Land Use and Watershed Health in the United States: An Empirical Assessment

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Abstract: This nation-scale, watershed-level analysis focuses on the major trends and the spatial pattern of land use and the impact on watershed health. We estimate a simultaneous equation system to analyze the impact of land use on aquatic health in watersheds across the United States.
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Land Use and Watershed Health in the United States: An Empirical Assessment

Ivan Hascic and JunJie Wu [1]

Introduction

Land use changes have been identified as one of the most pervasive socioeconomic driving forces affecting watershed ecosystems (Office of Technology Assessment 1990). It has been widely recognized that agricultural land and chemical use is a leading cause of water pollution both in inland and coastal waters; drainage of wetlands and irrigation water diversions have brought many wildlife species to the verge of extinction; and urban land development has also been linked to many environmental problems, including water and air pollution, urban runoff and flooding, traffic congestion, and loss of wildlife habitat. Habitat destruction, fragmentation, and alteration associated with urban development have been identified as the leading causes of biodiversity decline. It has been estimated that between 1975 and 2015, species extinction will occur at a rate of 1 to 11 percent per decade, with aquatic species being at a higher risk of extinction than mammals and birds. Losses of this magnitude impact the entire ecosystem and human well-being (USEPA 2004). Compounding this problem is the current pace at which land is being converted to urban development. Close to 30% of the population in the U.S. lives in cities and an additional 50% lives in the suburbs. More land is covered by urban and built-up areas (over 5% of the total surface area of the U.S.) than by the combined total land in state or national parks or preserved by the Nature Conservancy. Furthermore, urban land is growing faster than preserved land (McKinney 2002).

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In this study we evaluate the interactions between water quality and aquatic ecosystem health as affected by land use and other human activities in watersheds covering the lower 48 states of the United States (about 2,100 watersheds). In particular, we concentrate on environmental problems related to habitat alteration, nutrient runoff, eutrophication, toxic pollution, and bioaccumulation. We analyze how these environmental problems affect the status of wetland and aquatic species and whether land use changes exacerbate the impacts. Aquatic organisms are exceptionally vulnerable to the outside environmental conditions (Blaustein 1994, Blaustein et al. 1994, Hartwell and Ollivier 1998) and their health provides an early indicator of environmental conditions.

Previous studies have analyzed the structure and functions of various components of ecosystems at the watershed or river basin scales (e.g., Harding et al. 1998). A number of studies have examined the impact of agricultural practices on water quality at the field, farm, or watershed levels (e.g., De Roo 1980; Gilliam and Hoyt 1987; Wu et al. 1997; Anderson et al. 1985). The increased concerns over agricultural water pollution have also fueled the need for timely information on the location of areas with high potential for water contamination from agricultural chemical use. Several studies (Mueller et al., 1995; Nielsen and Lee, 1987; Kellogg, Maizel and Goss, 1992; Wu et al., 1997; Wu et al. 1999) have attempted to provide this information by conducting national or regional assessment of water contamination potential from agricultural chemical use. The impact of land use and water quality on wildlife species has also been investigated in the literature (e.g., Ehrlich and Ehrlich 1981; Knight et al. 1995; Harding et al. 1998; Rottenborn 1999; Czech et al. 2000; McKinney 2002). Several studies have examined the land use -

ecosystem linkage at the regional or national scales (e.g., Frissell 1993; Wu et al. 1997; Czech et al. 2000; Malmqvist and Rundle 2002). They have identified a number of factors potentially affecting the quality of aquatic environment. For example, Frissell (1993) found that cumulative damage to aquatic habitats caused by logging, grazing, urbanization, and other land uses plays a major role in species diversity losses. Czech et al. (2000) found that urbanization endangers more species in the mainland United States than any other human activity. Malmqvist and Rundle (2002) reviewed the long-term trends affecting water quality and identified several major factors affecting ecosystems, including mining and other industrial activities, atmospheric emissions and inputs from urban sources, and fertilizer use.

Watershed ecosystems are complex assemblages of plants, animals and microbes interacting with each other and their environment. The complexity of ecosystems requires integrative research and systems approach. However, very few studies have treated watersheds as an ecosystem and analyzed watershed health at the national scale. This study fills the gap by conducting a national-scale analysis of the interaction between water quality and aquatic health as affected by land use and other human activity in the United States.

The rest of this paper is organized as follows. The next section introduces the concept of watershed health and its key indicators. In section 3 we review the biological and ecological literature to identify the critical relationships between land use, water quality and wildlife abundance and present the empirical specification of the econometric models. Section 4 describes the technique used to estimate the models. Section 5 discusses the data. Section 6 presents our findings, and section 7 concludes the paper.

Watershed health in the United States

Aquatic ecosystems are characterized by a great biological diversity. In addition to being valuable in its own right, freshwater ecosystems are indispensable for the functioning of terrestrial ecosystems (The H.J. Heinz III Center 2002), and are largely responsible for maintaining and supporting overall environmental health (USEPA 2004). In this study four indicators were selected to describe the health of aquatic resources across the United States. The indicators were retrieved from the USEPA's Index of Watershed Indicators (IWI) containing data characterizing the condition and vulnerability of aquatic systems in the watersheds. The four selected indicators are discussed next.[2]

The indicator of *conventional ambient water quality* (CONVWQ) measures the percentage of samples in exceedance of a national reference level developed by the USEPA for four conventional pollutant concentrations in surface waters (phosphorus, ammonia, dissolved oxygen, pH).[3] According to USEPA, the criteria exceedances were calculated over a nine-year period 1990-1998 on the basis of the water quality monitoring data. Figure 1a) shows the conventional water quality indicator across the 2,100

[2] For further details on the IWI dataset refer to the USEPA's Watershed Atlas.

[3] These pollutant indicators describe the condition of the watershed with respect to its potential to excessive eutrophication, acidification, and availability of dissolved oxygen. These processes are among the major concerns in many aquatic ecosystems (Brouwer et al. 1991; Smith 1998; Mason 1977; Schnoor 1996; Laws 1993; Faurie et al. 2001; Vitousek et al. 1997; Seehausen et al. 1997; Carpenter et al. 1998; Sayer et al. 1999; Deaton and Winebrake 2000).

watersheds in the contiguous Unites States. Conventional water quality appears to be a nation-wide problem with the most severe levels in the Midwest and the Gulf and Atlantic coast.

The indicator of *toxic ambient water quality* (TOXICWQ) measures the percentage of samples in exceedance of the national chronic level for four toxic pollutant concentrations in surface waters (copper, nickel, zinc, chromium). The criteria exceedances were calculated over a nine-year period 1990-1998 on the basis of the water quality monitoring data. Figure 1b) shows that toxic water quality appears to be a regional rather than national problem. Watersheds in the Rocky Mountains and the southeastern U.S. show most severe problems.

The indicator of *fish consumption advisories* (FISHADV) describes the number of active advisories recommending limits on fish consumption, no consumption, or fishing bans in watersheds across the U.S. collected in 1998. According to USEPA (2002) fish consumption advisories are a good indicator of the condition of a watershed because they can represent bioaccumulation of toxic substances in fish and shellfish.[4] Advisories are issued where levels of contamination of locally harvested fish pose a threat to human health. The data contain information on active advisories for freshwater and marine fish and shellfish, amphibians, and other aquatic and wetland wildlife based on levels of selected contaminants. Figure 1c) shows the number of fish consumption advisories

[4] Bioaccumulation is a process of acquiring higher concentrations of persistent pollutants in the organism's body than those present in the surrounding environment and/or the food (Walker 1990). Fat-soluble substances can enter the body via gills, the body surface, or are transferred to successively higher trophic levels of the food chain, and build up in the lipid tissues of the organism (Skidmore 1964; Handy and Eddy 1990; Van der Zanden and Rasmussen 1996).

across the contiguous United States indicating that fish contamination is a problem confined mostly to the Great Lakes region, the Northeast, and Florida.

The indicator of *species at risk* (SPERISK) provides information about the number of aquatic and wetland species at risk of extinction (plants and animals) present in a given watershed in 1996. The data layer contains records of native species meeting the condition of occurrence, conservation status, and habitat. The three conditions require: (a) at least one documented occurrence in the watershed since 1970, (b) the species has been classified by the Natural Heritage Network as critically imperiled, imperiled, or vulnerable (identified as G1, G2, or G3 by the Nature Conservancy) or listed under the federal Endangered Species Act as threatened or endangered, and (c) the species is dependent on aquatic or wetland habitats. Figure 1d) shows that no area in the U.S. is spared of the threat to aquatic biodiversity, although areas to the east of Mississippi River, the Southeast, and the West coast rank among the top.

Empirical specification

A system of simultaneous equations is used to analyze the interactions among land use and watershed health. The modeling system is constructed on the basis of selected ecological and biological relationships. The system consists of four equations representing models of conventional water quality, toxic water quality, bioaccumulation, and aquatic wildlife abundance. Each of the equations is discussed below.

Conventional water quality model

The conventional water quality model captures the relationship between different types of land uses and their effect on water quality via the processes of eutrophication and dissolved oxygen depletion. Excessive eutrophication is attributed to nutrient loading resulting from agriculture and discharges of organic wastes from urban activities, including industry (Keyes 1976; Laws 1993; Schnoor 1996; Carpenter et al. 1998). The major sources of biological oxygen demand include domestic, farm, and industrial effluents, urban runoff, and other organic waste (Fergusson 1982; Alloway 1995; Deaton and Winebrake 2000). Equation (1) represents the conventional water quality function:

$$y_{1i} = \beta_0 + \beta_1'\mathbf{a}_{1i} + \beta_2'\mathbf{u}_{1i} + \beta_3'\mathbf{p}_{1i} + \beta_4'\mathbf{d}_i + \varepsilon_{1i} \qquad (1)$$

where i = 1, 2, …, 2100 is an index of watershed in the contiguous U.S., y_{1i} is an indicator of conventional water quality based on four conventional pollutant concentrations in surface water (phosphorus, ammonia, dissolved oxygen, pH), $\mathbf{a}_{1i}$ is a vector of agricultural land use variables, $\mathbf{u}_{1i}$ is a vector of urban and industrial land use variables, $\mathbf{p}_{1i}$ is a vector of physical characteristics measuring the vulnerability of individual watersheds to surface water pollution, and $\mathbf{d}_i$ is a vector of spatial dummies.

Toxic water quality model

The presence of toxic contaminants in watersheds and their subsequent bioaccumulation constitute another set of key relationships. We focus on metallic contamination since the USEPA's toxic water quality indicator (TOXICWQ) measures pollution by selected heavy metals (Cr, Cu, Ni, Zn). The major anthropogenic sources of metallic pollution of water bodies include urban, industrial, commercial, and mining uses (Keyes 1976;

Fergusson 1982). The whole life cycle from extraction and processing to manufacturing, use, and disposal of a product is involved in metallic water contamination. Industry can contribute to soil and water pollution in the following ways: (a) emission of aerosols and dusts and consequent atmospheric deposition, (b) liquid effluents and discharge of sewage into water ways, and (c) creation of waste dumps (Fergusson 1982; Stephenson 1987; Alloway 1995). Besides metalliferous mining and industrial processes, other major sources of metallic contamination of surface waters include domestic uses, urban and road runoff, and runoff from agricultural lands (Keyes 1976; Fergusson 1982; Stephenson 1987; Alloway 1995). Equation (2) represents the toxic water quality function:

$$y_{2i} = \gamma_0 + \gamma_1'\mathbf{a}_{2i} + \gamma_2'\mathbf{u}_{2i} + \gamma_3'\mathbf{p}_{2i} + \gamma_4'\mathbf{d}_i + \varepsilon_{2i} \qquad (2)$$

where y_{2i} is an indicator of toxic water quality based on four toxic pollutant concentrations in surface water (Cr, Cu, Ni, Zn), $\mathbf{a}_{2i}$ is a vector of agricultural land use variables, $\mathbf{u}_{2i}$ is a vector of urban and industrial land use variables, $\mathbf{p}_{2i}$ is a vector of physical characteristics of the watershed, and $\mathbf{d}_i$ is a vector of spatial dummies.

Bioaccumulation model

Heavy metals and organic contaminants are the most typical persistent pollutants. Indeed, examination of the underlying data for the variable FISHADV reveals that heavy metals and persistent organic pollutants are responsible for 57% and 43% advisories, respectively. Mercury and PCB’s clearly dominate the list. Combined they caused as much as 88% of all advisories, and together with another five compounds (chlordane, dioxins, mirex, DDT, cadmium) their share reaches 99%.

The major anthropogenic sources of mercury inputs include fossil fuel combustion, metallurgy, chemical and electrical manufacturing, and instruments for measurement and control (Fergusson 1982; Stephenson 1987). PCBs were widely used as industrial coolants and lubricants and in other industrial applications (Alloway 1995; USDHHS 2004). Although the manufacture of PCBs in the U.S. was banned in 1977, their continued presence in the environment is maintained from the disposal of waste of previously manufactured PCB-containing material (Mahanty and Gresshoff 1978). PCBs are very stable and highly resistant compounds (Laws 1993). As a result, they continue to be present in the environment and the food chain (Stone 1995). Besides domestic and industrial sources, agricultural pesticides are another leading source of some of the persistent organic pollutants. Organochlorine pesticides include DDT, chlordane, heptachlor, aldrin, dieldrin, alachlor, or atrazine. Many of them have been banned by the USEPA as carcinogens (Laws 1993). Examination of the fish consumption advisories data reveals that many of the pesticides recorded in fish tissues in 1998 had been banned by the USEPA long before. Equation (3) represents the bioaccumulation function:[5]

$$\ln y_{3i} = \delta_0 + \delta_1 y_{2i} + \delta_2 y_{2i}^2 + \delta_3' \mathbf{h}_{3i} + \delta_4' \mathbf{l}_{3i} + \varepsilon_{3i} \qquad (3)$$

where y_{3i} is an indicator of bioaccumulation based on the number of fish consumption advisories issued in the watershed, y_{2i} is the toxic water quality indicator (2), y_{2i}^2 is the square of y_{2i}, $\mathbf{h}_{3i}$ is a vector of physical and habitat variables, and $\mathbf{l}_{3i}$ is a vector of additional land use variables.

[5] Motivation for the log-linear specification is explained in the section on Estimation method.

Aquatic life abundance model

The fourth equation in the system represents the relationship between land use, water quality, and wildlife abundance in aquatic ecosystems. Previous studies have shown that wildlife abundance is a function of a number of factors, some of which are discussed next. Occurrence of decreased diversity of both animal and plant species has been identified with excessive eutrophication (e.g., Schindler 1990; Schindler 1994; Schnoor 1996; Vitousek et al. 1997; Seehausen et al. 1997; Sayer et al. 1999), oxygen shortages (Carpenter et al. 1998; Smith 1998; Deaton and Winebrake 2000), as well as acidification of water bodies (Schindler 1990; 1994).

Changes in species diversity and abundance have also been attributed to elevated concentrations of heavy metals (Skidmore 1964, Waldichuk 1979; Handy and Eddy 1990; Laws 1993) and organic pesticides. For example, organophosphate pesticides (e.g. malathion and parathion) are toxic nearly to all animals and pyrethroids (synthetic derivatives, such as allethrin or dimethrin) are extremely toxic to fish (Laws 1993).

Persistent organic pollutants, such as dioxins and PCBs, have also been found to be toxic to animal and plant species (Laws 1993; USDHHS 2004). For example, Mosser et al. (1972) found that low concentrations of DDT or PCBs disrupt the species composition of phytoplankton communities, thereby affecting the whole ecosystems.

Equation (4) represents the aquatic life abundance function:

$$\ln y_{4i} = \eta_0 + \eta_1 y_{1i} + \eta_2 y_{1i}^2 + \eta_3 y_{2i} + \eta_4 y_{2i}^2 + \eta_5 y_{3i} + \eta_6 y_{3i}^2 + \eta_7' \mathbf{h}_{4i} + \eta_8' \mathbf{l}_{4i} + \varepsilon_{4i} \quad (4)$$

where y_{4i} is an indicator of abundance of aquatic life based on the number of aquatic and wetland species at risk of extinction present in a watershed, y_{1i} is the conventional water quality indicator (1), y_{2i} is the toxic water quality indicator (2), y_{3i} is the indicator of bioaccumulation (3), regressors y_{1i}^2, y_{2i}^2, and y_{3i}^2 are the squares of the respective three indicators, $\mathbf{h}_{4i}$ is a vector of habitat variables, and $\mathbf{l}_{4i}$ is a vector of additional land use variables which includes atrazin and diazinon as examples of toxic pesticides.

Equations (1), (2), (3), and (4) together constitute our simultaneous equation system. Each of the equations represents a particular watershed indicator as a function of environmental and land use variables. Equations (2) and (3), as well as equations (1), (2), (3) and (4), each constitute a triangular system with recursive determination of the dependent variables (Greene, pp.659). In the next section, we discuss the technique used to estimate the system.

Estimation method

Maddala (pp. 242-45) suggests a two-stage technique for estimating a simultaneous equation system with discrete dependent variables. In the first stage, we estimate the reduced form equations (1) and (2) using OLS. Predicted values were computed for the full sample of 2,109 observations. In the second stage, the parameters in the structural equations are estimated by applying maximum likelihood. We estimate equation (3) as a negative binomial model. We regress $\ln(y_3)$ on the predicted values from equation (2) and a set of exogenous variables. Similarly, we estimate equation (4) as a negative binomial model by regressing $\ln(y_4)$ on the predicted values from equations (1), (2), and (3), and a set of exogenous variables.

Cameron and Trivedi (1998) suggest that Poisson regression or the negative binomial model are the appropriate techniques to model discrete noncategorical variables, referred to as count data. The Poisson model is a nonlinear regression model used to model the number of occurrences of an event (event counts). In our case, an event count is the number of times a fish advisory has been issued or the number of times occurrence of an endangered species has been recorded. The Poisson model is characterized by the equality of conditional mean and conditional variance. However, the assumption of equidispersion is not appropriate in our situation since the data indicate overdispersion (see table 2 for sample mean and variance of FISHADV and SPERISK). Cameron and Trivedi (1998) suggest that the standard way to account for overdispersion is the negative binomial (NB) model, a generalization of the Poisson. They suggest that the most common implementation of the negative binomial model is the NB2 model with the quadratic variance function.

Data

The data used in this study come from three sources: The USEPA's Index of Watershed Indicators, the USDA's National Resources Inventories, and the NOAA's Coastal Assessment and Data Synthesis System. The study area includes the contiguous United States. All data have been retrieved by the 8-digit hydrologic units developed by the USGS. The whole study area thus contains ca. 2,100 hydrologic units. Smith et al. (1997) suggest that these watersheds are a logical choice for characterizing national-level water quality because they represent a systematically developed and widely recognized delineation of U.S. watersheds, and provide a spatially representative view of water quality conditions. Tables 1 and 2 show the descriptions and basic statistics of the variables selected for this study.

Land use and other human impacts

The USDA's National Resources Inventories (NRI) contain detailed data on land use, land cover, and natural resource conditions on U.S. nonfederal lands. Unless mentioned otherwise, all variables are constructed as percent of total land area of the hydrologic unit. This study uses the following NRI land use categories: *cultivated cropland* (CC), *noncultivated cropland* (NONCC), *pastureland* (PAST), *forest land* (FO), *rural transportation land* (TR), and two subcategories of barren land - *oil wasteland* (OIL) and *mining land* (MIN). In this study, cultivated cropland, noncultivated cropland, pastureland, and rangeland are categorized as *agricultural land* (AG) and urban and built-up areas as *urban land* (UR). In addition, *urban land* and *rural transportation land* combined are categorized as *developed land* (DE). The variable *pesticide-intensive crops* (PEST) measures the percent area sown by crops which are typically treated by high doses of pesticides, including horticultural crops, corn, and soybeans. In addition, variables *irrigated land* (IRRIG), *federal land* (FED), and *Conservation Reserve Program land* (CRP) are used in this study. Detailed definitions of the land use/cover categories can be found in the NRI glossary. The variable *population density* (POPDEN) was calculated as the per-acre population density of each 8-digit watershed based on USEPA's watershed-scale 1990 Census population data. Pesticide use variables were obtained from the NOAA's (National Oceanic and Atmospheric Administration) Coastal

Assessment and Data Synthesis System containing information on the use of pesticides in agricultural production. The dataset includes statistics on 185 and 208 chemical compounds for the years 1987 and 1992, respectively. Only the 1992 data were used in this study, since NOAA expressed some reservations about the reliability of the 1987 vintage (NOAA 1999). Two of the compounds, atrazin (ATRA) and diazinon (DIAZ), were used in our analysis. Additional information can be found in NOAA (1999).

Watershed physical and habitat characteristics

The vulnerability of watersheds to ecosystem damages is determined by a number of physical and habitat characteristics, including the following: the NRI-based *total acreage* of the watershed (AREA); *water areas* (WATER) reflecting the percent area of permanent open water constructed as the sum of census water and small water areas; and the variable *other aquatic habitat* (AQHAB) representing the percent area of palustrine and estuarine wetlands as defined by the Cowardin classification system. The NRI erosion estimates are used to compute the variable *wind erosion* (EIWIND), measuring the soil loss (tons/acre/year) due to wind erosion based on the Wind Erosion Equation. The variable *water erosion* (USLE) measures the soil loss (tons/acre/year) due to sheet and rill erosion (rainfall and runoff) based on estimates using the Universal Soil Loss Equation (USDA 2000). The variable *soil permeability* (SOILPERM) measures the degree of soil permeability which can affect the risk of contamination of ground water resources, and consequently quality of surface waters where ground water feeds rivers and lakes.

Spatial variables

Spatial dummy variables were constructed in order to capture some of the spatial variability across the large study area. The NRI-based Major Land Resource Areas (MLRA) are a plausible choice. The USDA defines an MLRA as a geographic area that is characterized by a particular pattern of soils, climate, water resources, land uses, and type of farming. Each hydrologic unit was assigned to a single MLRA by overlaying the hydrologic units by MLRAs. This produced a set of 147 MLRA's covering the 48 contiguous states. Such a large set of dummy variables caused multicollinearity. Consequently, there was a need to cluster the existing MLRAs into a smaller number of spatial units. This was carried out in two ways. First, a set of 41 '*Areas*' was constructed by clustering the MLRAs based on their geographic proximity and examination of their climate, land cover, and other characteristics. Aggregation was carried out on the basis of the information provided by USDA.[6] Second, we adopted the set of 20 Land Resource Regions (LRRs), denoted as '*Regions*' in this paper. According to USDA, an LRR is an aggregation of MLRAs with similar characteristics.

Estimation results

Conventional water quality model

Table 3 presents the parameter estimates of the conventional water quality model using the *Areas* and *Regions* as spatial dummies, respectively. The table contains two sets of estimates, based on 1997 data and on 1982-97 four-year averages, if they are available.

[6] http://www.nrcs.usda.gov/technical/land/mlra/mlralegend.html

Variables CC, PAST, UR, and EIWIND are significant at the 5% level or higher and with positive signs in all specifications.[7] Hence, conventional water quality can be explained by agricultural and urban land uses, with wind erosion exacerbating the impacts. In one specification, we tested also inclusion of variable FO, yielding a negative and insignificant coefficient. When it comes to the spatial dummies, we report only the ones with significant regression coefficients. Table 3 shows that eleven *Areas* and eight *Regions* are significant at the 10% level and better. Of these, central and southern California (Area 4), Glaciated Plains (Area 15), Indiana and Ohio till plain (Area 29), lower Mississippi River (Area 35), Gulf coast (Area 40), and Florida (Area 41) have coefficients with a positive sign indicating serious water quality concerns. These areas are characterized by large agricultural sectors or urbanization. On the other hand, densely forested areas such as western Pacific Northwest (Area 1), Michigan peninsula (Area 24), parts of the Great Lakes (Area 27), and New England (Area 38) have coefficients with negative signs, indicating overall low water quality problems. Among the *Regions*, central and southern California (Region C), the Southwest (Region D), Northern and Western Great Plains (Regions F and G), Northern Lake States (Region K), Central Midwest (Region M), the Atlantic and Gulf coast (Region T) and Florida (Region U) are all significant with positive signs. Overall, there is evidence that conventional water quality problems can be associated with agricultural land and heavily urbanized land. Estimation of a log-linear functional form of equation (1) yields similar results.

[7] While in the case of CC and UR such results are expected, the rationale for a positive sign and high significance of PAST may be less obvious. The common characteristic of CC and PAST is that they both measure area where fertilizer application is one of the management practices.

Toxic water quality model

Parameter estimates of the toxic water quality model are presented in table 4. The results suggest that mining (MIN) is the major determinant of metallic pollution, together with rural transportation (TR) and urban land (UR). The coefficient for MIN is positive and significant at the 5% level and better in all specifications. Agriculture (AG) does not appear to be a source of metallic pollution of the nation's water bodies. Among the spatial dummies, six *Areas* are significant at the 5% level and better, including central and southern California (Area 4), southeastern Arizona (Area 11), northern and southern Rocky Mountains (Area 13 and 14), Carolina and Georgia Piedmont and Sand Hills (Area 37), and the Gulf coast (Area 40). All coefficients have a positive sign and their absolute magnitude is quite remarkable. These areas are characterized by mining operations or urbanization. Table 4 shows that seven *Regions* are significant at the 5% level and better, all with a positive sign. These include central and southern California (Region C), the Southwest (Region D), Rocky Mountains (Region E), south Atlantic and Gulf slopes (Region P), the Northeast (Region R) and Atlantic and Gulf coast (Region T). Overall, there is evidence that metallic contamination of water bodies can be associated with mining activities and heavily urbanized land. Estimation of a log-linear specification of equation (2) yields similar results.

Predicted values for the full sample of observations were computed for both water quality models. This yields four sets of predicted values – one for each time domain and each set of spatial dummies. Procedure GENMOD in SAS was used to fit the Poisson and the negative binomial regression models.

Fish consumption advisory model

Table 5 presents the parameter estimates of the Fish consumption advisory model.[8] Both, NB2 and Poisson regression estimates are listed. All NB2 estimates are statistically significant at the 1% level except for two variables (TOXIC_hatSQ and PEST8287). The parameter estimates of TOXICWQ_hat (the predicted values of TOXICWQ) and its square (TOXICWQ_hatSQ) suggest that there is a threshold value (approx.=32.6) beyond which we operate on the increasing part of the convex parabola. Hence, increased toxic pollution levels can be associated with fish consumption advisories only for certain range of values. Coefficient of POPDEN is positive and significant, as expected. High population density may increase the number of fish consumption advisories for at least two reasons. High population density increases the possibility of water pollution and bioaccumulation which may increase the number of fish consumption advisories. Second, with population density more people will be affected by fish contamination. As a result, government agencies are more likely to issue fish consumption advisory. The motivation for inclusion of the total acreage of watershed (AREA), and the percent area of aquatic habitat (WATER and AQHAB) is the expectation that larger watersheds, as well as watersheds with larger aquatic habitat are more likely to support higher number of aquatic species and thus possibly carry more advisories.

Table 5 shows also two statistics to assess goodness of fit; Deviance divided by degrees of freedom and Pearson Chi-square coefficient divided by degrees of freedom. Values close to 1 indicate a good fit. Values greater than 1 indicate overdispersion, i.e.

[8] We report only results based on 1982-97 averages. Results based on 1997 data are similar.

the true variance is greater than the mean. Evidence of over- or underdispersion indicates inadequate fit. In our case, the values of these two statistics indicate considerably better fit of the NB2 model compared to the Poisson model. Finally, comparison of values of the log-likelihood also indicate preference for the NB2 model. We test for overdispersion with a likelihood ratio test with the null hypothesis being $\alpha = 0$ and the alternative $\alpha > 0$. The likelihood ratio statistic is computed as LR = -2(log$L_{Poisson}$ – logL_{NB2}). We reject the null hypothesis at the 1% significance level if LR > Chi-square (0.98,1)=5.41 (Cameron and Trivedi 1998). This leads us to abandon the Poisson distribution assumption. Overall, the above analysis indicates adequate fit of the NB2 model.

Species at risk model

Table 6 presents the NB2 parameter estimates of the Species at risk model.[9] The results suggest that for sufficiently low levels of CONWQ and TOXICWQ (approx.=30.6 and 22.1, respectively)[10] we operate on the positively sloped portion of the concave parabola. Pollution levels in this range can be associated with increased numbers of endangered species. The motivation for inclusion of AREA, WATER, and AQHAB is the expectation that the size of watershed or the size of aquatic habitat are related to the number of species (including the rare ones) living in a given watershed. All three variables are positive and highly significant. We tested also additional land use variables. The coefficients of FED and CRP are negative and significant at the 10% level and better. This suggests that both, federal land and CRP land can be associated with lower numbers of endangered species. The regression coefficients of ATRA and DIAZ are positive.

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[9] Again, only results based on 1982-97 averages are reported.
[10] Compare with sample means 16.5 and 7.8, respectively.

Statistical significance has been established only for the former. The goodness-of-fit measures indicate a good fit of the NB2 model. Both, deviance and Pearson Chi-square divided the degrees of freedom are close to unity. The LR test also indicates a preference for the NB2 model.

Conclusions

In this paper we conduct a nation-scale analysis focused on the interaction between land use and watershed health. We found that decline of conventional water quality is best explained by agricultural and urban land uses, with wind erosion exacerbating the impacts. The major determinants of heavy metal contamination of surface waters include mining, followed by urban land use and transportation. These major trends in water quality further impact the health of aquatic resources. Population density is the best predictor of the number of fish consumption advisories issued in a given watershed. Finally, our analysis indicates that the deterioration of conventional water quality and toxic water quality is likely to increase the occurrence of endangered species. On the other hand, federal land and land in Conservation Reserve Program can be associated with lower numbers of endangered species.

References

Anderson, G. D., J. J. Opaluch, and W. M. Sullivan. "Nonpoint Agricultural Pollution: Pesticide Contamination of Groundwater Supplies." *Amer J Agr.Econ.* 67(1985):1238-43.

Alloway, B.J., ed. *Heavy Metals in Soils.* 2nd. ed. Chapman and Hall, 1995.

Blaustein, A.R. "Chicken Little or Nero's Fiddle? A Perspective on Declining Amphibian Populations." *Herpetologica* 50(1) (1994): 85-97.

Blaustein, A.R., Wake, D.B., and W.P. Sousa. "Amphibian Declines: Judging Stability, Persistence, and Susceptibility of Populations to Local and Global Extinctions." *Conservation Biology* 8(1) (1994): 60-71.

Brouwer, F.M., Thomas, A.J., and M.J. Chadwick. *Land Use Changes in Europe: Processes of Change, Environmental Transformations and Future Patterns*, Kluwer Publ., 1991.

Cameron, A.C., and P.K. Trivedi. *Regression Analysis of Count Data.* Econometric Society Monographs No.30, Cambridge University Press, 1998.

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N., and V.H. Smith. "Nonpoint Pollution of Surface Waters with Phosphorus and Nitrogen." *Ecol. Applications* 8(3) (1998): 559-568.

Czech, B., Krausman, P.R., and P.K. Devers. "Economic Associations among Causes of Species Endangerment in the United States." *BioScience* 50 (2000): 593-601.

Deaton, M. L., and J.J. Winebrake. *Dynamic Modeling of Environmental Systems*. New York: Springer-Verlag, 2000.

De Roo, H. C. "Nitrate Fluctuations in Ground Water as Influenced by Use of Fertilizer." Connecticut Agricultural Experiment Station, New Haven, Bulletin 779, 1980.

Ehrlich, Paul R., and Anne H. Ehrlich. *Extinction: The causes and consequences of the disappearance of species*. New York : Random House, 1981.

Faurie, C., Ferra, C., Médori, P., and J. Dévaux. *Ecology: Science and Practice*. A.A.Balkema Publ., 2001.

Fergusson, J.E. *Inorganic Chemistry and the Earth: Chemical Resources, their Extraction, Use and Environmental Impact*. Pergamon Press, 1982.

Frissell, C. A. “Topology of Extinction and Endangerment of Native Fish in the Pacific Northwest and California (U.S.A.).” *Conservation Biology* 7(2) (1993): 342-354.

Gilliam, J. W., and G. D. Hoyt. "Effect of Conservation Tillage on Fate and Transport of Nitrogen." *Effects of Conservation Tillage on Groundwater Quality*, eds. Lewis Publishers, Ic., Chelsea, Michigan, 1987, 217-240.

Greene, W.H. *Econometric Analysis.* 4th ed. Prentice Hall Inc., 2000.

Handy, R.D., and F.B. Eddy. “The Interactions Between the Surface of Rainbow Trout, Oncorhynchus Mykiss, and Waterborne Metal Toxicants (in Freshwater).” *Functional Ecology* 4(3) New Horizons in Ecotoxicology (1990): 385-392.

Harding, J.S., Benfield, E.F., Bolstad, P.V., Helfman, G.S., and E.B.D. Jones. “Stream Biodiversity: The Ghost of Land Use Past.” *Proceedings of the National Academy of Sciences of the United States of America* 95(25) (December 1998).

Hartwell, H.W., Jr., and L.M. Ollivier. “Stream Amphibians as Indicators of Ecosystem Stress: A Case Study from California’s Redwoods.” *Ecological Applications* 8(4) (1998): 1118-1132.

Kellogg, R.L., M.S. Maizel, and D.W. Goss. 1992. Agricultural chemical use and ground water quality: where are the potential problem areas? USDA Staff Rep., Soil Conservation Service/Economic Research Service, Washington, D.C.

Keyes, D.L. *Land Development and the Natural Environment: Estimating Impacts*. Washington: Urban Institute, 1976.

Knight, Richard L., and Kevin J. Gutzwiller. *Wildlife and Recreationists: Coexistence through Management and Research*. Washington, D.C. : Island Press, 1995.

Laws, E. A. *Aquatic Pollution, An Introductory Text*. 2nd ed. John Wiley & Sons, 1993.

McKinney, Michael L. “Influence of settlement time, human population, park shape and age, visitation and roads on the number of alien plant species in protected areas in the USA.” *Diversity & Distributions* 8, no. 6 (2002): 311-318.

Maddala, G. S. *Limited-Dependent and Qualitative Variables in Econometrics*. Cambridge Univ. Press, 1983.

Mahanty, H.K., and P.M. Gresshoff. “Influence of Polychlorinated Biphenyls (PCBs) on Growth of Freshwater Algae.” *Botanical Gazette* 139(2) (1978): 202-206.

Malmqvist, B., and S. Rundle. “Threats to the Running Water Ecosystems of the World.” *Environmental Conservation* 29(2) (2002): 134-153.

Mason, C. F. “Populations and Productions of Benthic Animals in Two Contrasting Shallow Lakes in Norfolk.” *Journal of Animal Ecology* 46(1) (1977): 147-172.

Mosser, J.L., Fisher, N.S., and C.F. Wurster. “Polychlorinated Biphenyls (PCBs) and DDT Alter Species Composition in Mixed Cultures of Algae.” *Science, New series* 176(4034) (1972):533-535.

Mueller, D.K., P.A. Hamilton, D.R. Helsel, K.J. Hitt, and B.C. Ruddy. 1995. Nutrients in ground water of the united states - an analysis of data through 1992. Water-Resources Investigations Rep. No. 95-4031. U.S. Geological Survey, Denver, CO.

National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), Special Projects Office (SPO), National Coastal Assessment (NCA) Branch, Coastal Assessment and Data Synthesis (CA&DS) System, *Pesticides.* Silver Spring, MD, 1999. Available online at http://cads.nos.noaa.gov

Nielsen, E.G., and L.K. Lee. 1987. The magnitude and costs of groundwater contamination from agricultural chemicals: a national perspective. Agr. Econ. Rep. No. 576, USDA, Economic Research Services, Washington D.C.

Office of Technology Assessment, U.S. Congress. *Beneath the Bottom Line: Agricultural Approaches to Reduce Agrichemical Contamination of Groundwater.* Rep. OTA-F-418, Washington, D.C., 1990.

Rottenborn, S. C. “Predicting the impacts of urbanization on riparian bird communities.” *Biological conservation.* 88, 3, (1999): 289.

Sayer, C., Roberts, N., Sadler, J., David, C., and P.M. Wade. “Biodiversity Changes in a Shallow Lake Ecosystem: A Multi-Proxy Palaeolimnological Analysis.” *Journal of Biogeography* 26(1) (1999): 97-114.

Schindler, D.W. “Changes Caused by Acidification to the Biodiversity, Productivity and Biochemical Cycles of Lakes.” *Acidification of Freshwater Ecosystems. Implications for the Future: Report of the Dahlem Workshop on Acidification of Freshwater Ecosystems held in Berlin, September 27-October 2, 1992*. Steinberg, C.E.W., and R.W. Wright (eds.); program advisory committee. Chichester ; New York: Wiley, 1994.

__. “Experimental Perturbations of Whole Lakes as Tests of Hypotheses Concerning Ecosystems Structure and Function.” *Oikos* 57 (1990): 25-41.

Schnoor, J.L. *Environmental Modeling: Fate and Transport of Pollutants in Water, Air, and Soil*. Wiley, 1996.

Seehausen, O.J., van Alpen, J.M., and F. Witte. "Cichlid Fish Diversity Threatened by Eutrophication that Curbs Sexual Selection." *Science* 277 (1997): 1808-1811.

Skidmore, J. F. "Toxicity of Zinc Compounds to Aquatic Animals, with Special Reference to Fish." *Quarterly Review of Biology* 39(3) (1964): 227-248.

Smith, V.H. "Cultural Eutrophication of Inland, Estuarine, and Coastal Waters." *Successes, Limitations, and Frontiers in Ecosystem Science.* Pace, M.L., and P.M. Groffman (eds.). New York: Springer-Verlag, 1998.

Smith, R.A., Schwarz, G.E., and R.B. Alexander. "Regional Interpretation of Water-Quality Monitoring Data." *Water Resources Research* 33(12) (1997): 2781-2798.

Stephenson, T. "Sources of Heavy Metals in Wastewater." *Heavy Metals in Wastewater and Sludge Treatment Processes, vol. 1, Sources, Analysis, and Legislation*. Lester, J.N., ed., CRC Press, 1987.

Stone, R. "Environmental Toxicants under Scrutiny at Baltimore Meeting." *Science, New series* 267(5205) (1995): 1770-71.

The H.J. Heinz III Center for Science, Economics and the Environment. *The State of the Nation's Ecosystems*. 2002.

U.S. Department of Agriculture. *National Resources Inventory: Background*. 2001a. Available online at http://www.nrcs.usda.gov/technical/NRI

U.S. Department of Agriculture. *National Resources Inventory: Highlights*. 2001b. Available online at http://www.nrcs.usda.gov/technical/NRI

U.S. Department of Agriculture. *Summary Report 1997 National Resources Inventory (revised December 2000)*. 2000.

U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry. May 2004. Information available online at http://www.atsdr.cdc.gov

U.S. Environmental Protection Agency. *Aquatic Biodiversity*. 2004. Available online at http://www.epa.gov/bioindicators/aquatic/threats.html

U.S. Environmental Protection Agency. *Index of Watershed Indicators: An Overview.* August 2002.

U.S. Environmental Protection Agency. *Watershed Atlas*. Information available at the following website http://www.epa.gov/wateratlas/geo/maplist.html

Van der Zanden, M.J., and J.B. Rasmussen. "A Trophic Position Model of Pelagic Food Webs: Impact on Contaminant Bioaccumulation in Lake Trout." *Ecological Monographs* 66(4) (1996): 451-477.

Vitousek, P.M., Aber, J.D., Howarth, R.D., Likens, G.E., Matson, P.A., Schindler, D.W., Schlesinger, W.H., and D.G. Tilman. "Human Alterations of the Global Nitrogen Cycle: Sources and Consequences." *Ecological Applications* 7 (1997): 737-750.

Waldichuk, M. "Review of the Problems." *Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences* 286(1015), The Assessment of Sublethal Effects of Pollutants in the Sea (August 1979): 399-422.

Wu, J.J., and B.A. Babcock. "Metamodeling Potential Nitrate Water Pollution in the Central United States." *Journal of Environmental Quality* 28 (1999): 1916-1928.

Wu, J.J., Bernardo, D.J., Mapp, H.P., Geleta, S., Teague, M.L., Watkins, K.B., Sabbagh, G.J., Elliott, R.L., and J.F. Stone. "An Evaluation of Nitrogen Runoff and Leaching in the High Plains." *J. Soil and Water Conser.* 52 (1997): 73-80.

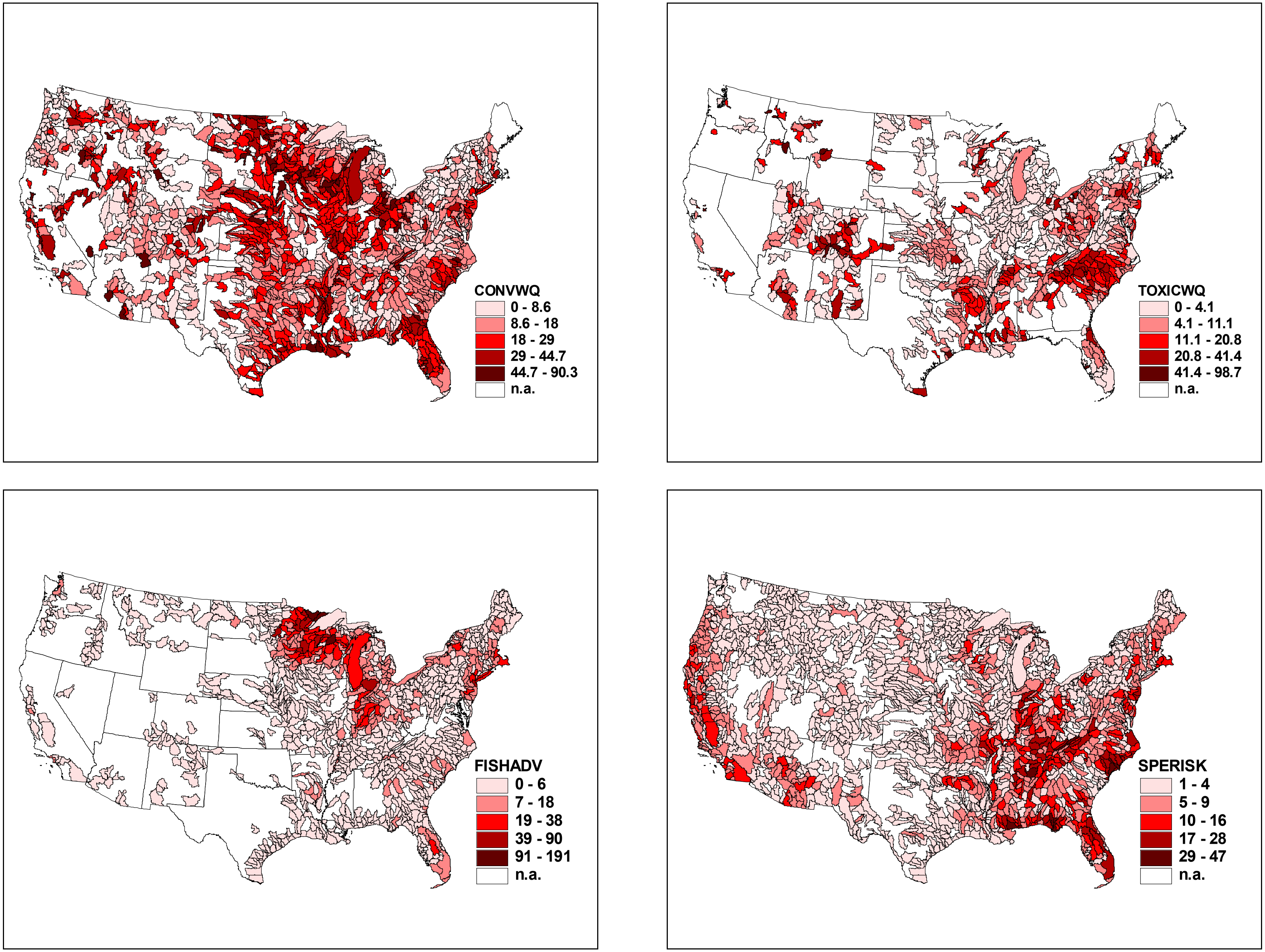

Figure 1. Selected watershed health indicators in the United States

Table 1. Description of Variables

Variables	Description	Collection Year	Data Source
CONVWQ	Conventional water quality	1990-98	U.S. EPA - IWI
TOXICWQ	Toxic water quality	1990-98	U.S. EPA - IWI
FISHADV	Fish consumption advisories	1998	U.S. EPA - IWI
SPERISK	Species at risk	1996	U.S. EPA - IWI
POPDEN	Population density (persons/acre)	1990	U.S. EPA - IWI
SOILPERM	Soil permeability index	1998	U.S. EPA - IWI
AG	Agricultural land (% area)	1982, 87, 92, 97	USDA - NRI
CC	Cultivated cropland (% area)	1982, 87, 92, 97	USDA - NRI
NONCC	Noncultivated cropland (% area)	1982, 87, 92, 97	USDA - NRI
PAST	Pastureland (% area)	1982, 87, 92, 97	USDA - NRI
FO	Forest land (% area)	1982, 87, 92, 97	USDA - NRI
DE	Developed land (% area)	1982, 87, 92, 97	USDA - NRI
UR	Urban land (% area)	1982, 87, 92, 97	USDA - NRI
TR	Rural transportation (% area)	1982, 87, 92, 97	USDA - NRI
MIN	Mining land (% area)	1982, 87, 92, 97	USDA - NRI
OIL	Oil wasteland (% area)	1982, 87, 92, 97	USDA - NRI
USLE	Water erosion (tons/acre/year)	1982, 87, 92, 97	USDA - NRI
EIWIND	Wind erosion, 4-year average (tons/acre/year)	1982, 87, 92, 97	USDA - NRI
IRRIG	Irrigated land (% area)	1982, 87, 92, 97	USDA - NRI
PEST	Pesticide-intensive crops (% area)	1982, 87, 92, 97	USDA - NRI
AREA	Total area of watershed (1,000 acres)	1997	USDA - NRI
WATER	Area of water bodies (% area)	1982, 87, 92, 97	USDA - NRI
AQHAB	Other aquatic habitat (% area)	1997	USDA - NRI
ATRA	Atrazin (1,000 lbs/acre)	1992	NOAA
DIAZ	Diazinon (1,000 lbs/acre)	1992	NOAA

Table 2. Summary Statistics

Variables	Obs.	Mean	Std Dev	Min	Max
CONVWQ	1344	16.46	12.44	0	90.30
TOXICWQ	758	7.80	10.19	0	98.70
FISHADV	930	5.94	12.42	0	191
SPERISK	1595	4.56	4.94	1	47
POPDEN	2062	18.31	65.06	0	1314.74
SOILPERM	2109	4.17	1.21	0	8.96
AG	2109	46.06	31.84	0	99.97
CC	2109	18.22	23.59	0	91.13
NONCC	2109	2.40	3.13	0	31.63
PAST	2109	6.74	9.02	0	70.88
FO	2109	23.72	26.46	0	96.21
DE	2109	5.23	8.29	0	82.81
UR	2109	3.77	7.99	0	82.50
TR	2109	1.15	0.67	0	3.27
MIN	2109	0.26	1.16	0	37.80
OIL	2109	0.01	0.07	0	2.11
IRRIG	2109	3.25	7.95	0	65.63
CRP	2109	0.99	2.04	0	16.71
FERT	2109	13.69	20.12	0	87.67
PEST	2109	8.50	16.67	0	87.29
PEST8287	2109	8.65	16.51	0	86.64
USLE	2109	1.86	1.97	0	18.64
EIWIND	2109	2.08	7.16	0	146.50
FED	2109	18.53	27.73	0	100
AREA	2109	918.73	576.11	4.30	5536.10
WATER	2109	3.00	7.89	0	100
AQHAB	2109	6.27	10.16	0	84.06
ATRA	1884	33.94	76.91	0	1194.49
DIAZ	1665	0.97	9.78	0	327.27

Note: Where available, the statistics for NRI-based variables were computed for 1982-97 averages.

Table 3. OLS Estimates of the Conventional Water Quality Model

Variables	1997 only	1982-97 average	1997 only	1982-97 average
Intercept	9.461***	9.7227***	7.48363***	7.86857***
CC	0.16865***	0.16454***	0.20622***	0.20209***
NONCC	-0.0307	-0.01239	-0.0281	-0.02083
PAST	0.12874**	0.10817**	0.14652***	0.12472***
IRRIG	-0.03982	-0.03404	0.0051	0.0139
UR	0.12576***	0.13362***	0.16323***	0.17454***
USLE	-0.20675	-0.28811	0.09382	0.01996
EIWIND	0.21015***	0.24668***	0.18975***	0.20505***
SOILPERM	0.41193	0.3968	-0.04091	-0.04893
Area 1	-7.32501**	-7.38434**		
Area 4	7.30879**	7.00121**		
Area 8	-4.63362	-5.22437*		
Area 15	5.77578*	5.2164*		
Area 24	-6.97614**	-7.25038**		
Area 27	-7.40375**	-7.72426**		
Area 29	8.38299**	8.39262**		
Area 35	9.37665***	9.46845***		
Area 38	-4.84776*	-4.89052*		
Area 40	8.15297**	8.05494**		
Area 41	6.60342**	6.8946**		
Region C			8.07656**	7.50876**
Region D			4.91743**	4.359*
Region F			7.45242***	6.69975**
Region G			7.3882***	6.76992**
Region K			4.14606*	3.77162
Region M			4.8679**	4.69801**
Region T			8.5879***	8.35674***
Region U			10.10141***	10.35378***
N	1344	1344	1344	1344
R2	0.2893	0.2871	0.2638	0.2613
adj R2	0.2641	0.2618	0.2487	0.2462

Note: One, two, and three asterisks indicate statistical significance at the 10%, 5%, and 1% level, respectively.

Table 4. OLS Estimates of the Toxic Water Quality Model

Variables	1997 only	1982-97 average	1997 only	1982-97 average
Intercept	3.4129	3.39221	1.27155	1.51425
AG	-0.07077***	-0.07093***	-0.05712**	-0.05683**
UR	0.01611	0.01342	0.05785*	0.06121
TR	2.07722**	2.06546**	2.51122***	2.56917***
MIN	0.80869**	0.75285**	0.88573**	0.828**
OIL	1.07709	0.88044	1.06064	0.85225
USLE	-0.30078	-0.132	-0.13009	-0.04811
EIWIND	-0.06718	-0.03013	0.05597	0.06566
SOILPERM	0.19524	0.15698	-0.06699	-0.11301
Area 4	11.89958**	12.36933**		
Area 11	12.09238**	12.02846**		
Area 13	23.81465***	23.98551***		
Area 14	11.28523**	11.4127**		
Area 37	8.69963*	8.77796*		
Area 40	16.02973**	16.59985**		
Region C			12.55037***	12.65592***
Region D			5.96035**	5.79542**
Region E			14.69737***	14.62101***
Region G			5.96882*	5.87901*
Region P			8.4798***	8.4567***
Region R			6.13192**	6.13392**
Region T			6.77805**	6.78972**
N	758	758	758	758
R2	0.247	0.2448	0.1833	0.1822
adj R2	0.1983	0.196	0.1531	0.152

Note: One, two, and three asterisks indicate statistical significance at the 10%, 5%, and 1% level, respectively.

Table 5. ML Estimates of the Fish Consumption Advisory Model

	Area-based		Region-based	
Variables	NB2	Poisson	NB2	Poisson
Intercept	1.4067***	1.5936***	1.7841***	1.8435***
TOXICWQ_hat	-0.084***	-0.0517***	-0.1861***	-0.1088***
TOXICWQ_hatSQ	0.0008	-0.0012**	0.0057***	0.0008
POPDEN	0.0028***	0.002***	0.0032***	0.0022***
PEST8287	-0.0021	-0.0035***	-0.0038*	-0.0052***
AREA	0.0004***	0.0003***	0.0004***	0.0003***
WATER	0.0197***	0.0119***	0.015***	0.011***
AQHAB	0.0321***	0.0224***	0.0334***	0.0214***
Dispersion	0.973	0	0.9328	0
Obs.	924	924	924	924
Deviance/DF	1.06	8.45	1.06	8.19
Pearson Chi-sq/DF	2.27	18.16	1.96	16.22
log L	7764.70	5087.37	7782.03	5205.63

Note: One, two, and three asterisks indicate statistical significance at the 10%, 5%, and 1% level, respectively.

Table 6. ML Estimates of the Species at Risk Model

	Area-based		Region-based	
Variables	NB2	NB2	NB2	NB2
Intercept	0.81***	0.533***	0.716***	0.6024***
CONVWQ_hat	0.0197	0.0752***	0.0271**	0.0703***
CONVWQ_hatSQ	-0.0006*	-0.0026***	-0.0008**	-0.0023***
TOXICWQ_hat	0.1014***	0.1124***	0.0933***	0.0974***
TOXICWQ_hatSQ	-0.0047***	-0.005***	-0.0042***	-0.0044***
FISHADV_hat	-0.1113***	-0.0976***	-0.102***	-0.1072***
FISHADV_hatSQ	0.001***	0.0007*	0.0007***	0.0007***
POPDEN	0.0023***	0.0018***	0.0025***	0.0023***
FED		-0.0022*		-0.0026**
CRP		-0.0659***		-0.0654***
ATRA		0.0021***		0.002***
DIAZ		0.0026		0.0019
AREA	0.0005***	0.0004***	0.0005***	0.0004***
WATER	0.017***	0.0196***	0.0113***	0.0161***
AQHAB	0.0262***	0.0215***	0.0259***	0.0227***
Dispersion	0.4487	0.4337	0.4305	0.4162
Obs.	1566	1249	1566	1249
Deviance/DF	0.96	0.97	0.95	0.97
Pearson Chi-sq/DF	1.31	1.22	1.27	1.20
log L (NB2)	5268.08	5363.24	5292.69	5382.19
log L (Poisson)	4322.55	4555.21	4393.30	4616.01

Note: One, two, and three asterisks indicate statistical significance at the 10%, 5%, and 1% level, respectively.

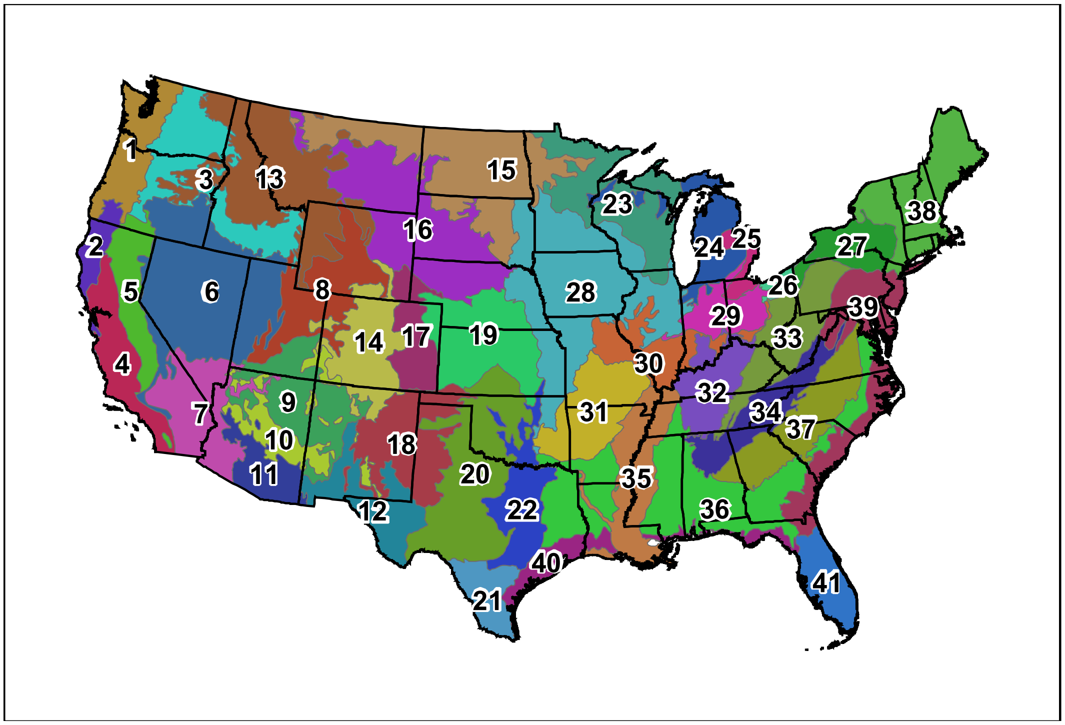

Figure A1. Aggregation of MLRAs into 41 Areas

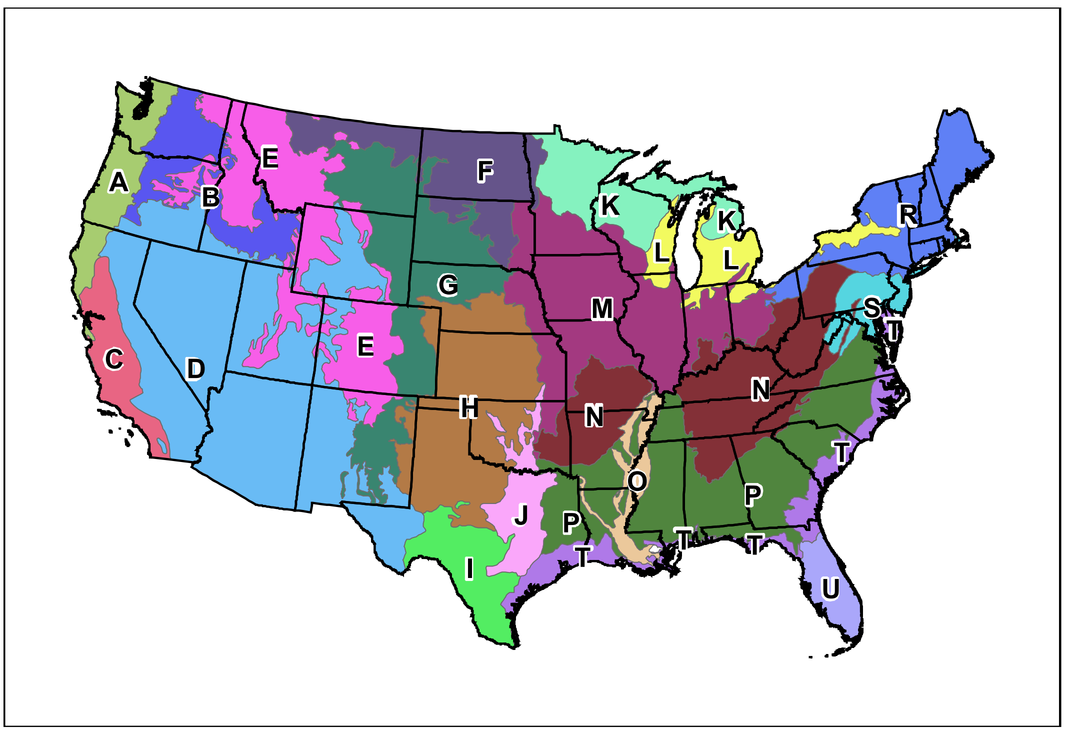

Figure A2. Aggregation of MLRAs into 20 Regions (Land Resource Regions)