Linking land use to inland lake ecosystem service values

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Abstract

Since the passing of the Clean Water Act, many efforts have been taken and regulations imposed to protect the nation's surface waters. Yet water quality issues linger in the United States due to impacts from agriculture, land use change and urban development, also called non-point source pollution. Simultaneously a growing population with increasing development, food, and energy demands continues to accelerate land use change, further exacerbating nutrient loading into freshwater bodies. Therefore decision makers and stakeholders need accessible tools for understanding the tradeoffs inherent to land use decisions and downstream water quality. Using the Millennium Ecosystem Assessment's Ecosystem Services framework we develop three discrete, spatially explicit, models, connecting the impacts of upstream land use changes to downstream inland lake water quality, and from there determine the consequences on local property values. These models were developed to require limited inputs using readily available data in an effort to make them accessible to policy and decision makers. The first model, a Phosphorus Loading Model, uses a spatial hierarchy approach and was developed with data from the Upper Mississippi River watershed. The second model, or Lake Tropic State Index Model, also developed using data from the Upper Mississippi River watershed, is a variation of the LakeMab model with outputs translated to Carlson's Trophic State Index. The third model, a Property Value Model, uses a hedonic pricing method and fixed effects approach and was derived with data from Michigan and Minnesota. We find that as hypothesized, an increase in the Trophic State of a lake decreases property values in close proximity to the lake. Lastly in order to assess the predictive capacity of the models in concert, they were applied to a future Michigan land use scenario for business-as-usual from 2000 to 2030.

Keywords: water quality; land use change; hedonic pricing; ecosystem services; economic-ecological model; integrated

Introduction

People depend on the environment for countless aspects of their well-being. Goods like drinking water, crops, seafood, and timber, as well as services like flood protection, climate regulation, nutrient retention, water purification, and even recreation and cultural benefits are all derived from natural ecosystem processes. While technological innovations have emerged to sustain and enhance these environmental benefits (such as water treatment plants, petro-chemical fertilizers, and aquaculture), the increasing strain on critical resources will eventually render many of these stopgap measures fiscally or physically infeasible. The Millennium Ecosystem Assessment, compiled in 2005 by scientists and policy experts around the globe, emphasized the importance of ecosystem services, or the goods and services that natural and human-modified ecosystems provide, and points to the valuation of ecosystem services as a vital assessment strategy for the future (Millennium Ecosystem Assessment 2005b). This new way of thinking about human dependencies on ecosystems and the imperative to understand the linkages between different ecosystems and the multitude of services they provide to people has since gained significant popularity in both academic and popular literature (Carpenter, et al. 2009). In an effort to facilitate this vein of scientific study, the National Academy of Sciences issued a report (National Research Council 2005) on ecosystem services that examined the linkages between terrestrial and aquatic ecosystems and emphasized the importance of spatially explicit ecosystem service valuation tools for decision-making. The report specifically highlighted a critical need for studies that link aquatic ecosystem structures to ecosystem services and value.

Inland Lake Ecosystem Services

The United States contains over 50,000 freshwater lakes and reservoirs, many of which offer critical ecosystem services to surrounding communities, industries, and tourists. People appreciate lakes for both their aesthetic beauty and the recreational opportunities they provide, and many states depend on lakes for tourism revenues (U.S. EPA 2011). People also depend on lakes for 70% of all drinking water, 7% of electricity production through hydropower, and supply to countless industries (U.S. EPA 2011, U.S. Geological Survey 2011). However, as human and natural stressors increasingly pose risks to lake water quality, studies show that decreases in water quality can significantly diminish the various benefits provided by lakes (e.g. Ingols 1957, Phaneuf et al. 2008, Egan et al. 2009, Dodds et al. 2009).

Lakes at Risk

Many U.S. lakes face adverse impacts from economic and agricultural development (U.S. EPA 2009). The U.S. EPA's 2009 National Lakes Assessment states that 42% of U.S. lakes experience frequent and severe nuisance algal blooms and low transparency (U.S. EPA, 2009). One study conservatively estimates that eutrophication and freshwater harmful algal blooms cost the U.S. $2.2 to $4.6 billion each year (Hudnell 2010). With the country's population expected to reach approximately 375 million people by 2030 (U.S. Census Bureau 2010), future land use predictions show dramatic urban expansion, possibly contributing an estimated 80% of predicted land use changes from now until 2051 (Radeloff et al. 2012). Simultaneously, U.S. agricultural activities currently cover over 40% of all land area (USDA Economic Research Service 2012). Increased agricultural yields, the result of extensification and intensification practices, are known to cause significant adverse ecological effects, including increased nutrient loading and water quality issues in water bodies (Matson et al. 1997). Concerns with feeding the growing global population make such farming practices indispensable. As a result, the tools used to manage water quality do not adequately account for future land use planning as non-point pollution sources like storm-water and fertilizer runoff, containing high levels of phosphorus and nitrogen, drive water quality issues (Parry 1998).

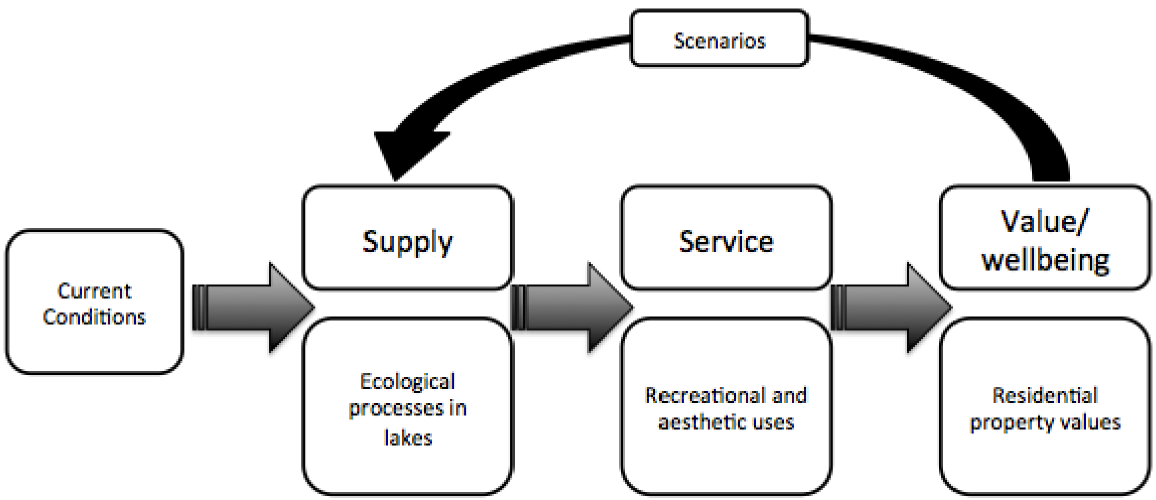
The tradeoffs between agricultural production, urban development, and lake ecosystem services are socially and ecologically complex. Decisions about upstream land use frequently fail to fully consider the impacts on downstream lake ecosystem services. In order to better understand the tradeoffs, we need to link upstream activities to downstream services and assess the associated influence on human well-being. A stakeholder analysis indicates a growing frustration with the lack of education about the impacts of upstream actions on water quality (See Supporting Material C). Ultimately, with more information about the services provided by lake water quality, decision-makers will be able to better account for the benefits and costs associated with different development scenarios and make more informed, sustainable decisions.

Linking Upstream Land Use to Downstream Impacts on Human Well-being

Concerted efforts have been made to understand the value of lake water quality (e.g., Parsons et al. 1992, Steinnes 1992, Egan et al. 2009, Dodds et al. 2009; in Michigan: Leggett and Bockstael 2000, Phaneuf et al. 1998) and the downstream ecological impacts of upstream land-use change on lakes and marine ecosystems (e.g., Dillon and Kirchner 1975, Rabalais et al. 2002). Most of these studies identify phosphorus and its impacts on lake clarity as the most commonly cited lake water quality issues. However, little research exists that directly links upstream land use activities to their impact on downstream ecosystem services and the value of those services in a spatially-explicit way (National Research Council 2005, Keeler et al. 2012).

Therefore our study fills the research needs identified by the National Research Council in four key ways. First the use of spatial hierarchy and fixed effects methods allows model users to aggregate land use impacts at various geospatially specific levels. Second the models are validated at large spatial scales, resulting in broad applicability. Third the models are simple and require minimal data inputs from readily accessible data sources in the United States, allowing user groups with minimal resources and skillsets to apply the models. And finally each model is discrete and flexible to accommodate different user needs in addition to future service and valuation models. Building upon the existing literature these attributes of our models help integrate the various disciplines needed to address the complexity of downstream water quality and ecosystem services issues.

FIGURE 1. Linking land cover phosphorus export to lake water quality and property values



Specifically utilizing the Keeler et al. (2012) framework for water quality valuation, this paper focuses on the ecosystem service pathway shown in Figure 1. This pathway begins with the supply of lake water quality, which is determined by ecological processes on land and in lakes, followed by the ecosystem services of recreational and aesthetic benefits to humans, followed by the value of these ecosystem services, as determined by the service impacts on surrounding residential property values. We designed three simple models that link land use actions to lake water quality, and finally, to ecosystem service value. The first model, the Phosphorus Loading Model, estimates phosphorus loads from land cover classes. The Phosphorus Loading Model links to a Trophic State Index Model that predicts inland lake phosphorus concentrations and lake trophic state. The Trophic State Index Model output links to the Lake Property Value Model, which estimates recreation and aesthetic values associated with lake water quality. As shown in Figure 1, these models use information about current conditions to estimate both current ecosystem services as well as the impacts on the identified ecological processes and ecosystem services for future scenarios. Given that the Midwestern United States benefit from many lakes and an active lake recreation culture, we developed the models in a Midwestern context, using ecological data from several states in the region and social data from both Michigan and Minnesota. We then applied the three models to a future land use scenario for Michigan, in order to predict the ecological and consequent economic impacts on lakes and the people who benefit from them.

Methods

Our goal in constructing this suite of models is to link changes in land cover to the trophic state of a lake through nutrient export, thereby allowing decision-makers to evaluate the impacts of changing land cover on trophic state and the subsequent change in human well-being. We built all three models using data from the Midwestern United States. The Phosphorus Loading Model and the modified LakeMab were developed with data from the Upper Mississippi River watershed. The Lake Property Value Model was created using data from Michigan and Minnesota. The resulting suite of models can be applied broadly to the Midwestern United States.

Multi-scale Models

In evaluating the dynamics of phosphorus export from the landscape and the influence of water quality on home values, we hypothesized that both relationships contain a strong spatial hierarchical structure. Both the Phosphorus Loading Model and the Lake Property Value Model estimate local outcomes that are driven by both local and regional environmental and social contexts. We account for these multi-scale considerations using the following regression form for both models:

Equation (1) $$y = \alpha + \beta_l l + \beta_r r + \epsilon_l + \epsilon_r$$

Where ***l*** is the set of local variables and ***r*** is the set of regional variables. In both models, the regional context is captured with a categorical variable representing some larger spatial hierarchy (county, ecoregion, etc.). In ecology, this approach is known as spatial hierarchy. In economics it is referred to as fixed effects.

Measuring Water Quality with Carlson's Trophic State Index

Though we estimate phosphorus concentrations in both the Phosphorus Loading Model and the LakeMab Model, we use Carlson's (1977) trophic state index (TSI) as our measure of lake water quality that links to the Lake Property Value Model. TSI represents water quality on a scale of 0 to 100, with high values representing low water quality. Each ten unit change represents a change in water quality of a factor of two. The simple 100-unit scale is easily interpreted, and is commonly used by the U.S. EPA, allowing non-specialists and decision-makers from multiple organizations to quickly compare results. Furthermore, the scale translates directly to the widely-recognized trophic states of oligotrophic (<41), mesotrophic (41-50), eutrophic (51-70), and hypereutrophic (>71). Additionally, TSI can be calculated from total lake phosphorus concentration, Secchi depth, or chlorophyll concentration, allowing us and model users to combine a broad range of data (See Equations 2-4 for conversions).

Equation (2) Secchi Depth (SD): $$TSI\ (SD) = 10\left(6 - \frac{\log(SD)}{\log(2)}\right)$$

Equation (3) Chlorophyll-a (Chl): $$TSI\ (Chl) = 10\left(6 - \frac{2.04 - 0.68\log(Chl)}{\log(2)}\right)$$

Equation (4) Total Phosphorus (TP): $$TSI\ (TP) = 10\left(6 - \frac{\log(\frac{48}{TP})}{\log(2)}\right)$$

Phosphorus Loading Model

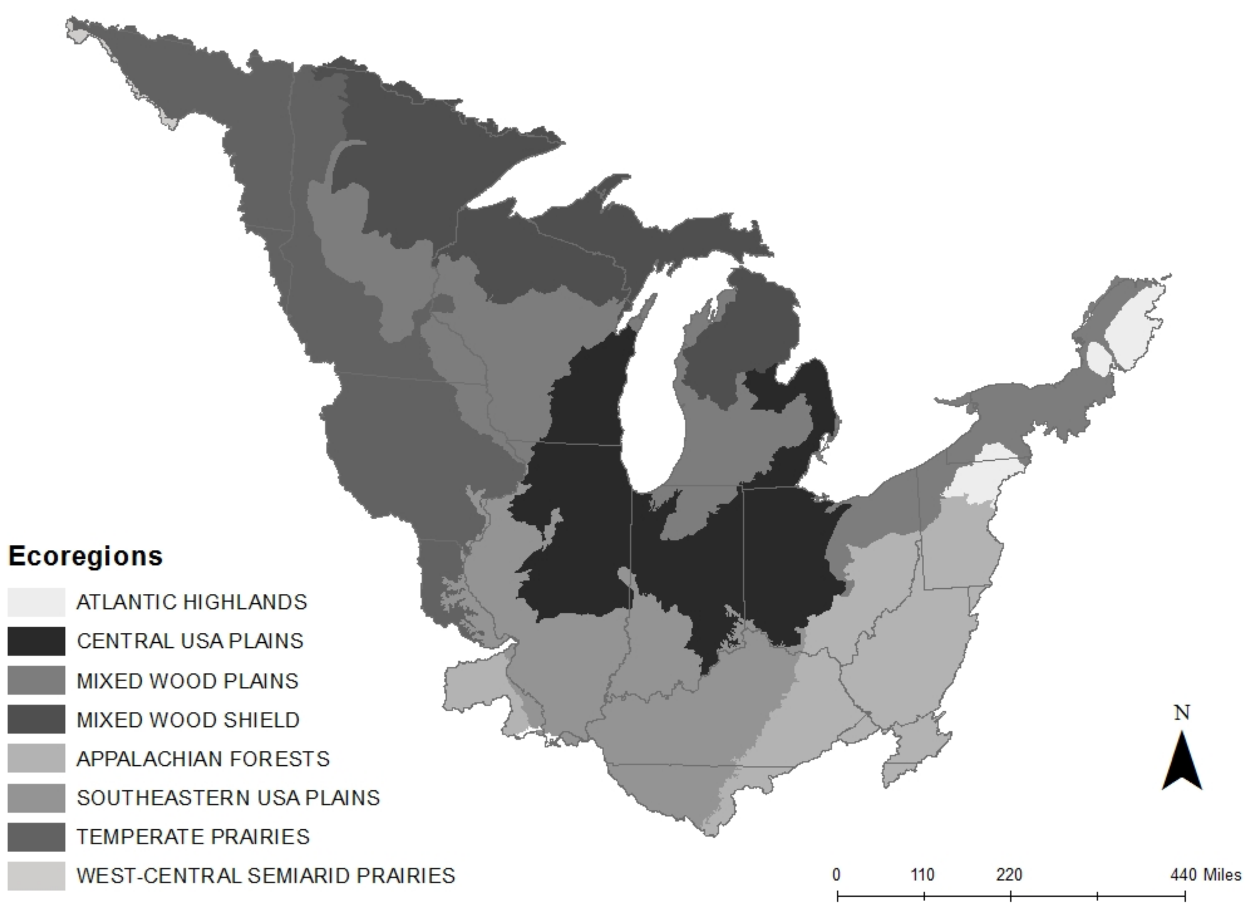
The Phosphorus Loading Model estimates the phosphorus delivered to lakes in the form of nutrient runoff from different land cover types. The connection between land cover/land use and nutrient loading to streams and rivers has been well documented (Reckhow 1980). However a precise relationship between specific land cover types and nutrient loading is hard to characterize due to regional variations in hydrologic, geologic, and social factors that influence the export of nutrients from a landscape. Studies linking human activities within a watershed to nutrient loads have focused on various scales, but often require complex data inputs that are difficult for regional decision-makers to compile and translate into usable relationships and projections. This is especially important for modeling landscape export to lakes, which requires reasonable estimates of tributary concentrations.

To generate reasonable phosphorus loading estimates from broadly available data, we developed a multi-level regression model using land cover and the volume of lake discharge as local variables and the level 2 ecoregion of the lake as a regional variable (see Figure 2). We used phosphorus loading values from the long-term annual loading estimates compiled by Saad, et al. (2011), as our dependent variable. This dataset includes long-term water-quality data from 1971 to 2006 for 810 sites across the upper Midwest, de-trended to 2002 and averaged. These averages represent the long-term expected loading value for 2002.

In order to link local land cover composition to phosphorus loading, we narrowed the Saad data to calibration sites located within one kilometer of the outlet of a Hydrologic Unit Code (HUC) 10 drainage area (n=241). Land cover data was taken from the 2001 National Land Cover Database (NLCD) within each HUC 10 containing a gauge site. Calibration sites were also coded with their level 2 EPA ecoregion, to account for the range of geologic and ecologic variation across the upper Midwest.

The Phosphorus Loading Model is structured as a hierarchical model, with the EPA level 2 ecoregions treated as regional categorical variables. The area of the level 2 land cover types, as coded into the NLCD 2001, HUC 10 watershed area, and discharge from the watershed, are treated as continuous variables. The regression structure is presented in Equation 1.

FIGURE 2. Ecoregions for the Phosphorus Loading Model



Modeling Lake Trophic State

The Phosphorus Loading Model provides the critical stream phosphorus concentration input needed to model phosphorus concentration of a lake. We used the LakeMab phosphorus model (Hakanson 2008) to simulate the phosphorus concentration of a lake system over time and under different loading scenarios. To improve the accuracy of LakeMab for the relatively small, shallow lakes found in Michigan (in comparison to the larger lakes used to parameterize LakeMab), we ran the model on a set of simulated lakes (n = 18,000) displaying the range of lake depths, areas, and flow volumes in our study dataset.

For shallow lakes and lakes with a high lake area to depth ratio, LakeMab either returned unrealistic phosphorus values (infinite) or resulted in chaotic behavior between model time-steps. We isolated the parameters responsible for this inconsistent behavior between lakes with similar characteristics, using a Classification and Regression Tree (CART) analysis on the simulated lake set. This identified regions of unstable lake characteristics, all close in value to another stable set of values. For example, the model predicted stable phosphorus concentrations for lakes with a maximum depth of 16 meters and any set of mean depth, flow, or surface area, while the model is unstable for lakes with a maximum depth of 15.5 meters and some combinations of the same variables. In order to work around this model instability, lakes with unstable combinations of characteristics were shifted into the closest stable configuration.

Morphology and flow data for 171 lakes distributed across the state of Michigan between 2002 and 2012 was provided by the Institute for Fisheries Research (IFR), a research group of the Michigan Department of Natural Resources. This dataset is also used to provide lake attribute data to the modified LakeMab model for use in the future land cover scenario.

To evaluate the predictions from LakeMab using the Phosphorus Loading model, the two models were applied to a subset of lakes from our dataset using land cover data from the 2006 NLCD to generate phosphorus loading from the landscape. Lake TSI predictions were generated for each of the lakes in our dataset by first applying the Phosphorus Loading Model to the land cover contained by the HUC 10 watershed of all the connected, non-headwater lakes in the sample. The lake specific drainage area is used for disconnected and headwater lakes. This distinction is made to account for the loading to upstream water bodies for lakes that are tributary fed, while not over-predicting the load to disconnected or headwater lakes. The predicted annual load is then divided by the annual lake discharge to yield a tributary phosphorus concentration. Phosphorus concentrations for 2006-2007 were collected by the Michigan Clean Water Corps (MiCorps), a volunteer lake water quality monitoring database managed by the Michigan Department of Environmental Quality, the Michigan Lake and Stream Associations, and the Huron River Watershed Council. Only 37 lakes from our data set have phosphorus concentration observations collected by MiCorps volunteers from either 2006 or 2007, the median years in which the lake attribute data was collected. MiCorps These observations were converted to TSI for comparison with the predicted TSI generated by LakeMab.

Once the tributary concentration value has been generated, the modified LakeMab model generates 200 months of phosphorus concentration data for the lake, which is then averaged to yield a single predicted phosphorus concentration for each lake and converted to TSI.

Lake Property Value Model

In order to value some of the economic benefits humans derive from lake water quality, we connected the modified LakeMab Model to a simple hedonic valuation model that estimates the residential housing property value attributable to lake TSI. We expected that as lake TSI increases (lake water quality decreases), home values decrease, and that homes surrounding oligotrophic (lakes with very high water quality) would be more sensitive to water quality degradation. The disproportionate impact of water quality changes on higher quality lakes makes sense, because people are likely more able to perceive a clean lake becoming slightly less clean and less perceptive of an already murky lake becoming a little more murky. Based on Walsh et al. (2011), we also hypothesized that the influence of lake water quality on home values would not be limited to lakefront homes, but would extend to residential properties within easy driving distance of a lake, as nearby properties capture some of the value associated with the ability to visit and recreate on a lake. Drawing from conventional hedonic valuation methods applied to water quality (Steinnes 1992), we developed a one-way, fixed effects regression to estimate average residential housing property values, controlling for three categories of local variables (environmental, neighborhood, and physical home attributes; see Table 1 for summary statistics) and the regional county variable.

Using Census Block Group (BG) data as our scale of spatial analysis, we improved upon the Dodds et al. (2009) approach which predicts changes in hedonic value due to estimated eutrophication at an ecoregion scale. BGs are statistical divisions consisting of clusters of blocks within larger Census Tracts that generally contain between 600 and 3,000 people. This finer scale of analysis enhances flexibility and utility for the models.

We used median Zillow[1] Zestimate data from 2011, aggregated at the 2010 BG level in Michigan and Minnesota, as our proxy for home market value (Zillow 2013). Zestimates are Zillow's estimated market value of a home, using a proprietary formula that includes data from appraisals, price history, and market conditions among other data that affect a property's price. Zestimate data is widely available in all U.S. states, making it an accessible data source for analysts and decision-makers. Though the accuracy of Zestimates in predicting individual home sale prices has been questioned (Hollas et al. 2010), we used Zestimates as they are regularly updated, consistently calculated across large scales, and easily accessible to decision-makers. Median home values at the BG level are fairly low, between $60,000 and $210,000. Higher value homes are located around tourist destinations in the Northern Lower Peninsula near Traverse City, and in the Detroit suburbs.

Regression Form

By including the multi-scale, fixed effects county control variables, we controlled for differences county policies could have on home values. For instance, county-based public transportation networks, public safety systems, or school systems can contribute to increased home values and likely differ across counties but are unlikely to differ among BGs within the same county. Walsh et al. (2011) identifies the 'neighbor effect' as a potential problem in water quality-related hedonic modeling, which assumes that homes in one BG derive some value from the characteristics of their neighboring BGs (Walsh et al. 2011). Incorporating county fixed effects allows us to control for this spatial autocorrelation between omitted variables, and is a common method in hedonic pricing studies (Kuminoff et al. 2010, e.g., Pope 2008a,b, Horsch and Lewis 2009, Kovacs et al. 2011). See Equation 1 for the general, multi-scale regression form.

Environmental Attributes

Inland lake water quality data for Michigan was obtained from the Michigan Clean Water Corps (MiCorps). Minnesota lake Secchi depth data was obtained from Heiskary et al. 2008. All Secchi depth values were translated to TSI using Equation 2. While both water quality data sources are based on volunteer data that may be collected and reported inconsistently, this type of data is often the only information available to decision-makers given their ongoing resource constraints. Both programs provide volunteer training to minimize the risk of monitoring and reporting errors.

BGs that do not contain lakes and BGs that contain lakes but have no TSI data were omitted from our sample. For the remaining BGs, we aggregated lake TSI data to the BG with the following approach. BGs with multiple TSI data points were assigned a mean TSI. The TSI values of lakes that intersected more than one BG were allocated to all intersecting BGs. To validate this approach we tested and showed that TSI data was statistically the same within the watersheds. For BGs that intersected multiple watersheds, we found no statistical difference in TSI data across watersheds.

In addition to TSI, we also controlled for the area of water in a BG, using a percent area water variable representing the percent of BG area covered by water. Finally, drawing from other hedonic studies that explore the influence of environmental factors on home values, we controlled for environmental disamenities (Leggett and Bockstael 2000). To do so, we used a dummy variable to indicate the presence or absence of a Superfund site within a BG.

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[1] Zillow is a home and real estate marketplace that provides information related to home values, rental values, mortgages, and other information in the United States. Zillow's database consists of more than 110 million homes.

Physical House and Neighborhood Attributes

Most physical house and neighborhood attributes for BGs were taken from the 2006-2010 American Communities Survey (ACS) published by the U.S. Census. To incorporate physical home characteristics, we calculated the weighted average year of home construction and the weighted average number of bedrooms. To incorporate neighborhood attributes, we controlled for mean household income, total population, percent of the population that is white, and average number of housing units. As a proxy for lake accessibility we controlled for proximity to a major highway, using the U.S. Department of Transportation National Functional Classification System defined as category 1 and 2 highways. Finally, we included a composite measure of quality of life based on the EASI quality of life index, which aggregates 29 measures for an average U.S. rank of 100.

TABLE 1. Summary Statistics of Select Variables

		Michigan (*N* = 189)	Minnesota (*N* = 747)
Variables	Units	Mean	Mean
Environment Attributes			
TSI	(0-100)	42.51	55.68
		(5.87)	(10.28)
% Area of Water	-	0.13711	0.11830
		(0.14)	(0.14)
Superfund	-	0.00529	0.00402
		(0.07)	(0.063)
Physical Home Attributes			
Year of Home Construction	-	1972.2	1972.4
		(7.68)	(10.69)
Number of Bedrooms	-	2.89	6.38
		(0.28)	(0.91)
Neighborhood Attributes			
Median Zestimate	2011 dollars	$140,995.80	$183,154.10
		(52,523)	(100,916)
Median Household Income	2011 dollars	$75,990.69	$70,763.86
		(25,124.58)	(27,532.91)
Total Population		1,308	1,395
		(530.87)	(703.72)
Percent of Population White	-	0.95	0.94
		(0.05)	(0.09)
Housing Units	-	717.2011	626.1874
		(282.38)	(286.49)
Distance to Highway	meters	14376.68	3198.66
		(23,250.04)	(5,664.09)
EASI ® Quality of Life Index	US Avg=100	54.25	54.69
		(9.98)	(9.01)

Standard deviations in parenthesis.

Results

Phosphorus Loading Model Results

As shown in previous studies, agricultural land is a significant predictor of phosphorus load, as are forested lands and forested wetlands. An interaction term between agricultural land and forested land is also significant at the 0.05 level. Interestingly, none of the urban land cover classes are significant, nor are any of the other land cover classes. Total watershed area was not significant, but watershed discharge was highly significant at the 0.01 significance level (see Table 2). The regression equation (Equation 5) is shown in the form of Equation 1, with area land cover and flow representing local variables at the HUC 10 and ecoregions representing the regional variable.

Equation (5)

$$\log(load)_i = \alpha + \beta_1 \log(agriculture)_i + \beta_2 \log(forested\ wetland)_i + \beta_3 \log(mixed\ forest)_i + \beta_4 \log(agriculture * mixed\ forest)_i + \beta(ecoregion) + \epsilon_i + \epsilon_{recoregion}$$

$R^2 = 0.79$

TABLE 2. Regression table for Phosphorus Loading Model

Local Variables (Std. Error)		Regional Variables (Std. Error)	
Agriculture	-0.2*	Atlantic Highlands	-0.5
	(-0.1)		(-0.6)
Forested Wetland	0.05*	Mixed Woods Plains	0.4
	(-0.02)		(-0.3)
Mixed Forest	-0.4**	Central USA Plains	0.8*
	(-0.1)		(-0.3)
Agriculture X Mixed Forest	0.02**	Southeastern USA Plains	1.2***
	(-0.01)		(-0.3)
Flow	0.9***	Ozark, Ouachita-Appalachian Forests	0.4
	(-0.04)		(-0.3)
Constant	8.6***	Temperate Prairies	1.1***
	(-1.9)		(-0.3)
Observations	180		
R-squared	0.79		
Adj. R-squared	0.78		
RMSE	10.28		

As a measure of predictive power, a measure similar to R^2, model efficiency, is calculated as the percent variance explained by model predictions. We calculated model efficiency for both the Phosphorus Loading Model and the Lake Property Value Model.

Equation (6) $$Model\ Efficiency = 1 - \frac{\sum(x_i - \hat{x}_i)^2}{\sum(x_i - \bar{x})^2}$$

We ran the Phosphorus Loading Model on the reserved validation data from across the Midwest, which returned a model efficiency of 0.75, similar to the 0.79 from the training dataset.

Modified LakeMab Model Results

As Figure 3 shows, the joint model has low error for mesotrophic lakes, while it tends to over-predict phosphorus concentrations for oligotrophic lakes and under-predict phosphorus concentrations for eutrophic lakes. For this model, error is defined as the difference between the observed phosphorus concentration and the predicted phosphorus concentration. The under-prediction for eutrophic lakes could be explained, because point source pollution data was an omitted variable in the Phosphorus Loading Model.

In addition to examining the ability of the Phosphorus Loading Model combined with the modified LakeMab Model to predict the TSI of a given lake, we also evaluated the accuracy of the models in categorically placing each lake in the correct trophic state: oligotrophic, mesotrophic, eutrophic, and hypereutrophic (see Figure 4 and Table 3). This is an important indicator of how well the combined models capture the overall nutrient loading into a particular lake as well as the nutrient dynamics of the same lake under the predicted loading conditions. Of the 37 lakes that we applied the combined models to, lakes were predicted in the correct trophic state with 70% accuracy (26 lakes).

FIGURE 3. Residual errors by TSI

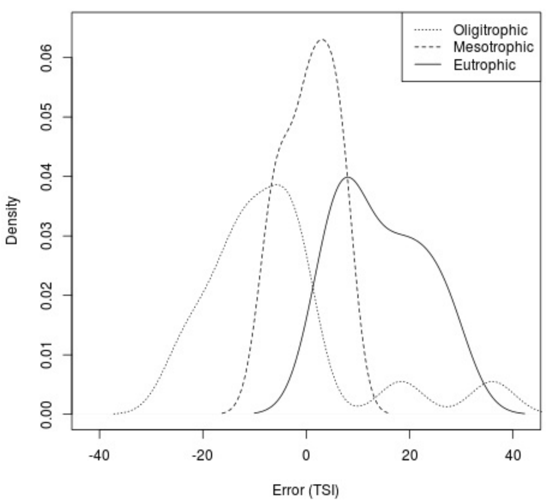


FIGURE 4. Predicted versus observed TSI

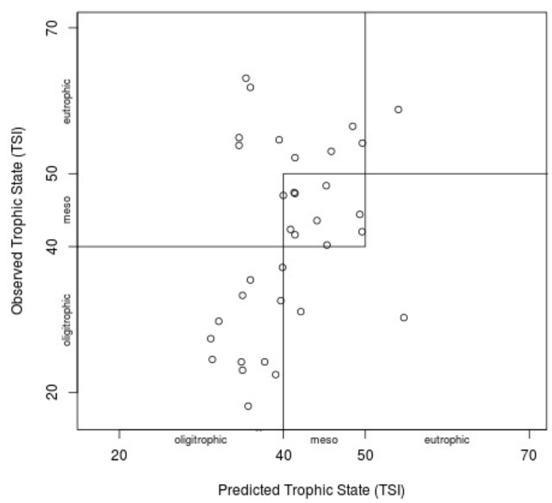


TABLE 3. Predicted versus observed trophic state for Michigan lakes

Trophic State		Observed		
		Oligotrophic	Mesotrophic	Eutrophic
Predicted	Oligotrophic	15	0	5
	Mesotrophic	1	10	4
	Eutrophic	1	0	1

Lake Property Value Model Results

Figure 5 shows the distribution and observed values for TSI and Zestimates in our sample data. Data is displayed by BG and is well-distributed across the state. There are few eutrophic and no hypereutrophic lakes in Michigan, indicating that Michigan inland lakes tend to be of high water quality.

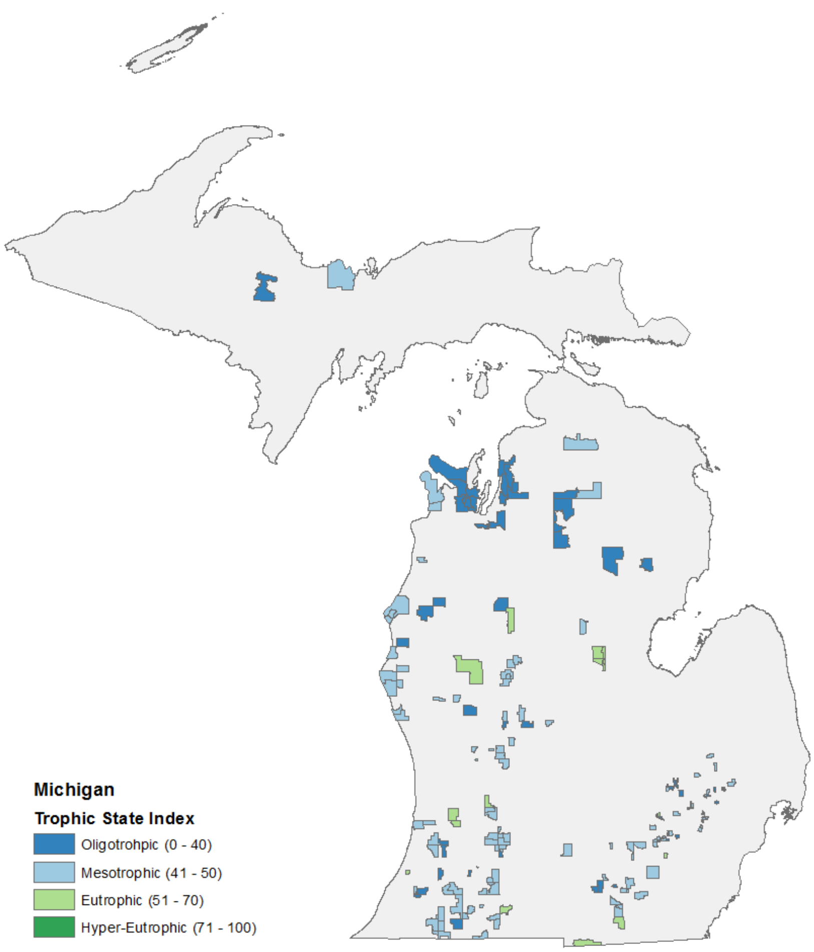
From the general hedonic form, we derived the Lake Property Value Model (Equation 7) with coefficients significant at the 0.01 level for five key independent variables (see Table 4). The dependent variable, log(*price*), represents the natural log of BG median Zestimates. *i* subscripts represent BG-level environmental, neighborhood, and home physical attributes. *C* represents the vector of counties absorbed in the model using fixed effects. ϵ is the error term for BG observations (*i*) and counties (*c*). We assume BG home values are going to be more sensitive to lake water quality if they have more area covered by water, and so we created a lake water quality variable (*lwq*) that is a ratio between the percent of the BG surface area covered by water and the BG TSI value (see Equation 8). Consistent with the 'spillover effect' hypothesis from Walsh et al. (2011), the *lwq* variable assumes property values are more sensitive to lake water quality if the area contains many lakes as compared to an area that contains only one small lake. The coefficient on the lake water quality variable cannot be directly interpreted. Still, it performed as expected: BGs containing lakes with higher TSI (lower water quality) averaged lower home values, controlling for other independent variables.

Equation (7) $\log(value)_i = \beta_0 + \beta C + \beta_1 (lwq)_i + \beta_2 \log(income)_i + \beta_3 (total\ population)_i + \beta_4 (\#\ bedrooms)_i + + \beta_5 (year\ built)_i + \epsilon_c + \epsilon_i$

Equation (8) $lwq = \left(\frac{\%\ area\ of\ water}{tsi}\right)$

Model Efficiency: 0.52

FIGURE 5. Distribution of TSI and Zestimate data by Michigan Census Block Groups



We also tested whether the variables that make up the *lwq* ratio were disproportionately impacting it. We ran the regression replacing the *lwq* term with TSI, percent water, 1/TSI, and percent-water together with 1/TSI in the same regression. See Supplemental Material B for more information. The *lwq* ratio variable returned the lowest RMSE and highest value of the *F* statistic, suggesting that percent water did not exhibit disproportionate influence on the *lwq* ratio.

As expected, average household income and median home value were highly positively correlated—as income increased by 1% per year, home value increased by 0.59%, holding all other independent variables constant. On average, an increase in BG population of one person was associated with a decrease in median home value of 0.0045%, holding all other independent variables constant.

For physical home attributes at the BG level, the average year homes were built, and the number of bedrooms, were both statistically significant. As expected, more recently constructed homes had higher median market values. Finally, as the average number of bedrooms per home in a BG increase, median home value increased.

TABLE 4. Hedonic Regression with County Fixed Effects for Minnesota and Michigan

Variables	*log*Median Zestimates
Lake Water Quality	14.72***
	(3.511)
*log*Median Household Income	0.587***
	(0.0536)
Total Population	-4.50e-05***
	(1.33e-05)
Year of Home Construction	0.00481***
	(0.00123)
Number of Bedrooms	0.0472**
	(0.0202)
Constant	-4.294*
	(2.252)
Observations	936
R-squared	0.796
Adj. R-squared	0.773
RMSE	0.222

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

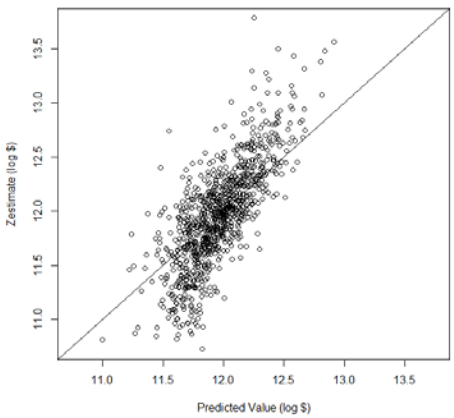
TABLE 5. Additional Variables Tested

Variables	t-stat	p-value
Environment Attributes		
Superfund	-0.15	0.878
Neighborhood Attributes		
Percent of Population White	0.90	0.368
Housing Units	4.57	0.000
Distance to Highway	-0.48	0.631
EASI ® Quality of Life Index	1.36	0.174
Observations	936	

Additional variables listed in Table 5 were not included in the final Lake Property Value Model. While number of housing units was found to be significant, it was not included in the final model, because a comparison of the root mean squared errors (RMSE) of the model with housing units and the model without revealed a higher RMSE for the model without housing units, indicating the simpler model had similar predictive capacity using fewer variables.

To evaluate the predictive power of the preferred model, we derived coefficients of the model using a subset of the dataset (*n*=631), and compared the estimated values of the validation set (*n*=305) to median Zestimates (see Figure 6). The model is a somewhat biased estimator as a predictor of home values, overestimating lower home values and underestimating higher home values.

FIGURE 6. Predicted versus observed median BG home values



As expected, the model showed greater home value sensitivity to water quality for BGs with oligotrophic lakes. We estimated the change in median home value due to a 1-unit increase in TSI and categorized the average home value change at the BG level based on their current trophic state, as shown in Table 6. With a 1-unit increase in TSI, the average median home value for oligotrophic BGs decreased by $295, while an equivalent 1-unit change in TSI shows an average decrease of $33 for median homes values in BGs containing hypereutrophic lakes, holding other independent variables constant.

TABLE 6. Change in average home values with a 1-unit increase in TSI

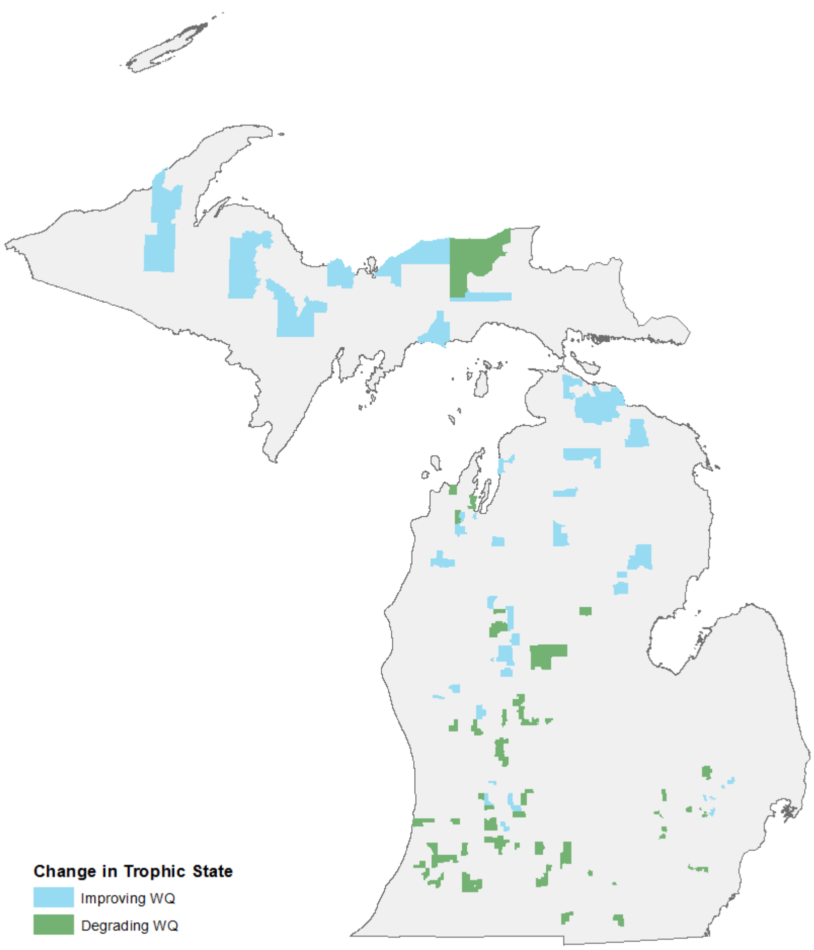
BG trophic state	# of BGs	Mean	Std. Dev.	Max	Min
Oligotrophic	78	-$294.52	$427.40	-$1968.28	-$1.26
Mesotrophic	324	-$189.87	$247.72	-$1713.19	$0
Eutrophic	454	-$106.03	$181.95	-$1923.00	$0
Hypereutrophic	80	-$32.55	$49.72	-$277.19	-$0.15

Scenario

Scenario analysis can help decision-makers understand and compare possible future impacts associated with policy and planning options. Using scenarios to understand how specific ecosystem services are impacted by decisions can be especially powerful, particularly when the scenarios are spatially-explicit. Our suite of lake water quality models can be applied to a variety of future land use scenarios to evaluate the tradeoffs among different land use types and lake recreational and aesthetic values.

To demonstrate the scenario analysis capacity of these models, we ran the three linked models on a Michigan business-as-usual (BAU) scenario called the Land Transformation Model, developed at Purdue University (Pijanowski et al. 2005). This dataset presents a historical set of land use and land cover (LULC) data for the year 2000 as well as a future LULC scenario for Michigan in 2030 and uses NLCD level 2 LULC designations. The LULC data from both the 2000 baseline and the 2030 scenario were used to project phosphorus loads and TSI values for the 171 lakes in the sample dataset, resulting in TSI changes due to the projected land cover. The resulting TSI values for the two time periods were used to run the Lake Property Value Model to estimate 2000 and 2030 home values. This was a simple scenario analysis to isolate the effects of land cover changes on lake ecosystem services, so other variables remained unchanged in the Lake Property Value Model. We used the Lake Property Value Model to estimate median BG home values for 2000 and 2030. The difference between the two model runs was calculated to determine the change in home price, due to a change in trophic state.

FIGURE 7. Spatial Distribution of TSI increases and decreases between 2000 and 2030

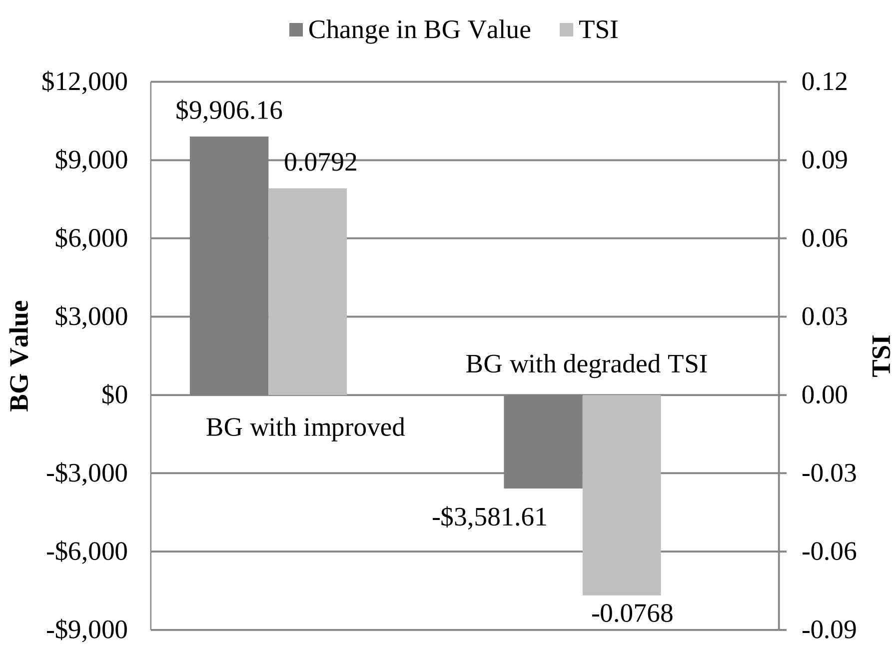


Between the 2000 baseline and the 2030 scenario, TSI is predicted to change within a range of -0.512 and 0.816 (see Table 7), indicating that some BGs will experience lake water quality improvements while others degradations (see Figure 7). Water quality degradation can be explained by projections for increased sprawl development in parts of Michigan. Improvements can be explained by increased forest or stream protections for recreational purposes. Results showed that improvements in lake water quality would cause increases in home values, and degradations in lake water quality would cause decreases in home values. Changes in median BG homes values ranged from a decrease of $106 to an increase of $167, over the 30-year timeframe of the scenario. We explored changes to total BG value, which was calculated by multiplying the estimated median home value by the total number of homes in a BG (see Figure 8). On average, BGs that experienced lake water quality improvements showed a decrease of 0.079 in TSI and an increase of $9,906 in total BG value. For BGs that experienced lake water quality degradation, results showed an average increase of 0.077 in TSI with an average decrease of $3,582 in total BG Value.

TABLE 7. BGs with maximum increases and decreases in TSI and home value between 2000 and 2030

	County	Change in TSI	Estimated 2000 Home Value	Estimated 2030 Home Value	Estimated Change in Median Home Value
Max Decrease in TSI	Ogemaw	-0.512	$86,153	$86,156	$2.96
Max Increase in TSI	Osceola	0.816	$72,514	$72,499	-$14.52
Max Increase in Home Value	Grand Traverse	-0.057	$225,516	$225,683	$166.95
Max Decrease in Home Value	Kent	0.672	$95,473	$95,367	-$105.66

FIGURE 8. Average BG value change for BGs with water quality improvements or deterioration



In response to the spatial distribution of water quality improvements and degradations found in Figure 7, we aggregated TSI and home value changes to three Michigan ecoregions, divided into the Upper Peninsula (UP), Northern Lower Peninsula (NLP), and the Southern Lower Peninsula (SLP). Model output results are shown in Table 8. The majority of lake water quality improvements occurred in the UP, where BGs experienced an average TSI decrease of 0.116 and an average total BG value increase of $7,762. The NLP is also projected to experience lake water quality improvements, with results showing an average 0.060 decrease in TSI and an average total BG value increase of $11,096. Our models predicted the SLP would experience the brunt of the lake water quality degradation, with an average increase of 0.055 in TSI, which is predicted to result in a $1,799 loss in total value per BG.

TABLE 8. Michigan TSI and property value changes between 2000 and 2030

	Number of Housing Units		Average Change in		
	Average in BG	Total across Ecoregion	TSI	Home Value	Total Home Value
Upper Peninsula	1,078	10,781	0.1159	$7.20	$7,762.32
Northern Lower Peninsula	816	41,626	0.0602	$13.59	$11,096.17
Southern Lower Peninsula	622	72,161	0.0551	-$2.89	-$1,799.43

Discussion

Simple ecosystem service models allow decision-makers and stakeholders a more accessible means of assessing the trade-offs inherent in land use decisions that directly impact their communities. Furthermore, models that allow stakeholders to understand the impacts of land use changes in a spatially explicit way can enable communities to make informed management decisions to mitigate the downstream impacts on lakes (see Supplemental Material C, D, and E).

Results from our scenario analysis complement several environmental and economic analyses relating to future development in Michigan. Sprawl development is expected to be fastest in Michigan's 'growth triangle,' which includes the four counties of Ottawa, Kent, Allegan and Muskegon in the Southern Lower Peninsula (Skole et al. 2012) as well as in the outskirts of metropolitan areas (Public Sector Consultants 2001). Within the data set, the scenario analysis identifies similar locations with the greatest TSI and home value change, including Kent County with the greatest home value loss (Table 7) and the Southern Lower Peninsula with the most economic loss in the BAU scenario (Figure 7, Table 8). The environmental and economic analyses suggests suburban sprawl and road development outside of metropolitan centers such as Detroit and across the SLP may be drivers of lake water quality degradation, while forest recovery in Northern Michigan will result in lake water quality improvements.

Though the BAU scenario analysis showed minimal changes to TSI and home values in Michigan by 2030, similar applications of the models could yield useful results at different spatial scales or in different policy contexts. Model users could evaluate similar scenarios for the larger Midwest, or apply the models to more extreme future land cover scenarios that project changes further in the future or incorporate climate change impacts and enhanced development. Additionally, the models could be applied to evaluate alternative planning scenarios at county or even BG scales.

Limitations of our approach

Because the Phosphorus Loading Model and the Lake Property Value Model are simple models, they only portray limited information about the stressors, issues, and benefits that stakeholders care about. The Lake Property Value Model does not account for longer-term positive feedback loops associated with changes in water quality. For example, a decline in lake water quality could lead to lower home values, which could contribute to the dispersion of higher income residents, resulting in a smaller tax base, thus reducing public services, and further depressing property values. These feedbacks are challenging to predict with simple models.

The simplicity of the models contributes to some of the unexplained variation. For the Phosphorus Loading Model, most studies that link land cover to phosphorus export identify urban land cover as a meaningful contributor to phosphorus loading (Reckhow, 1980). However, our model did not identify the relationship between urban land cover and phosphorus export as significant. This may be due to the use of level 2 land cover data, which divides urban land in four distinct classes, diluting the cumulative impact of urban areas. In a broader sense, the Phosphorus Loading Model assumes some homogeneity in land uses contained by each land cover type across a large geographic area. As land use varies within each cover class, a model relying only on land cover will not account for the relative impact of these land uses within each cover class on phosphorus export.

The Lake Property Value Model slightly overestimates low value homes and underestimates the most valuable homes, indicating that some important variables, like home acreage, may be omitted in favor of model simplicity. Zillow Zestimates lack precision and do not represent market-clearing or transaction values, which are more commonly used in traditional hedonic regression models. On the other hand, home transaction price data sources can be equally flawed and are extremely difficult to access broadly.

One important limitation of our approach is that our models do not explicitly quantify the ecosystem services lakes provide. Rather, the services—recreational and aesthetic demand—are captured implicitly in hedonic valuation. A recreation demand model, using travel cost method or other approaches, would provide a more explicit quantification of the ecosystem services, which could then be translated to a measure of human well-being, monetary or otherwise. Unfortunately, building a broadly applicable, simple model to estimate visitation rates and recreation activities on a lake presents significant challenges. Even in Michigan, government agencies record very limited visitation data for parks and lakes, and the datasets that exist are collected using varied measures of visitation that are difficult to harmonize.

We are also unable to conclusively capture the complete service value through hedonic valuation; however, the challenges associated with double-counting benefits when valuing different services is common in models. Still, this raises questions about the proportion of the value we are capturing through hedonic valuation. Our analysis excludes commercial property values and water treatment costs, amongst other potential services derived from lake water quality. Further research is needed to ascertain the types of additional valuation methods that can be used in conjunction with the Lake Property Value Model. This is important for any ecosystem service valuation effort, because calculating the total change in value associated with an action may substantively change what decisions are made and how stakeholders perceive their interests in different land use decisions.

Strengths of this approach

The Keeler et al. (2012) approach provides a cohesive and powerful framework for assessing water quality-related ecosystem services. Our simple, linked models can assist broad, varied groups of stakeholders in understanding how land use changes influence lake trophic state and associated changes in home values. Overall, the three models provide a good approximation of the influence of land use changes on lakes and dimensions of the recreational and aesthetic ecosystem services humans derive from lakes. In linking the three models, we create, for the first time, an explicit way to assess how different patterns and actions on the land upstream can change the ecosystem, and how those ecosystem changes ultimately influence some human well-being. By only requiring data sources that are widely accessible, the models can be used by institutions with limited resources and limited scientific backgrounds to answer questions at various scales. A significant strength of simple, ecosystem service models is their capacity to predict the impacts of future land use scenarios and the tradeoffs among different ecosystem services. Finally, our methods and results present a significant first step toward building additional ecosystem service models that stakeholders and decision-makers can use, such as nuisance aquatic weed growth, fisheries populations, and invasive species control.

Future research and applications

Future research is needed to apply this modeling approach to regions outside of the Midwestern United States. Additionally, in interviews with Michigan lake experts and user groups (see supplemental materials), we identified other important water quality issues that Michigan inland lakes are facing, including invasive species and algal blooms. Currently, the models do not address these salient issues, however, new models could build on our work to predict the risk and impacts of algal blooms and different invasive species. Finally, additional service and valuation models could be developed to capture additional sources of value associated with lake trophic states, such as recreational travel costs, fisheries, and avoided water treatment costs. Disaggregating the services lakes provide and modeling these separately would also allow decision-makers to better prioritize those services most at risk when evaluating land use scenarios. These models could separate the ecosystem service from the valuation, affording users more flexibility in how they present and interpret their results. `

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Supplemental Materials

Supplemental Material A

Michigan & Minnesota Specific Regression Tables

Variables	Michigan *log*Median Zestimates	Minnesota *log*Median Zestimates
Lake Water Quality	15.54**	10.90***
	(7.393)	(4.199)
*log*Median Household Income	0.511***	0.510***
	(0.100)	(0.0651)
Number of Bedrooms	0.313***	0.0944***
	(0.108)	(0.0255)
Housing Units	0.000159**	0.000305***
	(7.67e-05)	(7.16e-05)
Percent of Population White	0.921**	
	(0.423)	
Superfund	-0.400***	
	(0.119)	
Total Population		-0.000163***
		(3.11e-05)
Year of Home Construction		0.00513***
		(0.00133)
Constant	4.120***	-4.375*
	(1.077)	(2.392)
Observations	189	747
R-squared	0.765	0.806
Adjusted R-square	0.698	0.789
RMSE	0.199	0.221

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Supplemental Material B

Alternatives to the *lwq* Ratio

We compared the significance of the lake water quality *lwq* ratio (TSI/percent-water) against the following alternate variables: TSI; percent-water, 1/TSI; and percent-water & 1/TSI. We also ran backwards stepwise regression in an attempt to identify models that were specific to the alternate variables and only percent-water returned a model. For all alternate variables, they were used in place of the *lwq* variable in the model discussed under results. All comparisons were made under different subsets of the dataset (subsample within Michigan, subsample within Minnesota, subsample of the entire dataset, and in the full dataset) to identify how well the variable works across scales. Results can be found in a table of regression in the Supplemental Materials section. In the end, TSI/percent-water was chosen because the *lwq* term had the lowest RMSE, highest F stat, and the alternatives did not exhibit disproportionate influence on the *lwq* ratio.

	% Water / TSI	% Water	1/TSI	% Water & 1/TSI	TSI	% Water & TSI	% Water (stepwise)
Variables	lmedzest	lmedzest	lmedzest	lmedzest	lmedzest	lmedzest	lmedzest
Lake Water Quality	14.72***						
	(3.511)						
% Area of Water		0.280***		0.263***		0.263***	0.297***
		(0.0789)		(0.0794)		(0.0794)	(0.0788)
1/TSI			7.858***	6.150**			
			(3.000)	(2.989)			
TSI					-0.00259**	-0.00196*	
					(0.00110)	(0.00110)	
log Median Household Income	0.587***	0.592***	0.619***	0.586***	0.618***	0.586***	0.596***
	(0.0536)	(0.0534)	(0.0539)	(0.0535)	(0.0537)	(0.0534)	(0.0530)
Year of Home Construction	0.00481***	0.00472***	0.00401***	0.00463***	0.00399***	0.00463***	0.00331***
	(0.00123)	(0.00122)	(0.00123)	(0.00123)	(0.00123)	(0.00123)	(0.00112)
Number of Bedrooms	0.0472**	0.0458**	0.0364*	0.0471**	0.0368*	0.0473**	0.0446**
	(0.0202)	(0.0201)	(0.0203)	(0.0203)	(0.0203)	(0.0203)	(0.0203)
Total Population	-4.50e-05***	-4.59e-05***	-4.90e-05***	-4.40e-05***	-4.89e-05***	-4.40e-05***	
	(1.33e-05)	(1.33e-05)	(1.33e-05)	(1.33e-05)	(1.33e-05)	(1.34e-05)	
EASIQLIFE							-0.000238
							(0.00146)
Superfund							-0.0295
							(0.164)
Constant	-4.294*	-4.165*	-3.118	-4.060*	-2.790	-3.815*	-1.483
	(2.252)	(2.251)	(2.268)	(2.257)	(2.274)	(2.260)	(2.075)
Observations	936	936	936	936	936	936	936
R-squared	0.796	0.795	0.792	0.796	0.791	0.796	0.793
Adjusted R-square	0.773	0.772	0.768	0.773	0.768	0.773	0.769
RMSE	0.222	0.223	0.225	0.223	0.225	0.223	0.225

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Supplemental Material C

Stakeholder Analysis: Inland Lake Ecosystem Services in Michigan

Authors:
Kevin Le, Kirsten Howard, and Lisa Wan

We interviewed 18 stakeholders about lake issues in Michigan. We interviewed experts from five different sectors: government (local and state), non-governmental organizations (NGO), tourism and recreation industries, lake homeowner associations, and consulting companies. The objective of the interviews was to determine the major issues that concern Michigan inland lake users, the need for and potential uses of the lake ecosystem service models being developed by our team, and any suggestions for the types of model outputs that would be useful for specific groups.

Methods

Of 50 people contacted for interviews, 18 responded. We interviewed five experts from non-profit organizations, including American Rivers, Huron River Watershed Council, Michigan Trout Unlimited, Tip of the Mitt Watershed Council, and Legacy Land Conservancy. We interviewed two stakeholders from tourism and recreation industries, including the American Sailing Institute and the Ann Arbor Canoe Parks Livery. We conducted two interviews with members of lake homeowner associations, including the Island Lake Association and the Walloon Lake Association. Six interviews were conducted with representatives from government agencies, including the Michigan Department of Environmental Quality, Michigan Department of Natural Resources Institute for Fisheries Research, Washtenaw County Parks & Recreation, Washtenaw County Water Resources Commissioner's Office, Livingston County Water Resources Commissioner's Office, and the City of Ann Arbor. Finally, we conducted one interview with the consulting company Progressive Architecture & Engineering (Progressive AE).

Potential interviewees were initially contacted by email with a request to participate in an interview. A 5-minute electronic preliminary survey was sent to all 18 interviewees who volunteered. The preliminary survey asked participants about the issues and ecosystem services they considered most important and relevant to Michigan inland lakes. We then conducted a one-hour, semi-structured interview either in person or over the phone. Interview questions were designed to explore how interviewees interact with Michigan lakes as well as if and how the LakeMab model and Lake Property Value model could be useful for them or for others. We used snowball sampling to contact additional potential interviewees.[2]

Results

The preliminary electronic survey showed that interviewees consider fishing and boating activities most important for Michigan lakes, as seen in Figure 1. As seen in Figure 2, issues or problems that stakeholders consider most relevant to Michigan lakes include invasive aquatic species, algal growth, and algal blooms. The most common water quality variables used to assess lake water quality were phosphorus, invasive species, and water clarity measures, as seen in Figure 3.

[2] The research team obtained an exempt status from the University of Michigan Institutional Review Board.

Figure 1. Michigan Inland Lake Benefits

Of the 18 interviewees, the top three benefits of Michigan lakes are fishing, boating, and swimming. Interviewees ranked potential benefits of Michigan lakes and the scores were averaged to determine the top ranked benefits perceived by stakeholders.

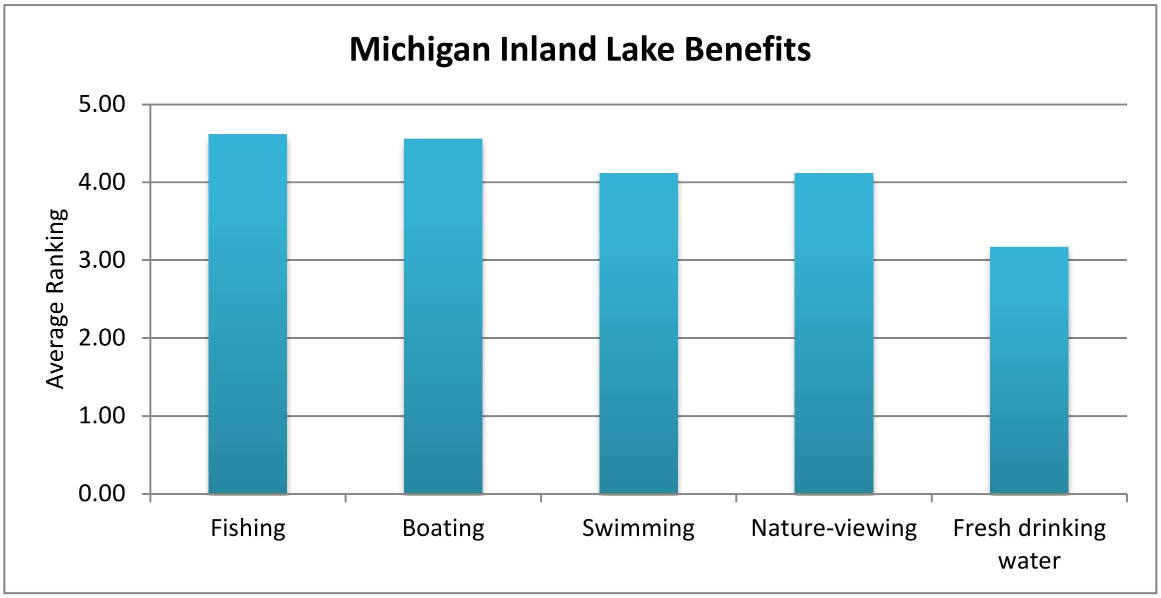


Figure 2. Michigan Inland Lake Issues

Of the 18 interviewees, the top three issues of Michigan lakes are invasive aquatic species, algal growth, and algal blooms. Interviewees ranked potential issues of Michigan lakes and the scores were averaged to determine the top ranked issues perceived by stakeholders.

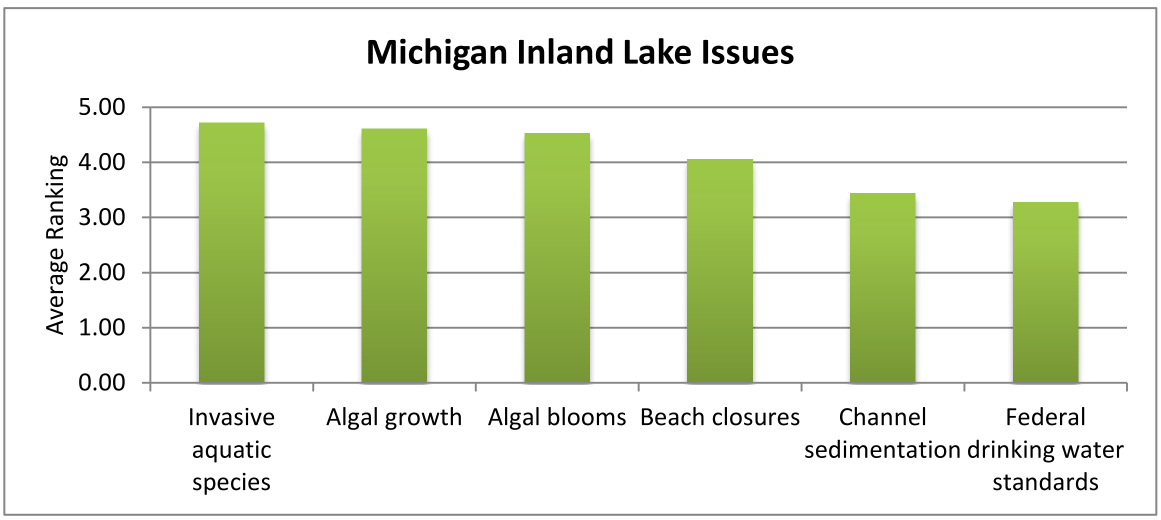
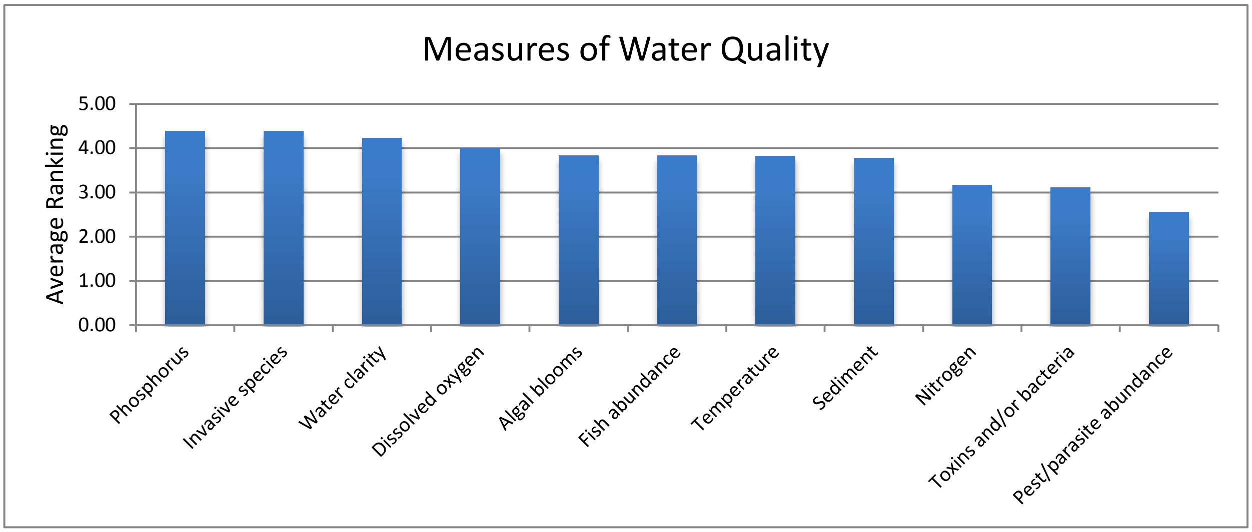


Figure 3. Measures of Water Quality

Of the 18 interviewees, the top three measure of water quality of Michigan lakes are phosphorus, invasive aquatic species, and water clarity. Interviewees ranked potential measures of water quality of Michigan lakes and the scores were averaged to determine the top ranked measures perceived by stakeholders.



Issues

Several interviewees indicated that algal growth and invasive weeds, specifically Eurasian Milfoil and Starry Stonewart, prevent high quality recreation on lakes and negatively affects lake users. Invasive species and total maximum daily loads are other issues that the stakeholders are struggling with. While the Lake Trophic State Index (TSI) model does not directly address these issues, future InVEST models that build on the TSI model to predict nuisance weed growth and algal blooms or new models that quantify impacts from other invasive species, such as zebra and quagga mussels, would garner significant interest among stakeholder groups in the Midwest.

The Huron River Watershed Council representative highlighted Lake Diane as a Michigan lake that could benefit from an analysis of how upstream actions influence downstream lake ecosystem services. Located in southern Michigan, this lake is surrounded by homes with manicured lawns that meet the lakeshore. With no riparian buffer surrounding the lakeshore to protect it, the lake suffers from significant fertilizer loading which had led to a high trophic state index and extremely low lake clarity. According to the Huron River Watershed Council, residents don't fully understand the collective impact of their actions, which highlights a need for resident education.

The American Sailing Institute representative referred to another lake in southern Michigan in need of improved management. Kent Lake is overrun with invasive weeds. This lake is primarily used for recreational purposes like sailing, however, boat navigation is increasingly challenging due to the weed growth. The American Sailing Institute and other recreationalists on the lake are considering moving to an alternative lake.

Challenges

Interviewees from government agencies, homeowner associations, and the consulting company all identified a lack of regulatory authority as a major challenge that impedes their ability to make improvements to lake water quality. All sectors excluding the consulting sector indicated that a lack of resources and scientific understanding limited action to take care of lake nuisances. With those limitations, decision-makers and lake users depend on short-term management strategies, like herbicide treatments on nuisance macrophytes. Lake users prefer short-term management options because they see the immediate benefits from the resources spent. Long-term management is rarely considered because constituencies lack understanding of the root upstream causes of nuisance algae and weeds, and significant resources are needed to take long-term action, such as purchasing land for conservation within the watershed.

Opportunities for the Models

Stakeholders identified three key ways they might use the suite of water quality models: education, advocacy, and prioritization. Interviewees from all sectors indicated that model outputs would be useful for education. Progressive AE is a consulting company that applies remedies to lake nuisances. They can generally explain the cause of the nuisance to lakefront residents, but have trouble motivating residents to change their behavior. Progressive AE believes that the model outputs could provide an extra level of detail that would enhance their general explanation. If residents were shown biophysical and economic data predicting the effects of a lawn at the edge of a lake versus a buffer along the lake edge, this information could trigger residents to be motivated to modify their behavior. This more specific information could also be used to demonstrate the benefits of long-term watershed management planning that would more concretely eliminate nuisances and reduce the need for annual short-term herbicide treatments.

Interviewees from the NGO sector indicated that the model outputs could be used to advocate for desired outcomes or more authority. A Michigan Trout Unlimited representative suggested that the model output can be used to strengthen their arguments when lobbying. Science-based tools and results can help them argue that decisions should be based on scientific analysis rather than uninformed judgment or political influence.

Interviewees from the NGO and government sectors both suggested that the models could be used to prioritize lands for conservation. The Michigan Department of Natural Resources Institute for Fisheries Research representative suggested that the model could be used to predict how nutrient loading changes will affect the landscape and to identify which water bodies are most vulnerable to change. This data would allow managers to prioritize water body issues and management actions.

Several interviewees had difficulty suggesting specific scenarios in which the models would be useful. This was likely due in part to a lack of understanding of the models among some stakeholders. Some interviewees suggested that they may encounter situations that trigger use of the models, but currently those situations are difficult to predict.

Action Now: The case of Lake Walloon

While most interviewees shared stories about lake issues and the challenges they struggle with, one organization boasted an impressive record of conservation work on their lake. Walloon Lake is located at the northern tip of the Lower Peninsula in Michigan, and is a popular recreational lake with a vibrant trout stock and boating community. The Walloon Lake Association is associated with the Walloon Lake Trust and Conservancy and together, they have made great strides to preserve and protect lake water quality. Funding to protect Walloon Lake comes from two sources: the Association, and the Trust and Conservancy. Lake residents pay dues that cover the administrative costs of the Association and the Conservancy has an endowment used to acquire easements around the lake to prevent future development. In addition, individual donations to the Conservancy are used to monitor and manage the lake. The Association has a variety of committees, including a lake water quality monitoring committee and a legislative committee, which lobbies local decision-making bodies to take stricter conservation action. For example, the committee is currently working to convince the local planning authorities to ban snow mobile activities near the lakeshore. The Association is also collaborating with the Little Traverse Bay Bands of Odawa Indians to promote the value of greenbelt areas along the lake edge. This Association is proving to be a strong protector of its lake and has found smart strategies to accomplish its goals. Community members have secured stable financial support for their mission to protect the lake and they collaborate with many groups to develop new ways to preserve their lake quality. This case is a great example of how a lake community can organize to actively protect the ecosystem services it values.

Supplemental Material D

Preliminary Survey Questions

1. What is your name?
2. What organization do you work for?
3. What is your job title?
4. Briefly describe your work and how it relates to Michigan lake water quality.
5. Rate the following benefits that people receive from Michigan lakes based on how relevant they have been in your work and experiences with Michigan lakes (1 = not relevant; 5 = very relevant)
    - Fishing
    - Boating
    - Swimming
    - Nature Viewing
    - Fresh Water Drinking
    - Other Benefits: ________
6. Rate the following issues[3] based on how relevant you think they are to Michigan lakes. (1 = not relevant; 5 = very relevant)
    - Channel Sedimentation
    - Compliance with Federal Drinking Water Standards
    - Invasive Aquatic Species
    - Algal Blooms
    - Algal Growth
    - Beach Closures
    - Other Issues: __________
7. Rate the following water quality variables based on how often they appear in your work and experience with Michigan lakes. (1 = not often at all; 5 = very often)
    - Nitrogen
    - Phosphorous
    - Algal Blooms
    - Water Clarity
    - Sediment
    - Dissolved Oxygen
    - Fish Abundance and Productivity
    - Temperature
    - Pest and/or Parasite Abundance
    - Toxins and/or Bacteria
    - Invasive Species
    - Other Water Quality Variables: _________

[3] PNAS. Linking water quality and well-being for improved assessment and valuation of ecosystem services. Bonnie Keeler, Stephen Polasky, Kate Brauman, Kris Johnson, Jacques Finlay, Ann O'Neill, Kent Kovacs, Brent Dalzell.

Supplemental Material D - Continued

Interview Questions

1. How does your work relate to Michigan lakes and lake water quality?
2. What local and governmental organizations do you interact with in your work on lake water quality issues?
    a. When you were working with those organizations, what issues came up related to lake water quality?
3. What projects related to lake water quality are you currently involved with or have you been involved with in the last five years in your work?
4. We're interested in learning how your organization makes decisions in terms of these projects. Can you tell me more about the process(es) your organization uses/used to analyze options when making decisions in those projects?
    a. What tools do you use to make decisions related to lake water quality in your work?
        i. Where did you find these tools? How do you access them?
        ii. Are there any tools that could be improved or don't currently exist that would help you make those decisions?
5. What are the biggest challenges you face when working on water quality issues? Can you provide a specific example of a challenge?
    a. What challenges do you face related to data availability? Can you provide a specific example?
    b. Would this tool have been useful in any of your past projects? Could you envision it being useful in future projects? How?
    c. Can you think of anyone else that might find it useful? Who?
6. In your opinion, what other kinds of information would be a useful output from this modeling tool?
7. Is there anything you would like to add that you think might be useful for our project? Do you have any additional questions for me?
8. Based on our conversation and your understanding of my research project, can you recommend anyone else I can speak to?

Supplemental Material E

Key Findings from Stakeholder Interviews

Organization	Major Findings	
	Challenges	**Potential Use**
Non-Governmental Organization		
American Rivers		• *educate* society on economic impacts • *education* can guide local government land use decisions • information can be helpful in CWA section 404 permitting decisions
Huron River Watershed Council	• active management is deterred by limited resources	• *educate* people on water quality impacts • information on the economic value can be a motivator for homeowners to think of treatment cost
Michigan Trout Unlimited	• legislation making it more difficult to buy/protect land • difficult to share information with members	• *prioritize* efficient land acquisition • information can support advocacy efforts
Tip of the Mitt Watershed Council	• limited funding	• information can support advocacy efforts
Legacy Land Conservancy	• inaccurate data for GIS use	• *prioritize* efficient land acquisition • *educate* on how best to use the land
Recreation & Tourism		
American Sailing Institute	• no funding to manage lakes	• information can ensure lakes are healthy and there is proper management
Ann Arbor Canoe Livery	• perception of the river is dirty; community needs to be educated otherwise	• *educate* people to understand that rivers are safe • *educate* community on recreational value of rivers
Washtenaw County Parks & Rec	• NIMBY; community doesn't want parks to be adjacent to their property	• *prioritize* efficient land acquisition
Homeowner Lake Associations		
Walloon Lake Association	• no enforcement authority • homeowners don't understand the need for a buffer from their lawns	• *educate* new organizations to see lake trends
Island Lake Association	• homeowners don't understand the need for a buffer from their lawns	• *educate* homeowners on the relationship of water quality and property value
Government (Local and State)		
City of Ann Arbor	• community needs to be educated on connection between upstream and downstream issues	• know value of stormwater
Michigan Department of Enironmental Quality	• no regulatory authority on nonsource point loads • limited funding	• *prioritize* watersheds with nutrient problems • *educate* residents on effect of development on lakes
Michigan Department of Natural Resoruces - Institute of Fisheries Research	• limited funding • no legal mandate to educate communities	• information can assist managers in making better informed decisions • understand patterns of lakes so can treat each lake accordingly
Washtenaw County Water Resource Commisioner's Office	• no regulation authority	• appraise property value correctly • *educate* lake residents on importance of buffers
Livingston County Water Resource Commisioner's Office	• limited funding • community needs to educated on drainage channels	• appraise property value correctly
Consulting		
Progressive AE	• lake associations have no authority to tax homeowners; management is based on voluntary contributions	• *educate* lake residents on the value and importance of long-term watershed management