

# ASSESSING NITROGEN CONTAMINATION POTENTIAL VIA REMOTE SENSING

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## Biographical Sketch of Authors

Bruce Seelig is a soil scientist that coordinates the water quality educational program for North Dakota State University. He has served in this capacity for nearly 13 years. Bruce's professional interests involve the application of soil survey information to resource assessment. Larry Beard is currently Head of the Economics Section, USDA, National Agricultural Statistics Service (NASS) in Washington, D.C., and serves as the Agency representative to USDA's Working Group on Water Quality. Larry has served in a broad capacity with NASS throughout his 26 year career. As State Director of the North Dakota Agricultural Statistics Service, from 1994-2001, Larry positioned the office to lead the development of the first ever statewide Cropland Data Layer. Dath Mita is a GIS/Remote Sensing Specialist with North Dakota State University (NDSU) Extension Service and North Dakota Agricultural Statistics Service. He is the project leader for Satellite Imagery Applications to Water Quality Project in North Dakota.

## Abstract

A remote sensing-based cropland layer (CDL) was included in a group of natural and anthropogenic factors to assess the potential for nitrogen contamination of groundwater in Dickey County, North Dakota. The CDL, produced by the Spatial Analysis Research Section, USDA, NASS and the Cooperative Extension Service, NDSU, was used to determine areas of cultivation, corn or potatoes, and summer fallow. ARCVIEW was used to import the CDL image of North Dakota for 1998. The image was converted to a grid and clipped to the appropriate area of assessment.

Compared to natural factors, many of the anthropogenic factors are subject to considerable change over time. Consequently, land use information from one season was modified using the ARCVIEW neighborhood statistics function to provide an estimate of land use probability. Mean values were calculated for areas of ½ mile radius with respect to cultivation, potatoes or corn, and summer fallow. These values were used to classify areas as low, intermediate, or high probability for these types of land use. The three land use probability layers were used in combination with other factors to determine groundwater sensitivity to nitrogen contamination.

## Methods

Factors that affect the fate of N in the environment are many and their interrelationships complex. Several attempts have been made to model the processes through which these factors operate to predict N translocation under cropped systems (Geleta et al., 1994; Jabro et al., 1995; Han et al., 1995; Madramootoo et al., 1995; Van der Ploeg et al., 1995; Yiridoe et al., 1997; Pang et al., 1998), natural systems (Creed et al., 1996), or due to certain physical characteristics (Li and Ghodrati, 1995). Some of these models have been combined to estimate groundwater vulnerability over large regions (Khakural and Robert, 1993; Shaffer and Wylie, 1993; Wylie, et al., 1995).

Review of studies related to N and groundwater reveal complexity that is unique to a specific site, but also some predictable patterns with respect to certain factors. In general, groundwater contamination is controlled by: 1) contaminant mobility; 2) contaminant availability; and 3) accessibility of the water resource. Research shows that some factors consistently exert significant control over the processes that affect mobility, availability, and accessibility. Combinations of these factors have been used to develop several different types of groundwater

assessment systems (Aller et al., 1985; Trojan and Perry, 1988; Cates and Madison, 1991; Pettyjohn et al., 1991; Seelig, 1994).

**Table 1. Natural factors that contribute to groundwater vulnerability to nitrogen.**

Natural Factors	Criteria
Soil aeration	Soils that are well, somewhat excessively, and excessively drained
Soil texture	Soils that are classified with a sandy, sandy-skeletal, or fragmental USDA family particle size
Depth to aquifer	Less than 50 feet from the surface to the top of the saturated zone in the aquifer
Hydrologic recharge area	Greater than 30 inches to the CaCO <sub>3</sub> in the soil profile

**Table 2. Anthropogenic factors that contribute to increased availability of nitrogen.**

Anthropogenic factors	Criteria
Concentrated human activity	Areas within city limits, or within boundaries of business or inhabitation outside of city limits
Cultivated land	Predominant land use requires manipulation of soil surface for the purpose of growing crops
Crops	Rotations with corn, potatoes, and vegetable crops
Summer fallow	Rotations that include idle periods for the purpose of storing water and nitrogen in the soil
Irrigation	Areas that receive water applications in addition to that received from natural rainfall

The following example demonstrates how the factors that influence groundwater sensitivity to nitrogen contamination can be combined to arrive at an overall conclusion for a given area. Dickey County, ND was selected as the area of the foregoing analysis. One of the critical requirements for each factor was availability or accessibility of data on a statewide basis. Remote sensing-based digital imagery of land use and crop types (USDA/NASS/Research Division, 2001) is available from the U.S. Department of Agriculture's (USDA) North Dakota Agricultural Statistics Service (Refer to the poster presentation "USDA/NASS Cropland Data Layer"). Data can be extracted from these images that discriminate between areas of **cultivation, various crops, and summer fallow**.

The cropland data layer is one of the first set of publicly releasable crop specific digital data layers, suitable for use in geographic information systems (GIS) applications. Limitations of this data are declared. Currently, the Cropland Data Layer Program (CDLP) encompasses the states of Arkansas, Illinois, Indiana, Iowa, Mississippi, Nebraska, and North Dakota. The focus of CDLP is producing both digital categorized geo-referenced output products using imagery from the Thematic Mapper (TM) instrument on the Landsat 5 and the Enhanced Thematic Mapper (ETM+) on the Landsat 7 satellite. Extensive and annual ground truth data are captured and utilized to provide the most current and accurate delineation of land use change and crop-type specificity. The CDLP represents a cooperative venture between three USDA Agencies (headquarters units of NASS, the Foreign Agriculture Service, and the Farm Service Agency) plus in-state agreements between NASS State Statistical Offices and their respective state partners.

The data required to do a groundwater assessment for sensitivity to nitrogen contamination is available for any area of North Dakota. However, manipulation of the data, particularly on extensive areas, is tremendously cumbersome and time-consuming if done without the aid of a computer. In the following example the GIS

computer program ARC VIEW 3.1 (ESRI, 1998) was used to process the Dickey County data for assessment. A PC with 233 MHz microprocessor, 64 MB RAM, and 2 GB hard drive was used to do the analysis.

The combination of factors listed in Tables 1 and 2 can be accomplished in many ways. In other words, factors may be weighted to account for their importance or dominance with respect to the natural processes that affect water and solute flow. Assignment of factor weights should be done with extreme care and should be supported by a significant amount of evidence, preferably experimental results. In general, the following method does not assign weights to the factors due to the lack of scientific evidence that would validate such assignment. Instead, groundwater sensitivity is related to the intensity in which each factor manifests itself and the additive intensity of all the factors together.

The location of glacial and alluvial aquifers in Dickey County, ND was determined by referring to the County Groundwater Studies Report published by the North Dakota Water Commission (NDWC). Aquifer sensitivity was found by combining the results of the vulnerability determination with the assessment of the anthropogenic factors. The number of sensitivity categories was based on the desire to demonstrate a smooth continuum of sensitivity and also display areas with distinctly different management requirements.

## Results and Discussion

### Analysis of the Natural Factors (Vulnerability)

A project for analysis of Dickey County using the ARC VIEW program was opened. Soils data from the NRCS Soil Survey Geographic (SSURGO) database were extracted for Dickey County. Tabular data is a component of the digital soil survey and occurs in several tables. For the analysis of Dickey County, soil factors were assessed for all components of each mapping unit. In other words, soil components of less extent carry the same importance as those of greater extent with respect to groundwater sensitivity assessment.

After the appropriate tables were linked, ARC VIEW was used to query the tables for the data that represented vulnerable conditions. For the **soil aeration** factor, all soils with drainage classes of excessively, somewhat excessively, and well drained were selected for Dickey County. For the **soil texture** factor, all soils with single particle size classes of sandy, sandy skeletal, and fragmental and soils with dual particle size classes with the lower material being one of these three classes were selected for Dickey County. For the **hydrologic recharge** factor, the depth to CaCO<sub>3</sub> was determined from the typical pedon description for each soil and added to the table. All soils with typical depths to CaCO<sub>3</sub> >30 inches were selected for Dickey County.

The **depth to top of the saturated aquifer** was determined using data from the NDWC for Dickey County. Well location and depth to saturation were available in digital format. Depth to the top of the aquifer was extracted from the well logs in the Dickey County groundwater resources report and added to the digital data table. ARC VIEW was used to convert the digital data set with point locations to a grid and then to interpolate both sets of depth values. Both interpolated grids were reclassified into classes of 0-50 ft and >50 ft. A function in ARC VIEW called map calculator was used to then add the two grids which resulted in areas where both the aquifer depth and depth to saturation were 0-50 ft.

The data files for **soil aeration**, **soil texture**, and **hydrologic recharge** were converted to grid files within the ARC VIEW project and added to the **depth to top of the saturated aquifer** using the map calculator. The result shows vulnerability of groundwater in Dickey County as five classes, **High**, **High Intermediate**, **Intermediate**, **Low Intermediate**, and **Low**.

### Analysis of the Anthropogenic Factors

ARC VIEW was used to import an image of land use in North Dakota for 1998 produced by the Spatial Analysis Research Section, USDA, NASS, RD. The image was converted to a grid and clipped using the Dickey County outline provided by the North Dakota Department of Transportation (NDDOT). Compared to the natural factors, many of the anthropogenic factors are subject to considerable change over time. This is particularly true for cropping and other land use patterns. Consequently, land use information from one season was modified using the ARC VIEW neighborhood statistics function to provide an estimate of land use probability. Mean values were calculated for areas of 1/2 mile radius for summer fallow, cultivation, and potatoes or corn. These values were then used to classify areas in Dickey County as low, intermediate, or high probability for these types of land use.

ARC VIEW was also used to import data from the NDDOT and NDWC to create grid coverages for areas of concentrated human activity and probability of irrigation.

### Combining Natural and Anthropogenic Factor Analyses

The ARC VIEW map calculator was used to sum the results of the vulnerability analysis and the anthropogenic potential analysis to determine groundwater sensitivity to nitrogen contamination. Digital data outlining aquifer boundaries in Dickey County obtained from the NDWC were used to clip those areas that overlay the aquifers to determine aquifer sensitivity.

Studying the aquifer sensitivity map for Dickey County reveals that the areas of greatest concern are in the eastern part of the county. Using the ARC VIEW zoom function, aquifer sensitivity of smaller areas can be determined, such as near the town of Oakes, ND, where there is relatively high potential for aquifer contamination. By zooming to an even smaller area, such as the northwest (NW) quarter of section 27 about 1 mile southeast of Oakes, the factors that contribute to the sensitivity in specific fields can be determined. The largest area has High Intermediate sensitivity and the contributing vulnerability factors are a shallow depth to water and groundwater recharge. Cultivation is shown to be the primary anthropogenic factor contributing to area of High Intermediate sensitivity.

If the NW quarter of section 27 is managed as one unit, groundwater protection efforts should be based on the factors of greatest areal extent as outlined above. Reduction in aquifer contamination potential can be accomplished by using management methods listed in NDSU Extension Report ER 62 (Seelig, 2000). Soil testing and proper fertilizer management would be the primary recommendations for aquifer protection in this area. In contrast, the northeast (NE) quarter of section 27 has predominantly High aquifer sensitivity. This area assumes greater importance for aquifer protection than the NW quarter due to greater sensitivity. Greater probability of corn or potatoes grown in this area is one of the factors that contributes to the higher sensitivity. Compared to the NW quarter, management priorities would also be different. The primary recommendation would be strict avoidance of fertilizer applications in the fall. Split applications of nitrogen fertilizer would be recommended along with use of a nitrification inhibitor or a slow-release product. The use of nitrogen and water scavenging crops in the rotation also plays a more important role in the NE quarter due to the likelihood of corn and/or potatoes in the rotation.

## Conclusions

Land use information obtained from remotely sensed satellite imagery is important when integrated with other factors known to affect nitrogen and water movement. Determination of aquifer sensitivity is enhanced by characterization of the areal extent of land use practices. Management recommendations based on aquifer sensitivity determinations that consider probability of critical land use are more likely to effectively reduce the potential for nitrogen contamination.

The information and recommendations provided from the foregoing analysis must be tempered with reality. The recommendations are quite general; each site will require more precise recommendations based on agronomic and economic principles that are beyond the scope of this study. It must also be recognized that categories represented in this analysis rely on a set of assumptions and probabilities that are subject to error. Every analysis should be rectified with actual conditions at the site before recommendations are implemented.

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