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Nitrate Pollution Externality Associated with Increased Corn Demand for Ethanol: a Case Study of Olmsted County in Minnesota

Kshama Harpankar
Department of Applied Economics
University of Minnesota
Email:harp0096@umn.edu

Abstract

Land use practices generate various environmental externalities. With the increased interest in biofuel production, it is imperative to understand the benefits and costs associated with resource allocation choices made for biofuel production. This paper contributes to the full cost accounting of biofuels research by estimating potential nitrate pollution cost associated with land use change that may result from increasing corn prices due to demand from ethanol producers. The increased demand for corn from ethanol producers is assumed to translate into changed spatial pattern of land use. Specifically this paper develops a regression model to empirically explain the relationship between groundwater nitrate levels in private wells in Olmsted County in Minnesota and a number of variables that may affect nitrate levels in groundwater including land use practices. Coefficients of the regression model are then employed to estimate the potential nitrate pollution levels under each land use scenario assumed. Finally percentage change in nitrate concentrations predicted under each land use scenario is applied to the observed nitrate concentrations in the private wells and a cost estimate is developed based on number of wells expected to exceed the 10 mg/L level.

Keywords: Groundwater Nitrate pollution, Agricultural Externality, Corn demand for Ethanol.

1. INTRODUCTION

Economic production activities use natural resources as an input or use the environment as a "sink" to unload the pollution. The costs associated with using the environment in such a way are referred to as "externalities" as they arise as a side effect of economic activities and are not captured by prices paid by consumers or producers (Baumol & Oates, 1988). Land is a natural resource that features as an input in a variety of economic activities. The production decision of using land to produce food or to provide shelter or any other service is referred to as land use practice. Land use practices generate various environmental externalities. Considering the major role land plays in the provision of different services needed by the society, land use management is an important task that involves balancing multiple objectives like economic profitability, social considerations and the state of the environment. Efficient land use management often requires a mix of strategies and policy instruments. Understanding the types of externalities associated with each land use is crucial for these strategies and instruments to work.

Agriculture is an important land use practice. Agricultural production at the global scale has doubled in the last 35 years (Tilman, 2001, Millennium Ecosystem Assessment, 2005). With the introduction of modern technology, machinery, pesticides, and fertilizers, agricultural productivity has increased drastically. However the gains have not been without trade-offs. Due to the propensity of land to produce joint products agriculture often produces more than just food or feed. The environmental impacts associated with agricultural land use can be either positive or negative. Carbon sequestration is an example of a positive externality associated with agricultural land use where as nitrate pollution of ground water resource is an example of a negative externality. The negative environmental impacts of modern agriculture are wide-ranging. They include: 1) ground water pollution from nitrates and pesticides;2)surface water pollution from nitrogen and phosphrous;3)soil erosion 4) air pollution caused by methane, nitrous oxide and ammonia resulting from livestock, manure and fertilizer (Pretty et al,2000).

Why is considering externalities related to agriculture important? Agriculture is the leading cause of impaired water quality in rivers, lakes, estuaries as well as groundwater quality. Agricultural production is on the rise with production expected to double again by 2050. Sustainable development requires the reconciliation of demands for ecosystem services and increased agricultural production. Keeping this expected increase in production in mind, it is imperative to manage the footprints of agriculture carefully so as to avoid further degradation of the ecosystem services (Butler, 2007, Dale &Polasky, 2007). In addition to the potential increase in the agricultural production for food, using agricultural products for biofuel production adds a new dimension to the multi-functionality of agriculture. Identifying the environmental impacts of land use is of increasing interest to policy makers and resource planners in a world where there is increased interest in the use of agricultural products like corn, corn stover for biofuel production. The concern researchers have is if the food based biofuels can be sustainable, abundant, and environmentally beneficial energy sources (Hill et al, 2006, Fargione et al, 2008). Current biofuels compete for fertile land with food production while continuing to pollute the environment.

Analyzing spatial externalities associated with agriculture assumes more important role when we consider the impacts of biofuel production on the environment. According to the USDA ethanol production in the United States totaled almost 5 billion gallons in 2006. The production is expected to exceed 10 billion gallons by 2009. This large and rapid expansion of U.S. ethanol production affects virtually every aspect of the field crops sector, ranging from domestic demand and exports to prices and the allocation of acreage among crops. Rapid changes in the agricultural sector are already underway and will continue for many years as interest grows in renewable sources of energy to lessen the dependence on foreign oil (Westcott, 2007). In the light of this development, it will be helpful if the agricultural externalities are examined as a part of the trade-off analysis of using land to produce energy versus for producing food or feed.

Evaluating agricultural externalities related to crop production systems like corn or soybean is necessary as they are a part of the lifecycle of the fuel. To date, most efforts to evaluate different biofuel crops have focused on their merits for reducing greenhouse-gas emissions or fossil fuel use (Hill et al 2006, Farrell et al., 2006, Kim and Dale, 2005). Focusing alone on greenhouse gas emissions and energy content entails the risk of neglecting other environmental impacts. The arguments that support one biofuel crop over another can easily change when one considers their full environmental effects (Scharlemann and Laurance, 2008).Further research into environmental metrics not considered by the studies so far is needed to consider all environmental and socioeconomic impacts. To gain better understanding of the impacts, it is important to distinguish between impacts at local, regional and global scales (Uhlenbrook, 2007).

Little attention has been given to the problem of tracking the agricultural externalities related to water spatially and quantifying their impact at various spatial levels. For example there are no reliable estimates available for the damage caused by nitrogen fertilizers loadings in the marine water systems in the USA (example: damage costs for the Hypoxia in the Gulf of Mexico). The primary challenge for research in this area is empirical analysis and identification of the presence, extent, and monetary cost/benefit of agricultural spatial externalities. This paper takes a step forward in that direction by analyzing the spatial nature of an agricultural externality and utilizing the empirical relationship developed to predict changes in the externality in response to a change in land use practice.

This paper focuses on effects of changing agricultural practices on water quality, specifically the change in ground water nitrate concentrations as a result of increased corn production due to demand for corn from ethanol producers. This paper investigates the likelihood and extent of costs imposed by changes in cropping practices. Nitrate pollution of ground water is an externality that is spatial in nature. It emerges as a result of the movement of nitrogen fertilizer not taken up by the plant from the point of use on the farm to the ground water. The nature of this externality will vary depending on the spatial and temporal context. The main objectives of the research presented here are as follows:

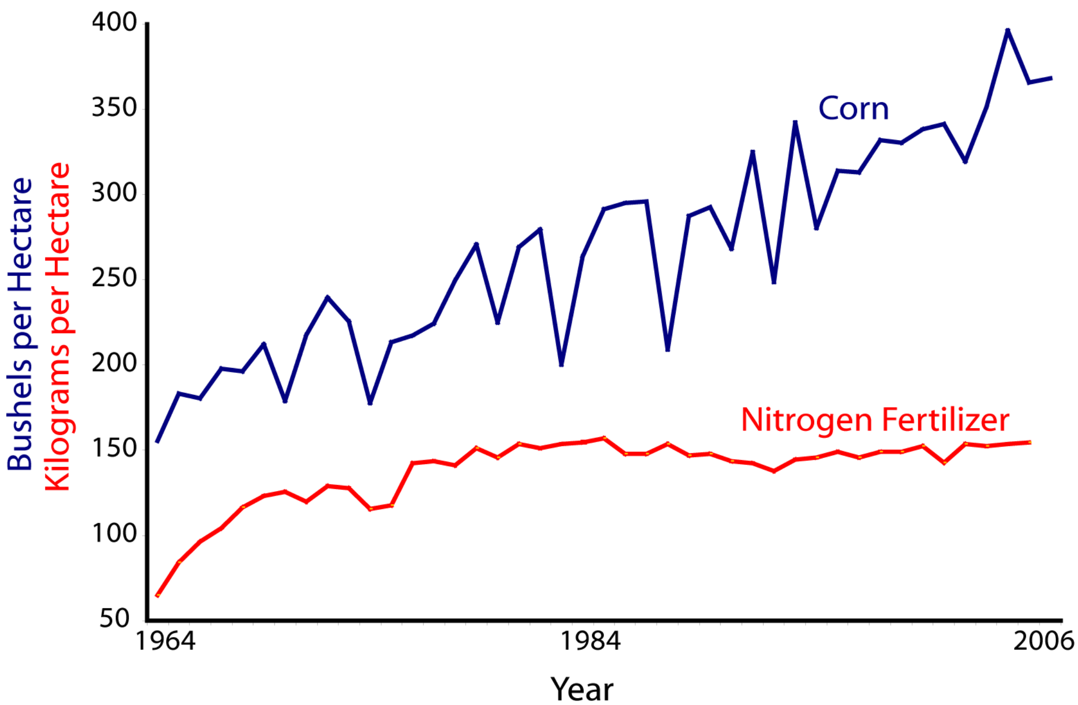
1. Develop an empirical relationship between ground water nitrate concentrations and land use variables
2. Employ the empirical relationship developed to project the ground water nitrate concentrations under the assumed land use change scenarios.
3. Using the projected nitrate concentration levels, develop a cost estimate for the county for each assumed land use scenario.

Section 2 provides background information on the ground water nitrate pollution externality and on the Olmsted County, which is the unit of study for this research.

2. NATURE OF THE EXTERNALITY

Maintaining soil fertility via chemical fertilization is one of the characteristics of modern agriculture. There is considerable amount of evidence to support the claim that human activities have altered the nitrogen cycle (Galloway, 2004).At the global level Tilman et al (1999) postulated that N fertilization would be 1.6-fold times present amounts by 2020 and 2.7 times present values by 2050.The use of nitrogen fertilizer at the national level in USA has been on a similar increasing trajectory. As shown in the figure below, the major consumer of nitrogen fertilizers among all the crops is the corn production system.

Figure 1: Nitrogen Fertilizer Use for Corn Production in USA.



Corn accounts for 80% of the nitrogen used as fertilizer in the Midwest (Donner 2004).Surface water and Groundwater contamination due to nitrate (NO3) leaching and greenhouse gas emission of the nitrous oxide (N2O) are the main environmental concerns for applied N fertilizer to the corn crop. In this paper I focus on the possibility of elevated nitrate concentrations in private domestic wells due to nitrogen fertilizer used for corn crop.

Crop based renewable fuels are clearly not going to solve the problem of energy dependence for the USA, in addition they may end up worsening the environmental problems like nitrate pollution of groundwater resources. The view that environmental balance is getting worse with corn production for ethanol is based on the following reasons/observations:

1. Nitrogen applied to corn crop is greater than nitrogen applied to most other crops, so changing the crop rotation patterns in favor of corn is likely to make the environmental impact worsen.
2. Some of the environmentally fragile land is supposed to come back into corn production as a result of rising corn prices.

I examine the possibility of land use change favoring corn production in the Olmsted County and predict the possible external costs resulting from nitrate pollution of the groundwater. For local resource planners information about occurrences of such localized externalities is helpful in making sure an optimal use of local resources.

One can make an argument that in the absence of the possibility of growing corn for ethanol, the corn will still be grown for food and feed, thereby leaving us with the nitrate pollution externality in either case. This is where it is necessary to take a look at the increasing corn prices as a result of demand from ethanol producers (Add a graph of increasing corn prices here). In the absence of this impetus the externality will still be present; however it is feared to worsen further due to the demand for corn from ethanol producers that stimulates the corn production. According to a report published by USDA (Westcott, 2007) higher corn prices will intensify demand competition among domestic industries and foreign buyers of feed grains as the ethanol producers continue to use up a sizable portion of the corn crop. USDA's 2007 long-term projections show average corn prices reaching $3.75 a bushel in the 2009/10 marketing year and then declining to $3.30 by 2016/17 as the ethanol expansion slows. Corn prices at these levels are record high and are unprecedented on a sustained basis, exceeding the previous high average over any 5-year period by more than 50 cents a bushel. Higher corn prices and producer returns are expected to encourage farmers to increase corn acreage. Much of this increase occurs by adjusting crop rotations between corn and soybeans (Westcott, 2007). Other sources of land for increased corn plantings include cropland used as pasture, reduced fallow, acreage returning to production from expiring CRP contracts, and shifts from other crops such as cotton. As per the USDA's *Prospective Plantings* report (2007), farmers' planting intentions for corn exceeded 90 million acres in the year 2007, up over 12 million acres from 2006.

With this background, what are the challenges facing the resource planners given the increased demand for corn acting as an incentive to change the cropping practices? If we can estimate the potential costs associated with each land use change scenario, it will help guide the policy to avoid undesirable environmental impacts in future. The aim of this paper is to investigate one such externality and estimate the potential cost for the county if the assumed land use scenario were to become reality.

The reason for choosing Olmsted County as the unit of analysis for this research is the unique geologic structure of the landscape of the Olmsted County. The geology and topography of the county along with land use practices contributes to groundwater pollution of nitrates. Olmsted County is located in southeastern Minnesota; it has a land area of 418,413 acres of which 235,259 is cultivated farm land (Olmsted County land use cover, 1992). Farming is the leading occupation in the county and corn, soybeans, oats and hay are main cash crops (County Soil survey). Olmsted County is known to have Karst topography characterized by sinkholes, caves, disappearing reaches of streams and rapid underground drainage. Due to the interconnection of surface and groundwater, the risk of aquifer contamination is relatively high.

The second important geologic feature of the county is the presence of the Decorah shale formation. The Decorah shale formation acts as a confining layer to upper carbonate aquifers above it, which tend to be very high in nitrate nitrogen concentrations. Water seeps from the upper aquifers over the shale and then percolates through overburden to recharge deeper aquifers that serve as drinking water supplies to cities such as Rochester and Preston. The Decorah Shale, when left intact, provides significant infiltration, absorption and denitrification of polluted water from the upper aquifers. When cropped or covered over with impervious surface, it loses these functions to the detriment of water quality and quantity (Southeast Minnesota Conservation Reserve Enhancement Program, 2003).For example a farm located on upper carbonate aquifer in the county is more likely to pollute groundwater than a farm located above the Decorah shale area. Thus the nitrate pollution resulting from land use change is not just a function of the land use alone. But it also is a function of factors like geology and topography of the region, climate ect. In this case a pound of nitrogen used on every farm will not be equally polluting across the landscape. The factors that determine the transport of nitrates from the point of use on the landscape to the groundwater will determine the proportion of the pound of nitrogen that ends up in the groundwater. Considering this complex relationship between land use, geology of the region and the environmental externality being evaluated, an integrated approach towards studying this problem is warranted. Therefore this study includes in the analysis, variables affecting transport of nitrates from the land use point to the groundwater as well as variables affecting attenuation of nitrates from the groundwater.

The baseline scenario is based on the land use practices observed in the year 2003. Water test data for private well nitrate concentrations is acquired from the Olmsted County Planning Department. As the baseline scenario is based on the year 2003, the water test results for the nitrate concentrations in private wells are selected for the year 2003 (and for two more years to have enough observations). This is the baseline pollution level associated with the baseline land use scenario of the year 2003. If more than one observation exists for a well for the time period under consideration then the observations are averaged to have one observation.

The following table shows the number of acres in each crop type as per the land use in the year 2003.

Table 1: Acres of land in each crop type in Olmsted County in 2003

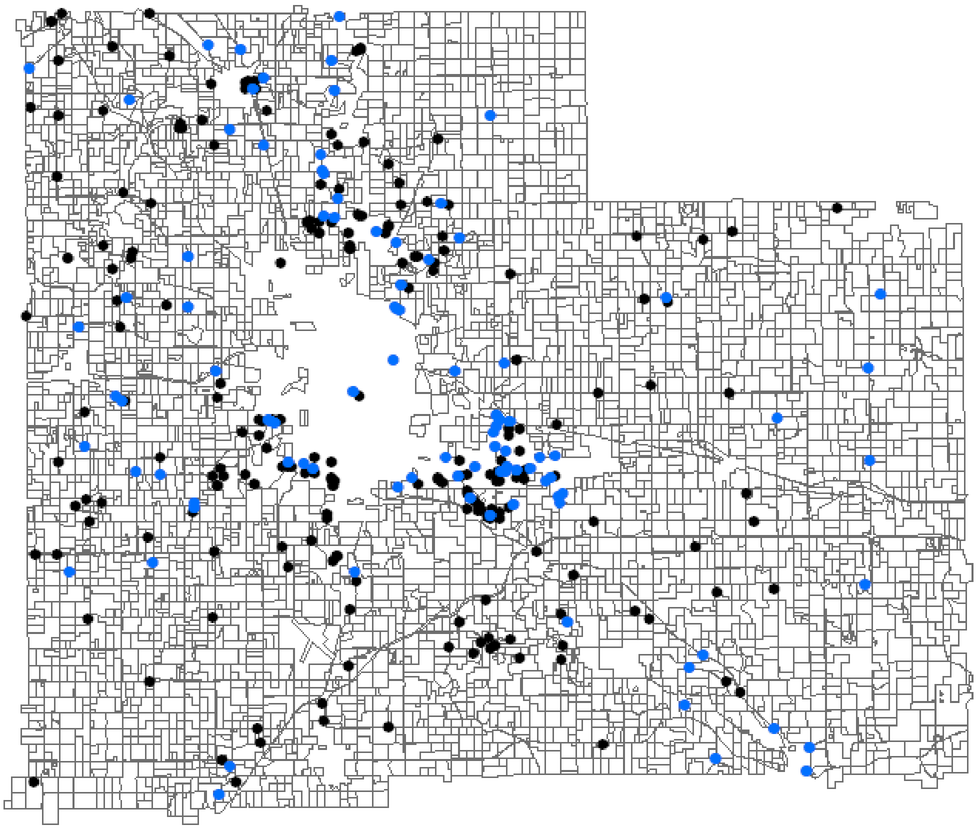
Land Use	Acres of Land	Percentage
CORN	108370.2	47.23%
SOYBEANS	71627.11	31.22%
PEAS	4165.65	1.82%
ALFALFA	20572.73	8.97%
GRASS	6280.38	2.74%
OATS	5044.93	2.20%
WHEAT	136.1	0.06%
BARLEY	0	0.00%
CRP	13231.98	5.77%
Total Cropland	229429.08	

Given this baseline, Following exploratory scenarios are assumed:

1. Land under corn-soybean rotation shifts to continuous corn rotation- the way this is incorporated in the model is via shifting of acres of land out of soybean production into corn production.
2. CRP acres shift into the corn production, everything else remaining the same.

The following map shows the distribution of wells used to create the baseline for ground water nitrate pollution level in the Olmsted County. The blue dots denote nitrate concentration levels higher than 2 mg/L, while the black dots denote nitrate concentration levels around the detection point of 0.1 mg/L and below than 2 mg/L.

Figure 2: State of nitrate concentrations in Olmsted County in 2003



The methodology used for the research is presented in detail in the following section.

3. Methodology

This exercise is intended to estimate the physical extent of the nitrate externality as a result of increased demand for corn from ethanol producers. In this section I describe the methodology followed for the research presented here. The analysis starts by developing a statistical model of the relationship between nitrate concentrations in private domestic wells and a number of variables found to affect the nitrate levels. The choice of explanatory variables used in the model in this study is guided by the studies that have estimated a statistical relationship between ground water nitrate concentrations and variables like hydrology and land use (Gardner and Vogel-2005, Lichtenberg & Shapiro-1997, Nolan &Hitt-2006,Kaown et al-2007,McLay et al-2001,Nolan-2001).

I use the classification system for the determinants of ground water nitrate levels as used by Nolan and Hitt (2006).Each of the variables fall under one of the following categories: Nitrogen source variables, Nitrate transportation variables and nitrate attenuation variables. The relationship between ground water nitrate concentrations and the explanatory variables can be explained as follows:

$$N_i = f(S_i, T_i, A_i, u_i)$$

Where
N_i is nitrate concentration in the well i
S_i is the group of Nitrogen source variables for well i
T_i is the group of nitrate transportation variables for well i
A_i is the group of nitrate attenuation variables for well i.

I examine two model specifications. The linear model is specified as follows:

$$N_i = \beta_o + \sum_{g}^{G} \beta_i S_{ig} + \sum_{j}^{J} \alpha_j T_{ij} + \sum_{k}^{K} \gamma_k A_{ik}$$

Where $\beta_1, \beta_2 ... \beta_g$ are parameters of g source variables, $\alpha_1, \alpha_2 ... \alpha_J$ are parameters associated with J nitrate transportation variables and $\gamma_1, \gamma_2 ... \gamma_K$ are parameters of K nitrate attenuation variables.

Similarly the exponential model is specified as given below

$$LN(N_i) = \beta_o + \sum_{g}^{G} \beta_i S_{ig} + \sum_{j}^{J} \alpha_j T_{ij} + \sum_{k}^{K} \gamma_k A_{ik}$$

Once again $\beta_1, \beta_2 ... \beta_g$ are parameters of g source variables, $\alpha_1, \alpha_2 ... \alpha_J$ are parameters associated with J nitrate transportation variables and $\gamma_1, \gamma_2 ... \gamma_K$ are parameters of K nitrate attenuation variables.

Nitrate concentration levels were not reported below 0.1 mg/ L. As the paragraph on the data section describes later, 46 percent of the observations are censored in this dataset. Therefore Tobit regression models were used for both model specifications.

The explanatory variables fall under the following three categories as explained below:

3. 1: N source Variables

These are variables that capture the source of nitrogen at the point of use. The land use type in the recharge area of the well is used as the general N source variable in this analysis to be able to distinguish between the contributions of different types of agricultural land uses. It has been shown that land use practices near wells contribute to nitrate pollution of ground water. There is considerable evidence that shows that agricultural land use is more likely to lead to elevated nitrate concentrations in ground water (Lichtenberg and Shapiro-1997, Nolan et al.-

1998).The cropping information for the county is available in the form of distribution of number of acres in each type of crop in each polygon for the year 2003. In order to construct the variable 'acres of land in each crop in the recharge area of the well' the following method is used: A buffer circle of 500 m feet radius is drawn around each well. Employing the "intersect" operation available in Arc-GIS the area of each polygon falling in the buffer circle is calculated. Acreage of land under each crop type is assumed to be uniformly distributed within each respective polygon. To estimate the acres of land in each crop type in each buffer circle, the ratios of land in each crop type and total crop land in the polygon are developed and area of each polygon falling under the buffer circle is multiplied by each respective ratio to arrive at the acres of land in each crop type. Variables for the acres of land in corn, soybean and other crops in the recharge area of the well are calculated in the above mentioned fashion. Acres of land in CRP in the buffer circle around the well point is another source variable that is important to get an estimate of the extent of change in the nitrate concentrations likely if the CRP acres in the county go back into corn production.

Generally nitrogen from fertilizer is already in the nitrate form and thereby leaches more easily. There is a positive correlation found between fertilizer nitrogen loadings and the ground water nitrate concentrations. Lichtenberg and Shapiro (1997) found corn production to be associated with higher nitrate levels because corn demands higher fertilizer input and extensive irrigation, which increases the rate at which nitrate leaches to the groundwater. For this study, nitrogen loadings variable, based on the acreage of land in each crop for each buffer circle was calculated by multiplying the number of acres in each crop with the representative nitrogen application rate for the crop type in the Olmsted County. This variable was used in an alternate specification (when land use variable was not used to avoid duplication).

3.2: Transport factors

This group of variables encompasses the factors that determine the amount of N that reaches the ground water from the point of use on land. I use two variables in this category, namely aquifer rank and presence of the confining unit, both of which are adopted from a study done by Khalid (2003) and are explained below.

The variable "Aquifer rank" refers to the vertical order of the aquifer position within the strategraphic column from the ground surface. The aquifer's rank indicates the number of overlying bedrock units. It is theorized that greater the aquifers rank the lower the nitrate concentration in that aquifer will be. The primary bedrock units that make up the strategraphic column in the Olmsted County area as shown in Olmsted County Geologic Atlas from top to bottom are:

Bedrock Name	**Code**
Maquoketa Formation	OMD
Stewartville Formation	OGS
Prosser Limestone	OGP
Cummingsville Formation	OGC
Decorah Shale, Platteville and Glenwood	ODCR
St. Peter Sandstone	OSTP
Prairie Du Chien Group	OPDC
Jordan Sandstone	CJDN

A scale of 1 to 9, from top to bottom, is used to vertically rank the position of each unit within this column. The typical ranks of St. Peter, Prarie du Chien and Jordan units are 6, 7, and 8 respectively (Figure 3), whereas the actual ranks vary from one place to another based on the number of the existing overlying bedrock units (Khalid, 2003).Aquifer rank grids were calculated based on the typical order of the aquifer in the strategraphic column (Figure 3) and the order of the first encountered bed rock (which equals the geology grid value).

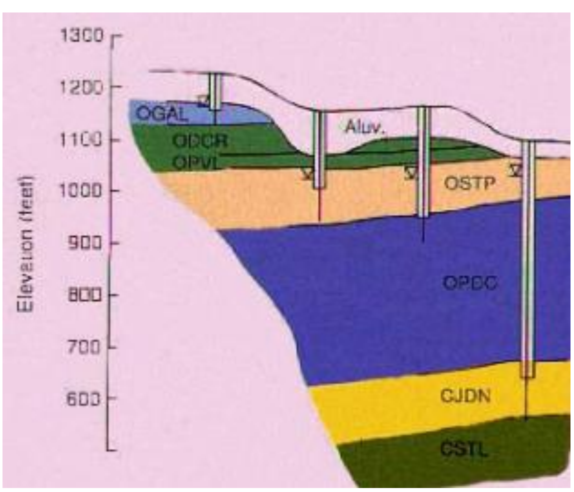
Aquifer rank grid = (the typical aquifer rank + 1) – (geology grid)

Aquifer rank for OSTP ranges from 1 to 6, for OPDC from 1 to 7, and for CJDN from 1 to 8.

Presence or absence of the Decorah Shale will be important in determining how much of the nitrogen used on the ground reaches the ground water. The definition of the "confinunit" variable is adopted from the study by Khalid (2003) as well. The Decorah-Platteville-Glenwood formations represent a confining unit that hydrogeologically separates the upper carbonate aquifer from the underlying St. Peter-Prairie du Chien-Jordan aquifer. The presence or absence of confining beds is one of the principal physical factors controlling water quality in Southeastern Minnesota. The assessed aquifers were assumed to be less susceptible to contamination where the overlying Decorah-Platteville-Glenwood confining unit is present. The typical rank of the confining unit in the stratigraphic column is five (Figure 3). The aquifer rank grid was consequently used to determine the presence and absence of the overlying confining unit. The confining unit is present if the aquifer rank is greater than the difference between the aquifer typical rank and the confining unit typical rank. Each of the three aquifer rank grids were accordingly reclassified into two grids based on presence and absence of the confining unit and by applying the relationship:

If aquifer rank grid > (Aquifer typical rank – 4) then the confining unit is present.

Figure 3:The setting of the three aquifers, Jordan sandstone (CJDN), Prairie du Chien formation (OPDC) and St. Peter sandstone (OSTP), and the Decorah-Platteville-Glenwood confining unit within the stratigraphic column (Figure source: Khalid, 2003).



3.3: Attenuation Factors

Once the nitrate reached the groundwater, attenuation factors like Well Depth will decide if the amount of nitrate present in the groundwater is likely to change. Well depth is frequently found to be a significant factor, inversely related to nitrate concentrations in wells, regardless of nitrate source (Lichtenberg and Shapiro, 1997). The aquifer volume is another variable that belongs in this category, however due to lack of data it could not be defined for this analysis. Well Depth is the single variable in the attenuation factors category that is used in this study.

Section 4 describes the data used for the analysis.

4. DATA

Water test data for private well nitrate concentrations along with land use data is acquired from the Olmsted County Planning Department. There were 148 observations in all that matched the selection criterion of the cropping year. From the total number of wells, 46 percent of wells had nitrate levels below the detection level, 39 percent had nitrate levels higher than the detection level but below the 4 mg/L level, while the percentage of wells falling between the intervals 4.1mg/L-10 mg/L and above 10 mg/L is 14 and 2 percent respectively. Maximum concentration in the sample was 12.1 mg/L. All the data for the explanatory variables comes from the Olmsted County Planning Department, Minnesota Geological Survey and Olmsted County Public Health Department.

Following table presents the descriptive statistics on the variables used in the analysis

Table 2: Descriptive Statistics

Descriptive Statistics				
Variable	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Nitrate	1.5601	2.6261	0.1	12.1
Confinunit	1	1	0	1
Depth	334.72	115.07	44	580
Rank	3.563	1.8512	1	7
Corn Acres	33.55914	30.45819	0	155.4309
Soybean Acres	26.70258	26.57671	0	135.2004
CRP Acres	6.04975	15.19091	0	112.4022

The following table presents the correlation matrix for the variables used in the analysis

Table 3: Correlation Coefficient Matrix

Pearson Correlation Coefficients							
	Nitrate	**Confinunit**	**DEPTH**	**rank**	**Corn**	**Soy**	**CRP**
Nitrate	1	-0.1216	-0.1971	-0.2321	-0.0673	-0.0497	-0.0147
Confinunit	-0.1216	1	0.0823	0.6177	0.0218	0.1772	-0.1833
DEPTH	-0.1971	0.0823	1	0.4046	0.1063	-0.0377	-0.0865
Rank	-0.2321	0.6177	0.4046	1	0.0518	0.0223	-0.116
Corn	-0.0673	0.0218	0.1063	0.0518	1	-0.4656	-0.388
Soy	-0.0497	0.1772	-0.0377	0.0223	-0.4656	1	-0.2426
CRP	-0.0147	-0.1833	-0.0865	-0.116	-0.388	-0.2426	1

5. RESULTS AND DISCUSSION

The results section is organized as follows: I begin with the results for the regression analysis and highlights the contribution of various determinants of ground water nitrate concentrations in drinking water wells in the Olmsted County. The regression results are then employed to model the two land use change scenarios. The change in nitrate concentrations as a result of changing land use practice is estimated. Finally based on the projections arrived at earlier, a raster map for the county is developed for each scenario to show the likelihood of pollution levels under each scenario and a cost estimate for each scenario is provided.

Table 4 provides the output of the two model specifications. We see that the nitrogen source variables are significant in both the model specifications. Among the transport variables, variable rank is significant for the exponential model specification. All the variables have the expected signs in both the model specification. The land use variables are significant in both the model specifications and have elasticity comparable to the similar values estimated in this literature. There is very strong evidence for increasing well nitrate concentrations in the presence of corn acres in the buffer circle of the well. The coefficients on soybean acres and CRP acres are negative in both model specifications as expected.

Presence of the confining unit does seem to have a negative relationship with the groundwater nitrate concentrations as expected, but the variable is not significant in both model specifications. One reason for the transportation variables to turn out insignificant in the model specifications could be that the transportation mechanism occurs on a larger scale than a buffer circle of 500 meters around a well point. Using the non nested hypothesis test it can be shown that the exponential model is a better fit for the data as compared to the linear model. The exponential model is therefore used for the land use change driven predictions for nitrate concentrations.

Table 4: Regression Model Results

Variable Name	Linear model	Exponential Model
Intercept	2.6958 (4.83***)	-0.1187 (2.29***)
Corn Acres	0.0282 (0.0121***)	0.0144 (0.0062***)
Soy Acres	-0.002 (0.0123**)	-0.02 (0.0058***)
CRP Acres	-0.015 (0.0157*)	-0.018 (0.0068**)
Depth	-0.0006 (0.0031)	-0.0002 (0.0015)
Rank	-0.0855 (0.3473)	-0.1282 (0.1728*)
Confinunit	-0.1687 (1.2015)	-0.3525 (0.5986)

Note that *** indicates significance at 1% level, * indicates significance at the 5% level and * indicates significance at the 10% level.

The following table presents the estimated elasticities of nitrate concentration with respect to the various explanatory variables. Elasticity provides a percentage change in the ground water nitrate concentrations as a result of one percent change in each of the respective explanatory variables. For the linear model elasticity is calculated as the product of the mean of the explanatory variable and its model coefficient, divided by mean nitrate concentration. For the exponential specification elasticity is calculated as the product of the mean of the explanatory variable and its model coefficient.

Table 5: Estimated Elasticities

Variable Name	Linear model	Exponential Model
CORN Acres	0.602782	0.483252
SOY Acres	-0.03402	-0.53405
CRP Acres	-0.0578	-0.1089
DEPTH	-0.12792	-0.06694
rank	-0.19403	-0.45677
Confinunit	-0.107452	-0.3525

The assumed land use scenarios are as follows: The first scenario is that land in soybean production is shifted into corn production; the second assumed land use scenario is that in addition to the soybean acres, the CRP acres too shift into corn production. Expected nitrate concentrations under the two assumed land use scenarios are calculated as follows: The soybean acres and the CRP acres along with the soybean acres are the variables that change in the two scenarios respectively. Using the regression model coefficients of the exponential model, predicted nitrate concentrations for the baseline scenario along with the two assumed scenarios are calculated. For each assumed land use scenario, the change in the predicted nitrate concentrations from the baseline scenario is calculated. This change is further employed to calculate the percentage change in the predicted nitrate concentrations by dividing the difference in the baseline and assumed land use related concentrations by baseline expected values. These percentage changes are then applied to the actual observed nitrate observation values to arrive at predicted nitrate concentrations under both land use scenarios.

Once the predicted nitrate concentrations were arrived at for both the land use scenarios, the data was imported into Arc-GIS to create nitrate value raster grids for each scenario using the interpolation techniques. Figure 4 and Figure 6 show the raster grid created for the Olmsted County using the interpolation technique of Kriging. Kriging is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points with z-values. Kriging is based on the regionalized variable theory that assumes that the spatial variation in the phenomenon represented by the z-values is statistically homogeneous throughout the surface (for example, the same pattern of variation can be observed at all locations on the surface).

The raster grids for both scenarios are employed to extract the number of domestic wells falling in each nitrate pollution category for each scenario. The county well index contains the relevant information for each type of well in the state of Minnesota. Only domestic wells were used for this analysis. Following table shows the number of domestic wells falling in each pollution category for each of the scenarios

Table 6: Number of Domestic Wells

Frequency of County wells	Scenario1	Scenario2
Less than 4mg/L	979	846
4 mg/L-10 Mg/L	279	393
Over 10 mg/L	143	151
-9999	72	72

This analysis uses a cost estimate provided by a study done by Lewandowski et al (2006).
The number of wells over 10 mg/L is multiplied by a yearly treatment cost of 94$ per well to arrive at the total cost for each scenario. The total yearly cost for the domestic well owners in the Olmsted County under the two scenarios is $ 13442 and $ 14194 respectively. The cost is higher if we assume every well over 4 mg/L level is being treated. The argument for choosing this threshold value is that negative health effects of ground water nitrate levels are visible even at this level (Nolan& Hill,2006). Thus under this assumption the annual cost for domestic well treatments in Olmsted County for the two assumed scenarios are $39668 and $51136 respectively.

We can see from the raster grids of the predicted values for both the scenarios that there seem to be pollution hotspots appearing in the north eastern and south eastern part of the county. This area would need special attention in guiding the land use practices so that the pollution situation can be controlled.

Figure 4: Model Prediction for Scenario 1

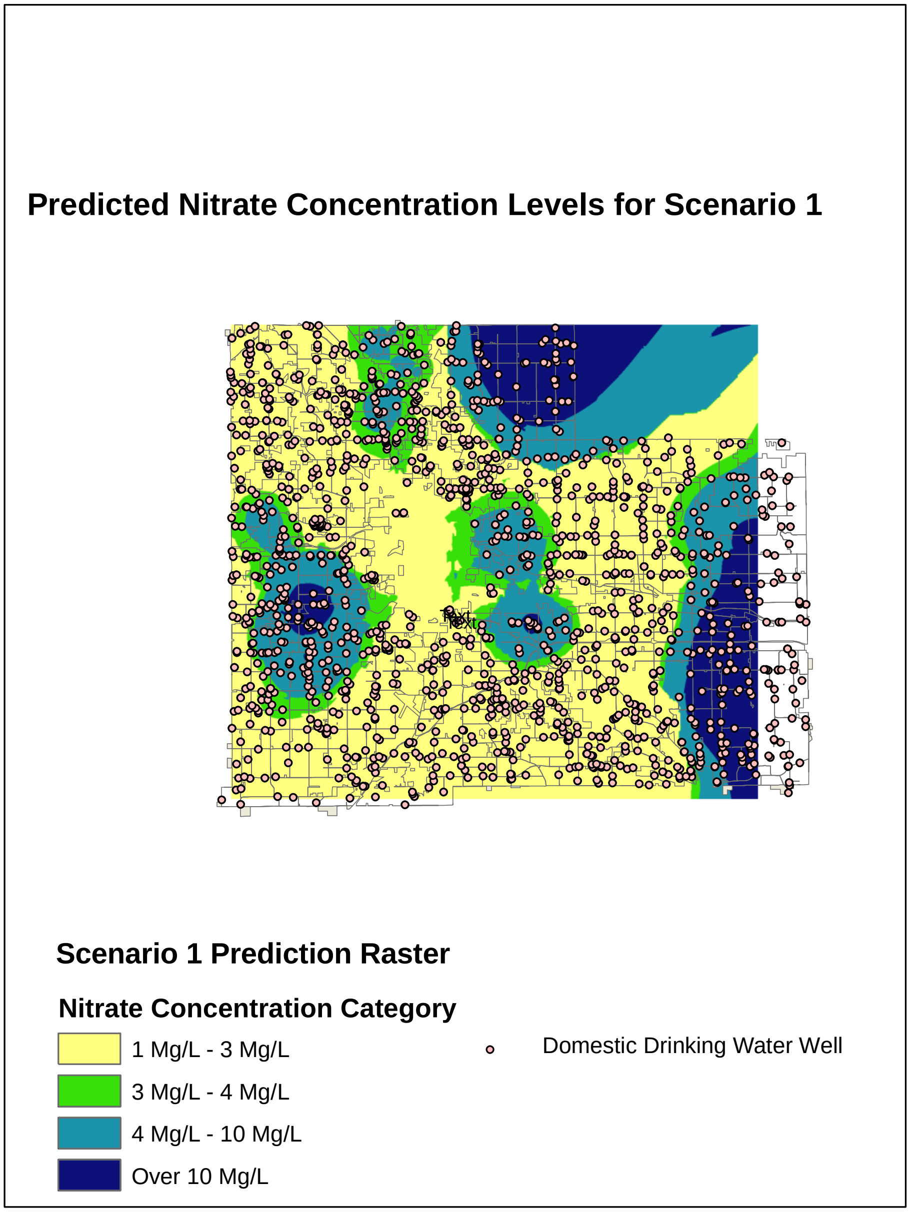
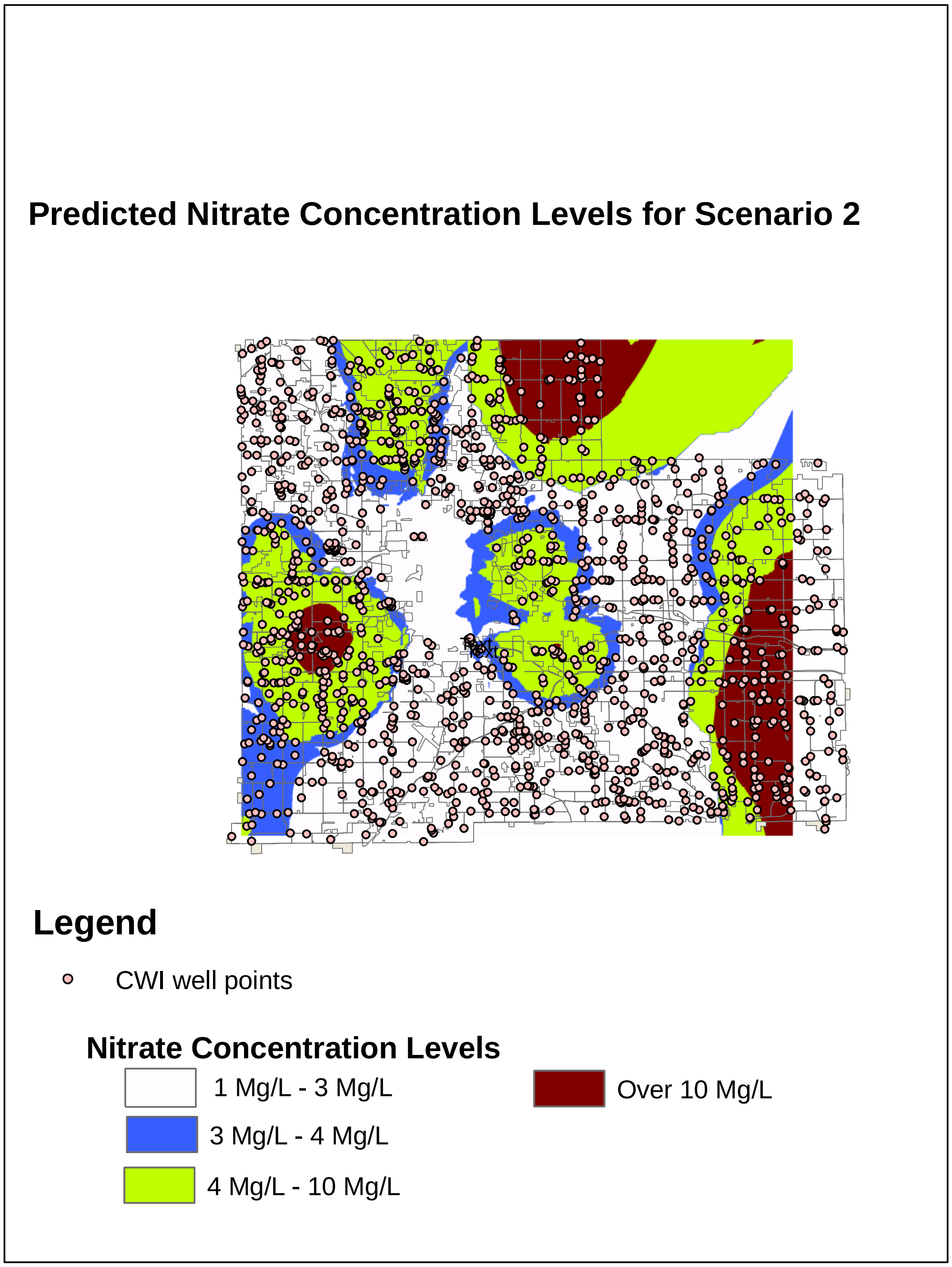


Figure 5: Model Prediction for Scenario 2



This paper developed an empirical relationship between ground water nitrate concentrations and variables influencing the nitrate concentrations for the Olmsted County; it utilized the relationship developed to predict the changes in the nature of externality as a result of the assumed land use scenarios. This is an externality on a local scale where the costs of the externality are also borne by local people. It may be internalized if farmers responsible for changing the land use practice in favor of corn production are also the ones who own the domestic wells with increasing nitrate concentrations. But usually that is not the case. The analysis provides an estimate for a local externality which will help local resource planners in policy design.

Even though the cost estimate provided by this study is a moderate one, it still is a cost. It should also be noted that this analysis leaves out costs of cleaning up the nitrates from public water system wells, which could amount to a significant annual cost for the county as more people depend on public water systems than on domestic wells.

Even though the variable "confinunit" turned out to be insignificant in this analysis, it brings out an important insight for land use planning. The Decorah Shale confining unit along with vegetation cover provides important denitrification services. The areas of the county where this confining unit is present should be guarded against being transformed into a land use that will affect the services provided by the Decorah Shale unit.

Nitrogen loading from septic tank systems in the urban areas and from concentrated animal farms has been shown to be a significant predictor of ground water nitrate concentrations. This analysis does not include these two other important determinants of ground water nitrate concentrations. Future study should add the two factors in the nitrogen source category

Finally the possible impacts of large scale biofuel production (using agricultural products like corn) on ground and surface water resources is a research area that needs further attention. The research presented here hopes to contribute to this cause.

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