REGIONAL VARIABILITY OF ON-GROUND NITROGEN LOADING DUE TO MULTIPLE LAND USES IN AGRICULTURE-DOMINATED WATERSHEDS

M. N. Almasri* and J. J. Kaluarachchi**

*Utah Water Research Laboratory and Department of Civil and Environmental Engineering, Utah State University, Logan, Utah 84322-8200, USA.(e-mail : *mnalmasri@cc.usu.edu, **jkalu@cc.usu.edu)*

ABSTRACT
Contamination of ground water resources from nitrate is a common occurrence in most parts of the world. The main source of nitrate to ground water is agriculture-based land use activities such as the use of fertilizer in farmlands and dairy farming operations. In order to understand the actual nitrate loading to ground water, the spatial and temporal distributions of on-ground nitrogen loadings from various land use and land use practices should be understood and quantified. These loadings can then be used in a soil nitrogen dynamics model to compute the net nitrate loading to ground water. In a large watershed, the assessment of on-ground nitrogen loading due to multiple land use activities can be complex; hence, the use of a geographic information system can be of great help and provide flexibility in the analysis. In this work, the extended area of the Sumas-Blaine aquifer in the State of Washington, USA, is used to demonstrate the spatial and temporal variability of nitrogen loading at a regional scale. Long-term data from this watershed will be considered and the applicability of the GIS-based analysis is presented. The results showed that manure and inorganic fertilizers contribute more than 87% of the total on-ground nitrogen loading in the study area.

Keywords: Agriculture; nitrates; land use; fertilizer; GIS; dairy; ground water

INTRODUCTION
Aquifers are important sources of drinking water in the US and elsewhere, and these sources are vulnerable to contamination (Solley et al., 1993). Nitrate (NO_3) is the most common pollutant found in shallow aquifers due to both point and non-point sources. Many studies in the US have shown that agricultural activities are the main source of elevated nitrate concentrations in ground water (Hudak, 2000; Harter et al., 2002). Elevated nitrate concentrations in drinking water are linked to health problems such as *methemoglobinemia* in infants (Wolfe and Patz, 2002). As such, the US Environmental Protection Agency (US EPA) has established a maximum contaminant level (MCL) of 10 mg/L as NO_3-N (US EPA, 2000).

Agricultural practices can result in non-point source pollution of ground water. Non-point sources of nitrogen (N) from agricultural activities include fertilizers, manure application, and leguminous crops. Additionally, non-point sources of nitrogen involve precipitation, irrigation with ground water containing nitrogen, and dry deposition (Cox and Kahle, 1999). The major point sources include septic tanks and dairy lagoons. Many studies have shown high concentrations of nitrate in areas with septic tanks and lagoons (Erickson, 1992; MacQuarrie et al., 2001). Regional assessment of ground water quality is complicated by the fact that nitrogen sources are spatially distributed. The identification of areas that receive heavy nitrogen loadings from point and non-point sources is important for land-use planners and environmental regulators. Such areas can pollute surface water bodies via runoff. Additionally, accurate estimates of nitrate leaching to ground water can be obtained by accounting for the spatial distributions of nitrogen sources and loadings.

Degradation of ground water quality, mainly from nitrate, is of great concern for the residents of Whatcom County, Washington State. The Sumas-Blaine aquifer (see Figures 1 and 2) is the principal surficial unconfined aquifer in Whatcom County located in the northwest corner of Washington State and is used for domestic, agricultural, and industrial purposes. Most of the soils in the area are categorized as well-drained, and the water table is shallow (Tooley and Erickson, 1996). The study area covers approximately 376 square miles and exceeds the Sumas-Blaine aquifer boundaries and includes parts of Canada. Since the ground water flow is from north to south, the extended area accounts for the substantial dairy and poultry manure application in berry plantations located on the Canadian side that has a major influence on ground water quality in the south.

Due to the intensive agricultural activities in the area (see Figure 2), the ground water quality in the aquifer has been continuously degrading and nitrate concentration is increasing (Kaluarachchi et al., 2002). The aquifer readily interacts with surface water and serves as an important source of summer streamflows for different rivers and creeks in the area. The influence of nitrate concentration in the baseflow is of great concern to regulators when dealing with surface water quality and corresponding impacts on valuable fish habitat.

This paper presents a simple, yet efficient, approach for estimating the spatial and temporal distribution of on-ground nitrogen loading from a large watershed in Washington State. The approach uses the National Land Cover Database (NLCD) grid of the US Geological Survey to determine the sources of nitrogen in the watershed based on the land use distribution. A geographic information system (GIS) is used to assess the spatial and temporal variability of nitrogen data

(ESRI, 1999). The on-ground nitrogen loading distribution can then be integrated with a soil nitrogen model to determine the nitrate leaching to ground water, both spatially and seasonally.

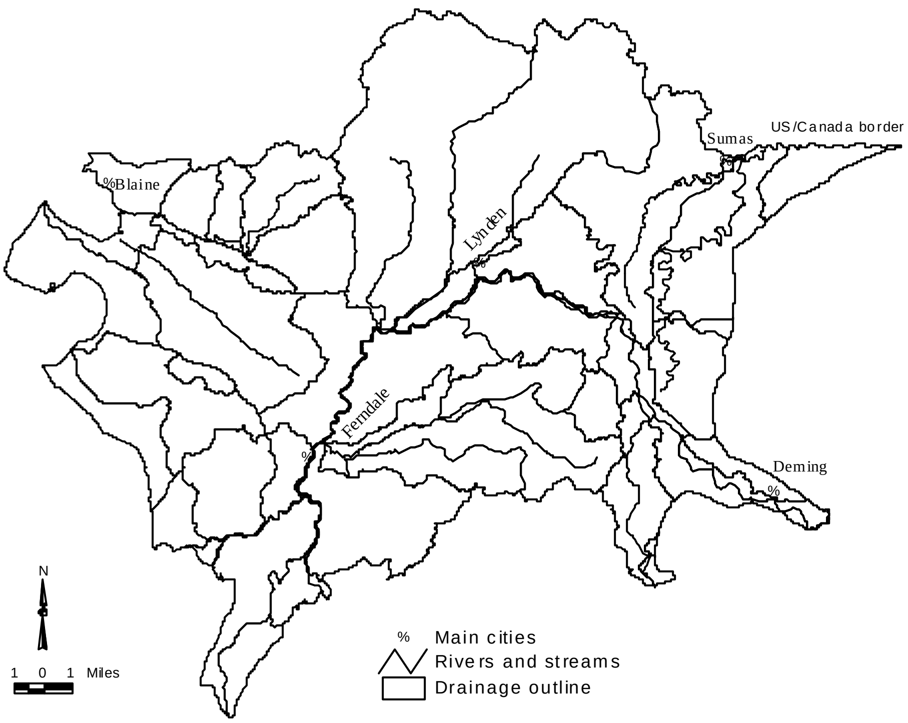

Figure 1. Physical layout of the study area showing the drainages, major surface water pathways, and major cities.

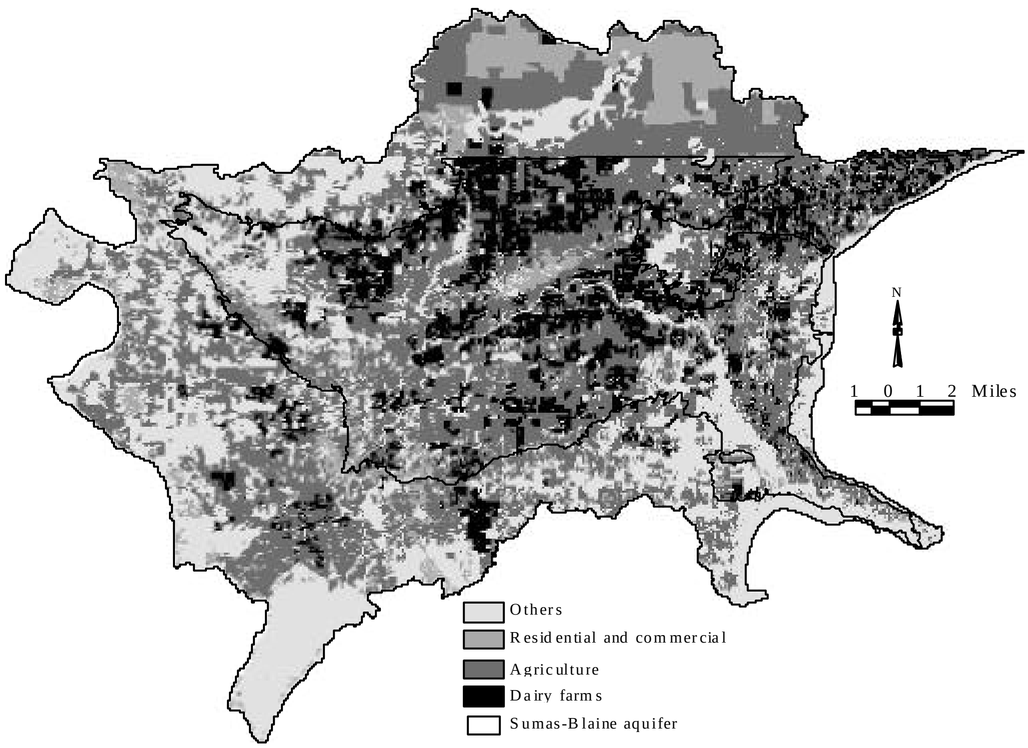

Figure 2. The land use pattern of the study area.

Table 3. Contribution of different nitrogen sources for each NLCD class.

NLCD class	Dairy manure	Wet deposition	Dry deposition (regional)	Dry deposition (dairy)	Irrigation	Fertilizer	Lawns	Legumes
Low Intensity Residential								
High Intensity Residential								
Commercial/Industrial/Transportation								
Bare Rock/Sand/Clay								
Quarries/Strip Mines/Gravel Pits								
Transitional								
Deciduous Forest								
Evergreen Forest								
Mixed Forest								
Shrubland								
Orchards/Vineyards/Other								
Grasslands/Herbaceous								
Pasture/Hay								
Row Crops								
Small Grains								
Fallow								
Urban/Recreational/Grasses								
Dairy Farms								
Woody Wetlands								
Emergent Herbaceous Wetlands								

APPROACH

The NLCD grid provides the land cover distribution across 21 land use classes and covers the entire US. This NLCD grid can be utilized to designate the spatial distribution of on-ground N loadings. This distribution is due to the different nitrogen sources contributing to a given land use cover. For example, the land use class of *dairy farm* receives nitrogen from manure application, wet deposition, regional and dairy dry deposition, and from nitrogen-contaminated water used in irrigation. Table 3 shows the different nitrogen sources that concurrently contribute to each NLCD class. In addition to the spatial distribution of on-ground nitrogen, there is also a temporal variability due to different nitrogen source applications at different periods in the year. This transient variability is due to the variability in the inorganic fertilizer application, time of animal grazing, precipitation, irrigation, and dairy farm lagoon operations. The main sources of nitrogen in the study area are dairy manure, nitrogen-rich fertilizers, septic tanks, dairy lagoons, wet and dry deposition, lawns and gardens, irrigation recharge, and legumes. The analysis is performed at a temporal resolution of one-month and at drainage-wide spatial resolution. There are 39 drainages representing the study area (see Figure 1).

ON-GROUND NITROGEN LOADING ESTIMATES

Manure application to agricultural fields has been identified as a significant source of nitrate in the ground water of the study area (Cox and Kahle, 1999) where there are approximately 53,000 milking cows; 7,500 dry cows; 12,800 heifers; and 7,600 calves. The ranges of annual production of nitrogen per head from milking cows, dry cows, heifers, and calves are 165-250, 120-180, 60-90, and 74-112 lbs, respectively (Kaluarachchi and Almasri, 2003). Using the animal distribution for the dairy class category and the individual nitrogen production rates, it is possible to compute the total nitrogen from dairy manure. Since the original NLCD does not include the *dairy farm* category, a dairy farm GIS polygon shapefile was merged with the NLCD grid. Poultry manure is extensively applied in the Canadian portion of the study area. Estimates of this poultry manure application are obtained from Brisbin (1995). Typically, dairy lagoons tend to leak if not properly sealed. Dairy farm lagoons are assumed to be empty from April to October and refilled in the remaining months. Cox and Kahle (1999) reported that seepage rates of nitrogen from lagoons vary from less than 0.1 up to 5 mm/day with an average ammonium (NH_4-N) concentration of 840 mg/L. The average surface area of dairy lagoons in the study area is 30,000 square feet. The average yearly nitrogen leaching from lagoons is then calculated and uniformly distributed throughout the months of operation. Since dairy lagoons are treated as point sources of nitrogen, a GIS point shapefile indicating dairy lagoon locations was used in the calculations.

The information related to fertilizer application for major crops in the study area was used to calculate the nitrogen loading due to inorganic fertilizers. The total nitrogen applied per crop per drainage was obtained by multiplying the fertilizer application rate with the actual fertilized area for a given crop. This amount of nitrogen was then distributed uniformly over the agricultural NLCD classes as shown in Table 3. Morton et al. (1988) reported that the annual lawn fertilizer application rate varies from 110 to 260 lbs/acre. In general, lawn fertilizers are applied in the summer and fall. Nitrogen loading from lawn fertilizers is calculated by multiplying the application rate with the corresponding areas of the NLCD classes shown in Table 3. Atmospheric deposition of nitrogen corresponds to dissolved nitrogen in precipitation and dry deposition (Kaluarachchi and Almasri, 2003). The average nitrogen concentration in rainfall in western Washington is 0.26 mg/L (Cox and Kahle, 1999). The monthly nitrogen loading from precipitation is calculated by multiplying this concentration with the monthly precipitation volume of each drainage. Dry deposition of nitrogen includes particulate fallout and sorption of gaseous materials. The regional annual nitrogen deposition for western Washington is about 1 lb/acre. The annual rate of dry redeposition of nitrogen volatilized from manure is 15 lbs/acre (Cox and Kahle, 1999). The total nitrogen loading from dry depositions equals the deposition rate multiplied by the corresponding areas of the NLCD classes as shown in Table 3.

Nitrogen addition to the subsurface from irrigation water can vary significantly from site to site depending on the quantity of water applied and the nitrogen content in water (Kaluarachchi and Almasri, 2003). The monthly mean concentrations of nitrate, ammonium, and organic-N of irrigation water in each drainage were estimated from the database compiled by Kaluarachchi et al. (2002). The concentrations are then multiplied by the monthly irrigation volume, assuming that 60% of agricultural use of ground water is for irrigation. The nitrogen loading computed from this method was assigned to the relevant land use classes given in Table 3. The nitrogen loading from septic systems was assumed to be 10 lbs per capita per year (Cox and Kahle, 1999). Similar to dairy farm lagoons, septic tanks are treated as point sources of nitrogen. A GIS point shapefile of septic system locations and the corresponding number of bedroom units served was used. The total number of septic tanks in the study area is 11,619. The total number of bedrooms served by septic tanks is approximately 26,400. It was assumed that a bedroom serves one person. Leguminous plants are common in the study area such as clover (Cox and Kahle, 1999). Cox and Kahle (1999) reported an annual contribution of 5 lbs/acre of NO_3-N from legumes for the study area and this nitrogen loading was assigned to the *pasture/hay* class as shown in Table 3.

The on-ground nitrogen loadings were computed for 39 drainages encompassing the study area, 20 land use classes from the NLCD of the study area, and over a 12-month transient variability. These different input conditions produce a total of 9,360 values of on-ground nitrogen loading.

RESULTS AND DISCUSSION

Table 4 illustrates the annual on-ground nitrogen loading from point and non-point sources of the study area along with the corresponding percentages of contribution. In Table 4, atmospheric deposition includes wet and dry depositions while the fertilizer loading includes the agricultural and lawn applications.

Table 4. The annual on-ground nitrogen loadings from different sources.

Non-Point Source	N loading ($lbs\text{-}acre^{-1}$)	Area (acres)	% of Total	N constituents (lbs)		
				NO_3-N	NH_4-N	Organic-N
Manure	356.1	41,252	66%	146,917	2,350,674	12,194,121
Fertilizers	73.2	63,196	21%	234,331	4,394,435	0
Atmospheric deposition	7.3	236,196	8%	1,172,977	548,431	0
Legumes	5.0	85,604	2%	428,020	0	0
Irrigation	1.6	106,298	1%	160,750	723	9,068
Point Source	**($lbs\text{-}unit^{-1}$)**	**Units**	**%**	**NO_3-N**	**NH_4-N**	**Organic-N**
Septic systems	22.8	11,619	1%	492	264,035	0
Dairy lagoons	1,900	190	2%	0	360,960	0

It is clear that manure is the main source of nitrogen in the study area, followed by fertilizer and atmospheric deposition. The total annual net nitrogen loading from manure exceeds 14.7 million lbs or 66% of the total nitrogen loading. Fertilizers are the second largest contributor with 4.6 million lbs of nitrogen or 21%. Point sources of nitrogen contribute an annual total of 1 million lbs of nitrogen to the study area. Although this contribution is about 3% of the total loading, septic tanks and dairy lagoons have significant local effects. Table 4 shows the nitrogen constituents of each source based on the work of Kaluarachchi and Almasri (2003). The majority of nitrogen from manure is in organic form that can eventually transform to nitrate from soil mineralization and nitrification. It is worthwhile to note that although dairy manure is the main nitrogen source in the study area, atmospheric deposition contributes eight-fold more nitrate than manure. Likewise, irrigation, which provides 1% of the total nitrogen, contributes considerable amounts of nitrate compared to manure and fertilizers.

Figure 3 depicts the monthly distribution of total on-ground nitrogen loading for the study area. As seen from Figure 3, the high on-ground nitrogen loadings are in the early spring to the middle of summer and are relatively low during the other months.

Throughout the year, manure loading is the maximum contributor to the total on-ground nitrogen loading except for April where fertilizer application is the maximum. Manure loading is high during the period of April to September since manure is mostly applied in this period and the lagoons are emptied. Fertilizer loading is high during April, May, and June due to the intense application over berries, hay, field corn, pasture, and grain fields. Figure 4 depicts the annual on-ground nitrogen loading for selected NLCD classes. Apparently, the *dairy farm* class receives the highest on-ground nitrogen loading followed by the *pasture/hay* class. Residential NLCD classes receive high nitrogen loadings due to the intense application of inorganic fertilizer on lawns. Finally, Figure 5 shows the areal distribution of total annual on-ground nitrogen loading across the study area. The figure shows that areas with high on-ground nitrogen loading are strongly correlated with areas of dairy farming and general agriculture.

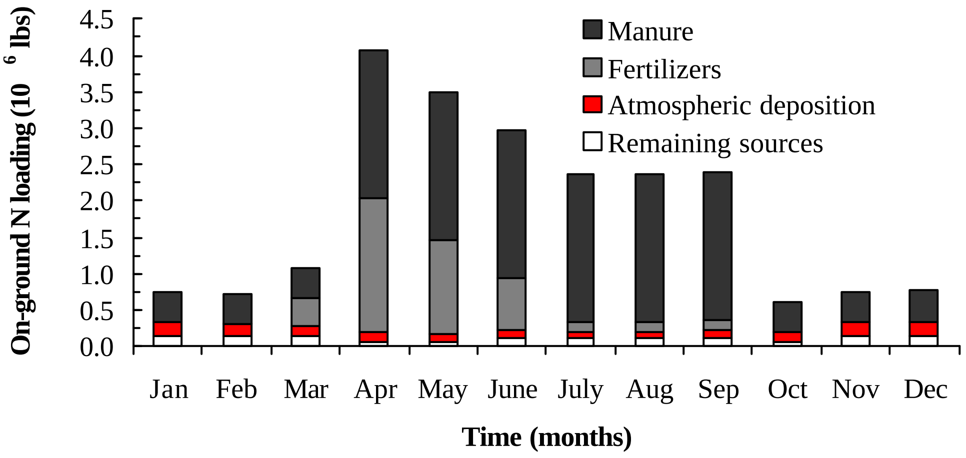

Figure 3. Monthly on-ground nitrogen loadings from different sources for the study area.

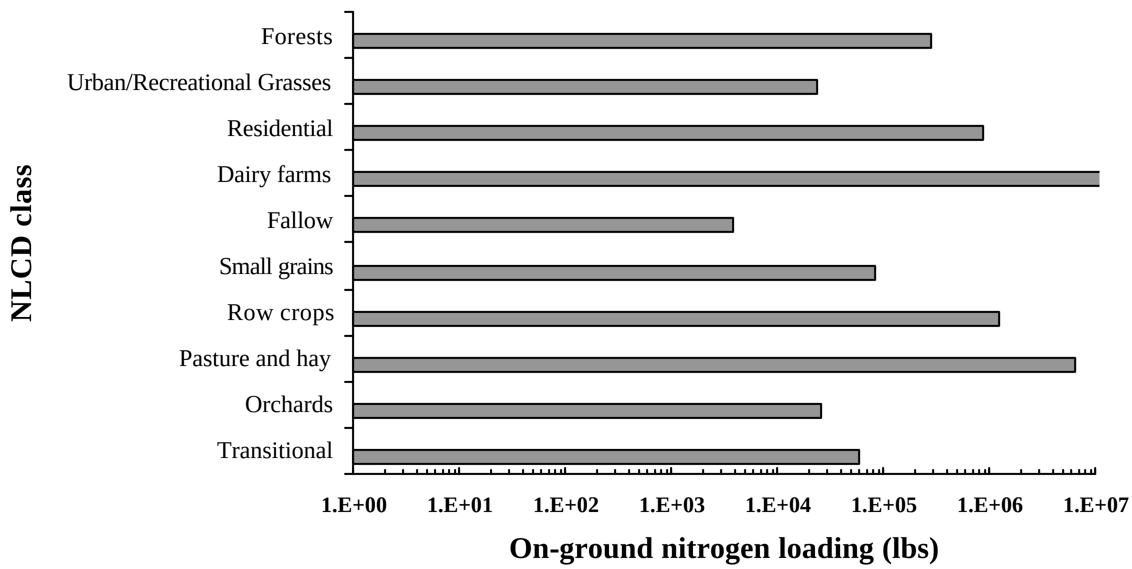

Figure 4. Annual on-ground nitrogen loading for different NLCD classes.

CONCLUSIONS

Although ground water pollution due to nitrogen is a widely studied problem, there is a need to develop improved modeling approaches to obtain a better insight to the physical problem; for example, better evaluation of the on-ground nitrogen loading distribution such that this information can be carried forward to a soil nitrogen model to predict the nitrate leaching to ground water. The use of high resolution on-ground nitrogen loading requires improved spatial analysis techniques such as GIS. One distinctive advantage of using GIS techniques is the ability to handle large databases and information streams. In this work, a GIS-based framework was proposed for a large watershed of 376 square miles in Washington State. The framework considers data of high-resolution land use practices to compute the on-ground nitrogen loading. The framework accounts for both point and non-point sources of nitrogen across 20 different land use classes and the calculations were performed at monthly intervals. This temporal resolution provided detailed information related to various land use practices; for example, fertilizer applications or dairy and poultry manure production varies by the season. Nitrogen sources considered here include inorganic fertilizers, dairy industries, atmospheric deposition, legumes, lawns, dairy lagoons, and septic tanks. The following conclusions were made based on the results of this work;

1. Manure is the main source of nitrogen in the study area, followed by fertilizers. Nevertheless, atmospheric deposition seems to be a significant source of nitrogen loading.

2. Point sources such as dairy lagoons and septic tanks contribute around 3% of the total nitrogen. Dairy lagoons have a larger nitrogen contribution than septic tank on a unit basis. Yet, the large septic tank density in the study area provides a significant source of nitrogen to the subsurface.
3. Although not shown here, the spatial distribution of on-ground nitrogen loading and nitrate leaching are correlated. High nitrate leaching is from dairy farms and agricultural areas. The difference between the on-ground nitrogen loading and nitrate leaching is substantial and indicate a buildup of nitrogen in the soil.
4. Possible future intervention of protective alternatives to minimize nitrate occurrences in the ground water of the study area should be directed mainly to areas where manure and fertilizer are applied.

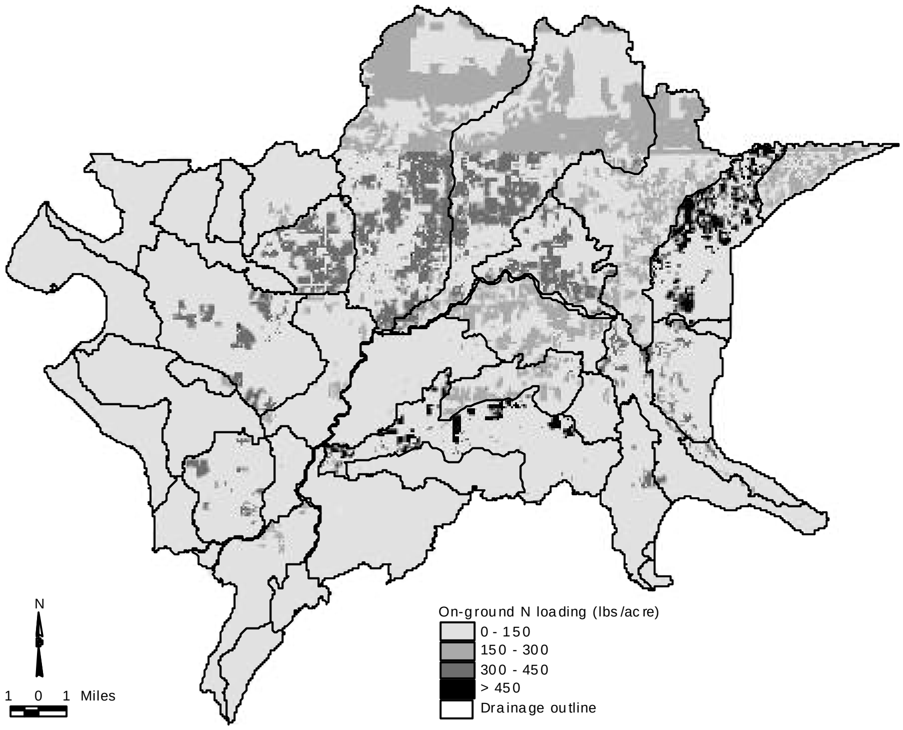

Figure 5. The total annual distribution of on-ground nitrogen within the study area.

REFERENCES

Brisbin P. E. (1995). *Agricultural nutrient management in the lower Fraser Valley*, Report 4, DOE FRAP 1995-27, http://www.rem.sfu.ca/FRAP/9527.pdf.

Cox S. E. and Kahle S. C. (1999). *Hydrogeology, ground-water quality, and sources of nitrate in lowland glacial aquifer of Whatcom County, Washington, and British Columbia, Canada.* USGS Water Resources Investigation Report 98-4195, Tacoma, WA.

Erickson D. (1992). *Ground Water Quality Assessment, Whatcom County Dairy Lagoon #2, Lynden, Washington.* Washington State Department of Ecology, Open-File Report, 26 p.

ESRI (1999). *ArcView*. Environmental Systems Research Institute, Inc.

Harter T., Davis H., Mathews M., and Meyer R. (2002). Shallow groundwater quality on dairy farms with irrigated forage crops. *Journal of Contaminant Hydrology*, **55**: 287-315.

Hudak P. F. (2000). Regional trends in nitrate content of Texas groundwater. *Journal of Hydrology*, **228**: 37-47.

Kaluarachchi J. J., Kra E., Twarakavi N., & Almasri M. N. (2002). *Nitrogen and pesticide contamination of ground water in Water Resource Inventory Area-1*. Ground water quality report for WRIA 1, Phase II Report, Utah State University,

Kaluarachchi J. J. and Almasri M. N. (2003). *Conceptual model of fate and transport of nitrate in the extended Sumas-Blaine Aquifer, Whatcom County, Washington*. Utah State University, Logan, UT.

MacQuarrie K. T. B., Sudicky E., and Robertson W. D. (2001). Numerical simulation of a fine-grained denitrification layer for removing septic system nitrate from shallow groundwater. *Journal of Hydrology*, **52**: 29-55.

Morton T. G., Could A. J., and Sullivan W. M. (1988). Influence of over watering and fertilization on N losses from home lawns. *Journal of Environmental Quality*, **17**: 124-130.

Solley W. B.,Pierce R. R., & Perlman H. A. (1993). *Estimated use of water in the United States in 1990*. USGS Circular 1081.

Tooley J. and Erickson D. (1996). *Nooksack watershed surficial aquifer characterization*. Washington State Department of Ecology, Ecology Report #96-311.

U.S. Environmental Protection Agency (2000). *Drinking water standards and health advisories*. U.S. Environmental Protection Agency, Office of Water, 822-B-00-001, 12 p.

Wolfe A. H. and Patz J. A. (2002). Reactive nitrogen and human health: Acute and long-term implications. *Ambio*, **31**(2): 120-125.