Returns by $10 (0.19%)	-0.02%	0.00%	-0.02%	0.02%	-0.04%	0.02%
↓Urban Returns by $500 (9.6%)	-1.14%	-0.11%	-0.73%	0.80%	-1.69%	1.16%
Agriculture Returns						
↑ Ag. Returns by $2 (1.33%)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
↑ Ag. Returns by $5 (3.33%)	0.00%	0.00%	0.00%	0.00%	-0.01%	0.00%
↑ Ag. Returns by $10 (6.67%)	0.00%	0.00%	-0.01%	0.00%	-0.01%	0.00%
↑ Ag. Returns by $15 (10%)	0.00%	0.00%	-0.01%	0.00%	-0.02%	0.00%
Reforestation Payments on Ag. Land						
↑ Forest. Returns by $2 (10 %)	-0.04%	0.01%	0.05%	0.00%	0.08%	0.00%
↑ Forest. Returns by $5 (25%)	-0.09%	0.01%	0.13%	0.01%	0.21%	0.01%
↑ Forest. Returns by $10 (50%)	-0.19%	0.03%	0.26%	0.02%	0.42%	0.01%

Simulation Results 4

- Incentive-based local land use policies can have a significant effect on the watershed indicators.

Table 5. Mean Percentage Change in Conventional Water Pollution Relative to Baseline-Cont.

Land Use Policy	*Most Urban Land*	*Least Urban Land*	*Most Ag. Land*	*Least Ag. Land*	*Most Forest Land*	*Least Forest Land*
Incentive-Based Policies						
↑ Inc.-Based Index 5%	-0.09% (1.7E-04)	-0.02% (7.8E-06)	-0.03% (5.6E-05)	-0.02% (6.0E-06)	-0.10% (1.7E-04)	-0.01% (4.8E-06)
↑ Inc.-Based Index 25%	-0.44% (3.0E-04)	-0.10% (2.9E-05)	-0.15% (7.2E-05)	-0.08% (3.0E-05)	-0.49% (2.5E-04)	-0.05% (2.4E-05)
↑ Inc.-Based Index 50%	-0.88% (4.9E-04)	-0.20% (5.8E-05)	-0.30% (1.0E-04)	-0.15% (6.0E-05)	-0.95% (3.5E-04)	-0.11% (4.8E-05)
↑ Inc.-Based Index to 1.0	-6.01% (2.2E-03)	-1.44% (3.2E-04)	-2.74% (8.1E-04)	-1.59% (4.0E-04)	-3.66% (1.1E-03)	-1.81% (4.9E-04)
Property Acquisition						
↑ Prop.-Acq. Index 5%	0.11% (1.4E-04)	0.03% (1.1E-05)	0.00% (5.4E-05)	0.03% (8.9E-06)	0.05% (1.5E-04)	0.03% (1.4E-05)
↑ Prop.-Acq. Index 25%	0.54% (2.1E-04)	0.15% (4.8E-05)	0.02% (5.9E-05)	0.13% (4.5E-05)	0.24% (1.5E-04)	0.16% (6.8E-05)
↑ Prop.-Acq. Index 50%	1.07% (3.6E-04)	0.30% (9.6E-05)	0.05% (7.4E-05)	0.27% (9.1E-05)	0.48% (1.8E-04)	0.32% (1.4E-04)
↑ Prop.-Acq. Index to 0.6	1.37% (5.6E-04)	3.85% (8.5E-04)	0.10% (5.5E-04)	3.94% (9.5E-04)	3.71% (1.0E-03)	4.07% (9.3E-04)

Standard errors in parentheses below percentage changes.

Table 6. Mean Percentage Change in Toxic Water Pollution Relative to Baseline – Cont.

Land Use Policy	*Most Urban Land*	*Least Urban Land*	*Most Ag. Land*	*Least Ag. Land*	*Most Forest Land*	*Least Forest Land*
Incentive-Based Policies						
↑ Inc.-Based Index 5%	-0.45%	-0.01%	-0.06%	-0.01%	-0.30%	-0.01%
↑ Inc.-Based Index 25%	-2.21%	-0.05%	-0.30%	-0.04%	-1.47%	-0.03%
↑ Inc.-Based Index 50%	-4.35%	-0.11%	-0.59%	-0.08%	-2.67%	-0.07%
↑ Inc.-Based Index to 1.0	-18.61%	-0.76%	-5.38%	-2.47%	-7.64%	-3.19%
Property Acquisition						
↑ Prop.-Acq. Index 5%	0.30%	-0.04%	0.00%	-0.04%	0.02%	-0.05%
↑ Prop.-Acq. Index 25%	1.46%	-0.20%	-0.03%	-0.18%	0.08%	-0.25%
↑ Prop.-Acq. Index 50%	2.78%	-0.39%	-0.06%	-0.36%	0.10%	-0.51%
↑ Prop.-Acq. Index to 0.6	5.31%	-4.74%	-1.35%	-6.12%	0.61%	-6.86%

Simulation Results 5

- The effect of policies are not uniform across the landscape.
  - Incentive-based land use policies were most effective in reducing water pollution in the most urban or agricultural watersheds
    - They are effective in reducing urban development and increasing forestland in those watersheds.
  - Property acquisition programs were not effective in reducing conventional water pollution.
  - In fact, they tend to increase conventional water pollution because they increase the amount of agricultural land, a major source of conventional water pollution.
  - This does not mean that such programs cannot be redesigned to protect conventional water quality in future.

Table 5. Mean Percentage Change in Conventional Water Pollution Relative to Baseline-Cont.

Land Use Policy	*Most Urban Land*	*Least Urban Land*	*Most Ag. Land*	*Least Ag. Land*	*Most Forest Land*	*Least Forest Land*
Incentive-Based Policies						
↑ Inc.-Based Index 5%	-0.09% (1.7E-04)	-0.02% (7.8E-06)	-0.03% (5.6E-05)	-0.02% (6.0E-06)	-0.10% (1.7E-04)	-0.01% (4.8E-06)
↑ Inc.-Based Index 25%	-0.44% (3.0E-04)	-0.10% (2.9E-05)	-0.15% (7.2E-05)	-0.08% (3.0E-05)	-0.49% (2.5E-04)	-0.05% (2.4E-05)
↑ Inc.-Based Index 50%	-0.88% (4.9E-04)	-0.20% (5.8E-05)	-0.30% (1.0E-04)	-0.15% (6.0E-05)	-0.95% (3.5E-04)	-0.11% (4.8E-05)
↑ Inc.-Based Index to 1.0	-6.01% (2.2E-03)	-1.44% (3.2E-04)	-2.74% (8.1E-04)	-1.59% (4.0E-04)	-3.66% (1.1E-03)	-1.81% (4.9E-04)
Property Acquisition						
↑ Prop.-Acq. Index 5%	0.11% (1.4E-04)	0.03% (1.1E-05)	0.00% (5.4E-05)	0.03% (8.9E-06)	0.05% (1.5E-04)	0.03% (1.4E-05)
↑ Prop.-Acq. Index 25%	0.54% (2.1E-04)	0.15% (4.8E-05)	0.02% (5.9E-05)	0.13% (4.5E-05)	0.24% (1.5E-04)	0.16% (6.8E-05)
↑ Prop.-Acq. Index 50%	1.07% (3.6E-04)	0.30% (9.6E-05)	0.05% (7.4E-05)	0.27% (9.1E-05)	0.48% (1.8E-04)	0.32% (1.4E-04)
↑ Prop.-Acq. Index to 0.6	1.37% (5.6E-04)	3.85% (8.5E-04)	0.10% (5.5E-04)	3.94% (9.5E-04)	3.71% (1.0E-03)	4.07% (9.3E-04)

Standard errors in parentheses below percentage changes.

Conclusions

- Policies that attempt to change the relative returns to alternative land uses are ineffective in protecting watershed ecosystems in any type of watersheds.
- However, local incentive-based land use policies and direct land acquisition programs can have a significant effect on water quality in some watersheds.
- Because the effects are not uniform across watersheds, there may be benefits for targeting such policies.
- Targeting could avoid unintended negative effects and help achieve watershed goals more cost effectively.

Caveats and Challenges

- Although the variables included in the watershed indicator models are selected based on the scientific literature, more research is needed to verify that the watershed indicator models represent causal relationships rather than correlations.
- We use relatively coarse land use data, and very simple indicator models.
- The reliability of the results could be improved with more detailed data and analysis.