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IDENTIFYING HIGH RISK AREAS OF N LEACHING IN THE SALT LAKE VALLEY, UTAH, USA

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Abbreviations: Geographic Information System-GIS; infrared-IR; maximum contaminant level-MCL; National Geospatial Management Center-NGMC; Natural Resources Conservation Service-NRCS; nitrate- NO_3-N; nitrite- NO_2-N; nitrogen-N; normalized difference vegetation index-NDVI; red-R; Soil Survey Geographic Database-SSURGO; United States Census Bureau-USCB; United States Department of Agriculture-USDA; United States Environmental Protection Agency-USEPA; United States Geological Survey-USGS; water insoluble nitrogen-WIN.

Keywords: Geographic Information System; urban landscape; NO_3-N leaching; soil texture; leaching risk)

ABSTRACT

Nitrogen (N) fertilization of urban turf areas, and potential nitrate (NO_3-N) leaching, may pose a hazard to groundwater quality. This research utilized a Geographic Information System (GIS) approach to estimate NO_3-N leaching mass from urban turf areas based on a one-dimensional N leaching model and to classify the NO_3-N leaching risk in the Salt Lake Valley, Utah, USA, based on soil texture. The methodology integrated a calibrated and verified Hydrus-1D N model, soil textures and urban turf areas to predict NO_3-N leaching to groundwater. Thirty United States Geological Survey (USGS) residential wells were installed and sampled in 1999 for NO_3-N concentration. A relationship between estimated NO_3-N leaching from urban landscapes and groundwater NO_3-N concentration was developed to determine the effect of soil texture and landscaped area on NO_3-N leaching from urban landscapes. The GIS approach was used to estimate the NO_3-N leaching risk to groundwater under efficient irrigation and fertilization scenarios and over-irrigation and over-fertilization scenarios. The results showed that soil texture played a role in NO_3-N leaching from urban landscapes to groundwater, and shallow groundwater was more susceptible to surface contamination compared to deep groundwater. The GIS technique identified areas where improved irrigation and fertilization management could reduce landscape NO_3-N leaching significantly, resulting in fewer NO_3-N leaching risk areas in the Salt Lake Valley, Utah, USA.

INTRODUCTION

Shallow unconfined groundwater systems are susceptible to contamination from near the ground's surface, so are not generally used as a source of drinking water in the Salt Lake Valley, Utah, USA (Thiros and Spangler, 2010). In many areas, the shallow aquifer and underlying principal aquifer are separated by less permeable, fine-grained sediment, which can inhibit the downward movement of water and potential surface contaminants. However, leakage to the deeper aquifer from the shallow aquifer may happen when a downward gradient exists and confining layers are thin and/or discontinuous (Thiros, 2003a). In the Salt Lake Valley, Utah, USA one third of the public water supply is from deep groundwater, while shallow aquifer water is not used for public supply. However, shallower groundwater quality needs to be protected to avoid contamination of deeper groundwater when a downward gradient exists (Thiros, 2003a).

Nitrate (NO_3-N) contamination to groundwater is a global issue (Hudak, 2000), and has been found throughout the United States (Spalding and Exner, 1993; Nolan et al., 1997; Harter et al., 2002). Drinking water with high NO_3-N concentrations can be harmful to human health since high NO_3-N concentrations can cause methemoglobinemia in infants and stomach cancer in adults (Addiscott et al., 1991; Wolfe and Patz, 2002). As a result, a maximum contaminant level (MCL) of 10 mg/l NO_3-N was established by the U.S. Environmental Protection Agency (USEPA, 2002).

Although NO_3-N can occur naturally in groundwater, increased concentrations in groundwater may have resulted from human activities due to increased applications of nitrogenous fertilizers since the last century. Nitrogen applied to soils is subject to plant uptake and denitrification. However, when N fertilizer application exceeds plant demand and the denitrification capacity of the soil, N leaching may occur in the form of NO_3-N, ultimately reaching groundwater (Almasri and Kaluarachchi, 2004). Agricultural lands receive the most N application, since N is a vital nutrient for enhancing crop production. As a result, agricultural activities are likely the major anthropogenic source of NO_3-N contamination to groundwater in agricultural areas (Livingston and Cory, 1998). Similarly, fertilizers applied to urban turfgrass landscapes and gardens may be a source of NO_3-N to urban groundwater (Thiros, 2003b), and may pose a hazard to groundwater quality. Ornamental turfgrass landscapes make up a large portion of residential property areas, and soil conditions in the Salt Lake Valley, Utah, USA region often necessitate the application of water and fertilizers to meet turfgrass requirements as well as homeowners' aesthetic expectations. However, homeowners often over-apply water and fertilizers because of a lack of understanding of actual plant needs. Water and fertilizer applied in excess of turf requirements may leach through the soil and contaminate ground and surface waters. Research reviewed by Petrovic (1990) suggested that NO_3-N applied to turf areas had the potential to leach through soils and contaminate groundwater if not properly applied. The use of fertilizers on recreational turf landscapes, such as golf courses, has also been identified as a potential source of NO_3-N in urban aquifers (Sharma et al., 1996; Wong et al., 1998), as well as turf fertilization in residential areas (Kopp and Guillard, 2005; Saha et al., 2007).

To reduce N leaching from urban turfgrass landscapes, it is necessary to determine the causal factors of increased groundwater nitrate concentration. The USGS studied the occurrence and distribution of NO_3-N in shallow groundwater underlying areas of recently developed (post 1963) residential and commercial land use in the Salt Lake Valley, Utah, USA based on the assumption that human activities influenced groundwater quality, with results indicating possible human influence on shallow groundwater quality (Thiros, 2003b). Since turfgrass landscapes make up a large portion of residential property areas and may receive excessive amounts of water and fertilizer, there may be a correlation between groundwater quality and the existence of residential areas around monitoring wells, as has been shown between agricultural land use activities and NO_3-N concentration in groundwater of agricultural areas (Keeney, 1989; Wylie et al., 1995; Hudak, 2000; Harter et al., 2002). However, in the Salt Lake Valley, Utah, USA, no correlation was found between the percentage of residential land surrounding the monitoring wells and the concentration of NO_3-N in water sampled from the wells in a USGS study (Thiros, 2003b). The absence of correlation between the percentage of residential area around the wells and groundwater NO_3-N concentration may be due to the fact that turfgrass areas, rather than the entire residential property area, receive the most fertilizer. In addition, the percent of landscaped area on each residential property is different. Soil textures under the landscapes may affect NO_3-N leaching as well (Sun, 2011). In this study, it was hypothesized that as the percentage of turfgrass area around the monitoring wells increased, the probability of contamination by NO_3-N in the well water also increased. Surface soil texture comprised of the largest soil particle sizes was also hypothesized to increase the probability of NO_3-N in the monitoring wells (Burkart et al., 1999; Nolan et al., 2002; Sun, 2011). Because no such correlations were found in the USGS study, a different approach—integrating turfgrass area, soil texture and different irrigation and fertilization scenarios—was employed to predict N-leaching potential from urban landscapes in the Salt Lake Valley.

Various approaches have been used to assess NO_3-N leaching to groundwater. For example, assuming that a specific fraction of on-ground N loading will leach as NO_3-N (Kim et al., 1993; Cox and Kahle, 1999; Shamrukh et al., 2001), conducting simple, efficient N mass balance calculations to estimate the NO_3-N leaching to groundwater in agricultural areas (Barry et al., 1993; Goss and Goorahoo, 1995; Puckett et al., 1999), and using soil N models to simulate the N dynamics in the soil (Ramanarayanan et al., 1998). To estimate NO_3-N leaching from different soil textures and different management scenarios, a N model is a logical choice. Therefore, a calibrated and verified Hydrus-1D model was utilized to simulate the fate and transport of NO_3-N from turfgrass and to determine the mass leaching of NO_3-N to groundwater for different soil textures. Spatial analysis techniques are also needed to assess NO_3-N leaching from turfgrass areas including different soil textures, and GIS provides a sound approach to evaluate the NO_3-N leaching from various soil textures (Almasri, 2008).

Identification of areas with high N leaching potential is also of importance for land use planners and environmental regulators. When identified, preventive activities can be implemented to decrease the NO_3-N leaching risk to groundwater in those identified high-risk areas (Tesoriero and Voss, 1997; Ramanarayanan et al., 1998). Identification of high-risk N leaching areas can pinpoint where groundwater needs to be protected and where improved and efficient turfgrass management is most needed.

Therefore, the objectives of this research were: (1) to reanalyze the 1999 USGS groundwater NO_3-N concentration dataset for NO_3-N leaching potential based on a current Hydrus-1D simulation, (2) to determine whether a relationship exists between potential NO_3-N leaching from urban landscapes and groundwater NO_3-N concentration using a current Hydrus-1D simulation, and (3) to identify the high NO_3-N leaching risk areas in the Salt Lake Valley that may pose potential effects to groundwater quality.

MATERIALS AND METHODS

1. Study Area. The Salt Lake Valley, Utah, USA is 45 km long and 29 km wide, and is an urban area bounded by the Wasatch Mountain Range, the Oquirrh Mountains, the Traverse Mountains, and the Great Salt Lake. The valley contains the most populated portions of Salt Lake County, including the Salt Lake City metropolitan area. The population of Salt Lake County in 2010 was 1,029,655 (USCB, 2010), and is projected to be 1,223,218 in 2020 (Utah State Data Center, 2000), requiring more water for public supply.

The climate in Salt Lake Valley is semi-arid with hot summers and moderately cold winters. The average annual precipitation is 250-500 mm mostly in the form of snow (Murphy, 1981). The hot and dry summers in the valley necessitate irrigating turfgrasses and ornamental landscapes to supplement precipitation during the growing season.

2. Shallow Well Monitoring. Shallow well NO_3-N concentration data from a 1999 USGS study were obtained from a USGS database. The original USGS data were collected in 1999 to quantify relationships between recent residential and commercial areas and groundwater quality (Thiros, 2003b). In the USGS study, "potential well locations were selected by using a computerized, stratified random selection process to ensure that the data collected were unbiased and representative of the quality of water underlying recently developed residential and commercial areas" (Scott, 1990). Forty-one sites in the Salt Lake Valley were selected using the following study criteria:

(1) A location in residential and commercial areas developed during 1963-94,

(2) A downward gradient between the shallow and deeper aquifers, and,

(3) A minimum distance between each site of 1 km.

In the USGS study, more newly developed areas (post 1994) were excluded due to the time necessary for new construction to affect groundwater quality (Squillace and Price, 1996). Similarly, urban areas developed before 1963, such as downtown Salt Lake City, were excluded because of the potential for the land use to have changed over time (Thiros, 2003b). The position of each well was determined in latitude and longitude (Figure 1) and shallow groundwater samples were collected in the summer and fall of 1999 (Thiros, 2003b). Nitrate plus nitrite (NO_2-N) were detected in samples, and NO_3-N was reported as the sum of NO_3-N and NO_2-N (Thiros, 2003b).

3. Soil Map. The soil map (scale 1:12,000) of the area was obtained from the Soil Survey Geographic (SSURGO) database distributed by the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS)-National Geospatial Management Center (NGMC) (Figure 1). The SSURGO-certified soils dataset is the most detailed level of soil geographic data developed by the National Cooperative Soil Survey. The information was prepared by digitizing maps, by compiling information onto a planimetrically correct base and digitizing, or by revising digitized maps using remotely sensed and other information. The data included a detailed, field verified inventory of soils and miscellaneous areas that normally occur in a repeatable pattern on the landscape and that can be cartographically shown at the scale mapped. The soil map was symbolized according to soil hydraulic conductivities from low to high (Figure 1).

4. Growing Season NO_3-N Leaching Simulation. A calibrated and validated public domain computer software package (Hydrus-1D) was used to simulate NO_3-N leaching from turfgrass grown on different soil textures during the local growing season (June to September). Over-irrigation and over-fertilization scenarios and efficient irrigation and fertilization scenarios were input to the model (Sun, 2011). The model simulated soil N transformation and transport in turfgrass using boundary condition inputs and outputs, including N-leaching from the root zone. All NO_3-N transform and transport parameters were the same as those utilized in the Hydrus-1D calibration process (Sun, 2011), and efficient irrigation and 2010 weather data were used as input boundary conditions to simulate NO_3-N leaching under an efficient irrigation and fertilizer management scenario. According to irrigation system evaluations in Salt Lake City, 150% of efficient irrigation and 200% of efficient monthly fertilization at 48.8 kg N ha^{-1} rates are typical and were applied in the simulation as over-irrigation and over-fertilization scenarios. Monthly fertilizer (33-0-0) applications were simulated from June to Sept. at a rate of 48.8 kg N ha^{-1} [2.22% ammonium, 3.93% urea, 8.53% NO_3-N, and 18.32% water insoluble nitrogen (WIN)]. Nitrogen leaching rates for different soil textures were also simulated. There are 23 soil textures on the soil map. However, only eight sets of van Genuchten parameters for the soil textures were available, either in the Hydrus-1D built-in database or from references (Table 1; van Genuchten, 1980). As a result, NO_3-N leaching for these eight soil textures was simulated, and for the rest of the soil textures, N leaching rates were estimated based on the eight simulations (Table 2). In the simulations, a 15 cm layer of top soil was assumed based on local information that property owners typically bring in top soil regardless of existing soil. Furthermore, it was assumed that Kentucky bluegrass (*Poa pratensis* L.) was grown on landscapes in the valley, that NO_3-N leached out of root zone (beyond 80 cm depth) ultimately reached groundwater, and that only turfgrass areas of the landscapes received N fertilizer.

5. Landscape Areas. Green pixels were extracted from an Aug. 3, 1999 satellite image to determine the green areas in the map with Normalized Difference Vegetation Index (NDVI) method and green areas in the valley were assumed to be turfgrass landscapes. The NDVI is a standardized index that allows the generation of an image displaying greenness according to the characteristics of two bands from a multispectral raster dataset—the chlorophyll pigment absorptions in the red band and the high reflectivity of plant materials in the near-infrared (NIR) band.

$$NDVI = [(IR - R)/(IR + R)] \quad (1)$$

where IR = pixel values from the infrared band, and R = pixel values from the red band. The index outputs values between -1.0 and 1.0, and values between 0.2 to 0.3 representing shrub and grasslands, while high values from 0.6 to 0.8 represent temperate and tropical rainforests. The equation ArcGIS uses to generate the output is:

$$NDVI = [(IR - R)/(IR + R)] \times 100 + 100 \quad (2)$$

This results in a value range of 0 to 200 and fits within an 8-bit structure. In this study, $125 < NDVI < 180$ were considered green areas.

6. Predicted NO_3-N Leaching Mass. Nitrate leaching from within a 500-m radius area around monitored wells was considered to affect well NO_3-N concentration since the minimum distance between each well site was 1 km. Therefore, a 500-m radius buffer was developed around each well location. An ArcGIS script was used to clip the soil polygons and the extracted landscape polygons within the 500-m radius buffer. Clipped soil and landscape polygons were intersected and new polygons of soils with landscapes were obtained. Nitrate leaching mass from the landscapes was calculated based on soil texture where:

$$NO_3\text{-N leaching mass (kg)} = \sum \text{landscaped soil areas (ha)} \times \text{simulated } NO_3\text{-N leaching rate for each soil type (kg ha}^{-1}\text{)} \quad (3)$$

7. Regression Between NO_3-N Concentration and Estimated NO_3-N Leaching Mass. The groundwater NO_3-N concentration data were divided into 6 groups according to well depth, which were designated in units of feet as per the USGS report (Thiros, 2003b). The divided groups were 23-36, 38.5, 43.5-48.5, 67.5-77.5, 83.5-92.3, and 95.5-123.5 feet (Table 3). Regressions and correlations were developed between groundwater NO_3-N concentrations and simulations based NO_3-N leaching masses within a 500-m radius around each well. Nitrate-N concentrations of less than 1 mg L^{-1} were removed from the regression since those wells were considered to be unaffected by human activities (USGS, 1999). The 153.5 feet deep well was also removed from the regression analysis because it was the only well that was deeper than the 95.5-123.5 feet group.

8. High-Risk Areas. According to the Hydrus-1D simulated/estimated NO_3-N leaching rates from different soils, maps of the Salt Lake Valley with classes of NO_3-N leaching risk identified were developed based on divided NO_3-N leaching ranges. Areas with N-leaching rates of less than 10 kg ha^{-1} were designated low risk, areas between 10-25 kg ha^{-1} were designated medium risk, and areas between 25-40 kg ha^{-1} were designated high risk. Areas higher than 40 kg ha^{-1} were designated extremely high-risk.

RESULTS AND DISCUSSION

1. NO_3-N Concentration of Shallow Residential Well Water. It has been reported that background NO_3-N concentrations in groundwater from areas not associated with agricultural management practices are commonly less than 2 to 3 mg L^{-1} (Hallberg and Keeney, 1993). As such, NO_3-N concentrations greater than 2 mg L^{-1} may indicate groundwater quality affected by human activities (USGS, 1999). The USGS shallow groundwater NO_3-N concentration data showed that 86.7% (26 of 30) of monitoring wells had NO_3-N concentrations higher than the assumed background level of 2 mg L^{-1}, suggesting a possible human influence on shallow groundwater quality (Table 3). The high frequency of monitoring well NO_3-N concentration exceeding background levels in the residential areas may have resulted from the application of nitrogenous fertilizers that ultimately leached as NO_3-N (Thiros, 2003b). The median NO_3-N concentration of the 30 samples was 6.85 mg L^{-1}, with concentrations ranging from less than 0.05 to 13.3 mg L^{-1} (Table 3). Three of the 30 monitoring wells had NO_3-N concentrations exceeding the USEPA MCL of 10 mg L^{-1} NO_3-N in drinking water (USEPA, 2002) (Table 3).

2. Correlation Between NO_3-N Concentration in Wells and Estimated NO_3-N Leaching Mass Around Each Well. Although landscape areas and soil textures were included in this approach to estimating NO_3-N leaching, there was no correlation between groundwater NO_3-N concentration and estimated NO_3-N leaching mass when all well groundwater NO_3-N concentration data were included. This finding supports the conclusion of the 1999 USGS study that there was no relationship between the type and area of residential land uses surrounding the monitoring wells and the concentration of NO_3-N in water sampled from the wells (Thiros, 2003b).

3. Groundwater NO_3-N Concentration and Well Depth. In addition to the shallow groundwater NO_3-N data from USGS (1999), NO_3-N concentration data from an additional 30 deep wells were considered (Figure 2) (Wallace and Lowe, 2008). It may be expected that shallow wells are more susceptible to contamination than deeper wells, and this was confirmed by plotting shallow and deep well NO_3-N concentration *vs*. well depth (Figure 2). In shallow groundwater (depth <50 m), NO_3-N concentration ranged from 0.2 to 13.3 mg L^{-1}. However, in deep wells (>50 m), none of the well NO_3-N concentrations exceeded the USEPA MCL limit of 10 mg L^{-1} and most of the well NO_3-N concentrations were less than 4 mg L^{-1}. This finding indicates that while NO_3-N was able to contaminate deep groundwater, shallow groundwater was more susceptible to NO_3-N contamination. When NO_3-N concentrations in deep groundwater were elevated, it may have been due to leakage from the shallow aquifer to the deeper principal aquifer, since leakage is possible where a downward gradient exists (Thiros, 2003a).

In the Salt Lake Valley, water from the deeper aquifer underlying the shallow groundwater system is used for the public drinking water supply (Thiros, 2003a). Nitrate-N concentrations of less than 10 mg L^{-1} observed in deep wells indicate that deep groundwater in the Salt Lake Valley is safe for drinking, when NO_3-N concentration is the concern. The low NO_3-N concentrations in deep wells may be affected by several factors. For example, the amount of time required for NO_3-N to reach deep groundwater results in a greater opportunity for denitrification. Additionally, leaked NO_3-N from shallow groundwater is diluted in the larger volumes of deep groundwater. And while the shallow aquifer may be susceptible to surface contamination from land use activities because of its proximity to the land surface, the deeper unconfined aquifer is vulnerable because of a lack of confining layers that can impede the downward movement of contaminated groundwater (Thiros, 2003a).

4. Risk Areas. Class of risk area maps were developed for urban areas in the Salt Lake Valley under efficient irrigation and fertilization management scenarios and over-irrigation and over-fertilization scenarios. Under conditions of over-irrigation and over-fertilization, 20% of urban areas were designated at high (25-40 kg ha^{-1}) or extremely high risk (>40 kg ha^{-1}) of contamination by NO_3-N leaching from urban landscapes, while 48% and 17% of urban areas had medium or low contamination risk, respectively (Figure 3). However, under efficient management, most of the urban areas were at low risk of contamination, meaning less than 10 kg ha^{-1} NO_3-N could be leached out of root zone (Figure 4).

Under these conditions, 83% of the areas had low contamination risk, and only 1% had medium contamination risk. Under efficient management scenarios, there were no high or extremely high-risk areas designated.

Studies have illustrated that groundwater is closely connected to the landscape and land use that it underlies, and is vulnerable to the management of the land surface above (Harter et al., 2002; Lerner and Harris, 2009). Recharge to groundwater and the use of groundwater can affect groundwater quality and quantity, and were determined by land use and management. As a result, inappropriate land use and poor land management may cause chronic groundwater quality problems (Lerner and Harris, 2009). Figures 4 & 5 indicate that groundwater may be well protected from NO_3-N leaching contamination from urban fertilization application if landscape irrigation and fertilization is managed efficiently. However, even if efficient management strategies are implemented in urban landscapes, immediate decreases in NO_3-N leaching to groundwater may not be possible because of the pool of N existing in soil (Almasri and Kaluarachchi, 2004). Research has shown that NO_3-N leaching continued even after the termination of operations and reduction in N loading in livestock feedlots, for example (Gormly and Spalding, 1979; Carey, 2002). And even when NO_3-N leaching from agricultural areas to groundwater decreases or stops immediately due to improved practices, groundwater NO_3-N concentrations will not drop immediately (Lerner and Harris, 2009). Some studies have found persistent groundwater N concentrations after NO_3-N contamination was stopped and management alternatives were in place for as long as 30 years (Gelhar and Wilson, 1974; Mercado, 1976; Hudak, 2000; Shamrukh et al., 2001; Nolan et al., 2002; Wakida and Lerner, 2002), confirming that groundwater NO_3-N concentrations do not drop immediately as a result.

5. Considerations. The interactions of land use, on-ground N loading, irrigation management, recharge, N dynamics, soil characteristics, and depth of soil are complex, so it is difficult to quantify NO_3-N leaching accurately (Almasri, 2007). Given this complexity and difficulty, the results of this study must be carefully evaluated and considered prior to making consequential policy or management decisions based on the findings.

One consideration results from the NO_3-N transport and transformation parameters. It has been demonstrated that soil type can affect N transformation rates and that soil transformation processes (mineralization/immobilization, nitrification, denitrification, and plant uptake) greatly affect NO_3-N leaching. Soil characteristics dictate N kinetics as well. For example, in well-drained soils with high infiltration rates, the rate of nitrification is high and denitrification may be insignificant. In contrast, in poorly drained soils, denitrification is high and nitrification may be insignificant (Almasri, 2007). In this study, nitrification and denitrification parameters were held constant for all the soil texture scenario simulations to estimate NO_3-N leaching from different soils. Furthermore, soil depth controls the time lag between on-ground applications of N and NO_3-N leaching, and influences the time span of soil N transformations (Almasri and Kaluarachchi, 2004). As a result, the NO_3-N leaching mass estimation for different soil textures is subject to some uncertainty.

Another consideration results from the soil textures of the soil survey map. The soil survey map is based on the top 2 m of soil, and soil textures deeper than 2 m are unknown. Although in this study the NO_3-N leaching estimation was based on simulated NO_3-N leaching from the top 80 cm of soil, the unknown soil textures deeper than 2 m may decrease NO_3-N leaching, or may even stop NO_3-N leaching if a confining layer exists.

Other considerations relate to the assumptions made in the study. For example, it was assumed that all property owners/managers bring in 15cm of top soil. It was further assumed that NO_3-N leaching beyond the turfgrass root zone would reach groundwater. However, NO_3-N leaching out of root zones is subject to denitrification and denitrification rates depend on soil texture and soil depth when temperature and moisture content are the same. In addition, all the landscape areas were assumed to be covered with turf. However, trees and shrubs are also common in landscapes and NO_3-N leaching out of turf root zones may be absorbed by shrubs and trees which have much deeper root systems and may decrease NO_3-N leaching to groundwater.

CONCLUSION

Although there were many assumptions made in this study, the proposed methodology of integrating soil textures and N modeling was useful for estimating NO_3-N leaching from urban landscapes in the Salt Lake Valley, Utah, USA and was validated with measured groundwater NO_3-N concentrations to some extent. Deep groundwater had much lower NO_3-N concentrations than shallow groundwater, and shallow groundwater was more susceptible to surface contamination. However, shallow groundwater contaminants are able to reach deep groundwater and decrease deep groundwater quality under conditions in which confining layers do not exist. The results of this study indicate that improvement of turf irrigation and fertilization management may decrease N-leaching significantly and greatly decrease the risk of groundwater being contaminated by NO_3-N leaching in the Salt Lake Valley, Utah, USA although such management changes cannot immediately halt or reverse the consequences of past NO_3-N leaching.

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Table 1. van Genuchten parameters for different soil textures used in the Hydrus-1D simulation.

Soil textures	θr	θs	α (1/cm)	n	Ks (cm d^{-1})
Coarse sandy loam	0.057	0.41	0.124	2.28	350.2
Loam	0.078	0.43	0.036	1.56	25
Fine sandy loam	0.112	0.44	0.009	2.873	100.8
Sand	0.045	0.43	0.145	2.68	712.8
Gravelly loam	0.1	0.47	0.09	1.46	50
Silt loam	0.067	0.45	0.02	1.41	10.8
Silty clay	0.089	0.43	0.01	1.23	1.68
Sandy loam	0.065	0.41	0.075	1.89	106.1

Table 2. Simulated/estimated NO_3-N leaching rates for Kentucky bluegrass under efficient irrigation and fertilization (100%), and over-irrigation (150%) and over-fertilization (200%) scenarios for soils of the survey map.

	Soil Texture	NO_3-N leaching (kg ha^{-1})	
		Efficient irrigation and fertilization	Over-irrigation and over-fertilization
Simulation	Coarse sandy loam	7.6	46.3
	Loam	0	16.9
	Fine sandy loam	0	14
	Sand	10.1	59
	Gravelly loam	1.2	19.5
	Silt loam	0	12.4
	Silty clay	0	10
	Sandy loam	2.5	29.9
Estimation	Silty clay loam	0	10
	Gravelly coarse	8	50
	Gravelly silt loam	1	15
	Extremely stony loam	8	50
	Loamy coarse sand	9	55
	Very fine sandy loam	0	13
	Cobbly coarse sandy	8	50
	Extremely stony loam	9	55
	Very cobbly loam	8	50
	Cobbly fine sandy loam	3	35
	Cobbly sandy loam	5	45
	Extremely stony loam	8	50
	Gravelly clay loam	1	15
	Greavelly sandy loam	8	50
	Stony loam	8	50
	Very cobbly loam sand	13	70
	Very cobbly silt loam	4	40
	Very gravelly sandy	8	50

Table 3. Grouping of wells, well depth, NO_3-N concentration, landscaped areas within a 500-m radius around wells, and estimated N leaching mass from the landscaped areas around each well in 1999.

Groups	Well Depth (ft)	NO_3-N concentration (mg L^{-1})	Landscape areas around wells (ha)	Sum NO_3-N leaching from landscape areas (kg)
23-36	23	4.45	43.8	1482
	36	4.14	42.5	2173
38.5	38.5	12.7	30.1	366
	38.5	3.55	23.5	275
	38.5	5.46	38.9	388
	38.5	2.37	23.5	277
	38.5	7.35	35.7	379
43.5-48.5	43.5	4.72	48.8	654
	43.5	7.05	15.5	222
	48.5	8.15	37.2	651
	48.5	7.66	42.0	493
67.5-77.5	67.5	6.67	38.4	697
	68.5	6.81	42.7	445
	68.5	7.2	53.8	538
	73	13.3	34.8	1888
	73.5	7.5	52.6	2209
	77.5	7.71	36.5	1356
83.5-92.5	83.5	12	42.1	607
	83.5	9.78	34.9	410
	92.5	6.85	43.3	453
95.5-123.5	95.5	3.94	48.9	745
	105.5	4.35	30.1	1062
	106	9.96	46.6	2469
	113.5	8.55	49.9	640
	123.5	1.38	50.6	506
Not included	153.5	9.49	23.4	304
	31.5	0.2	46.1	1230
	34	<0.05	63.8	1740
	77.5	0.25	46.1	1230

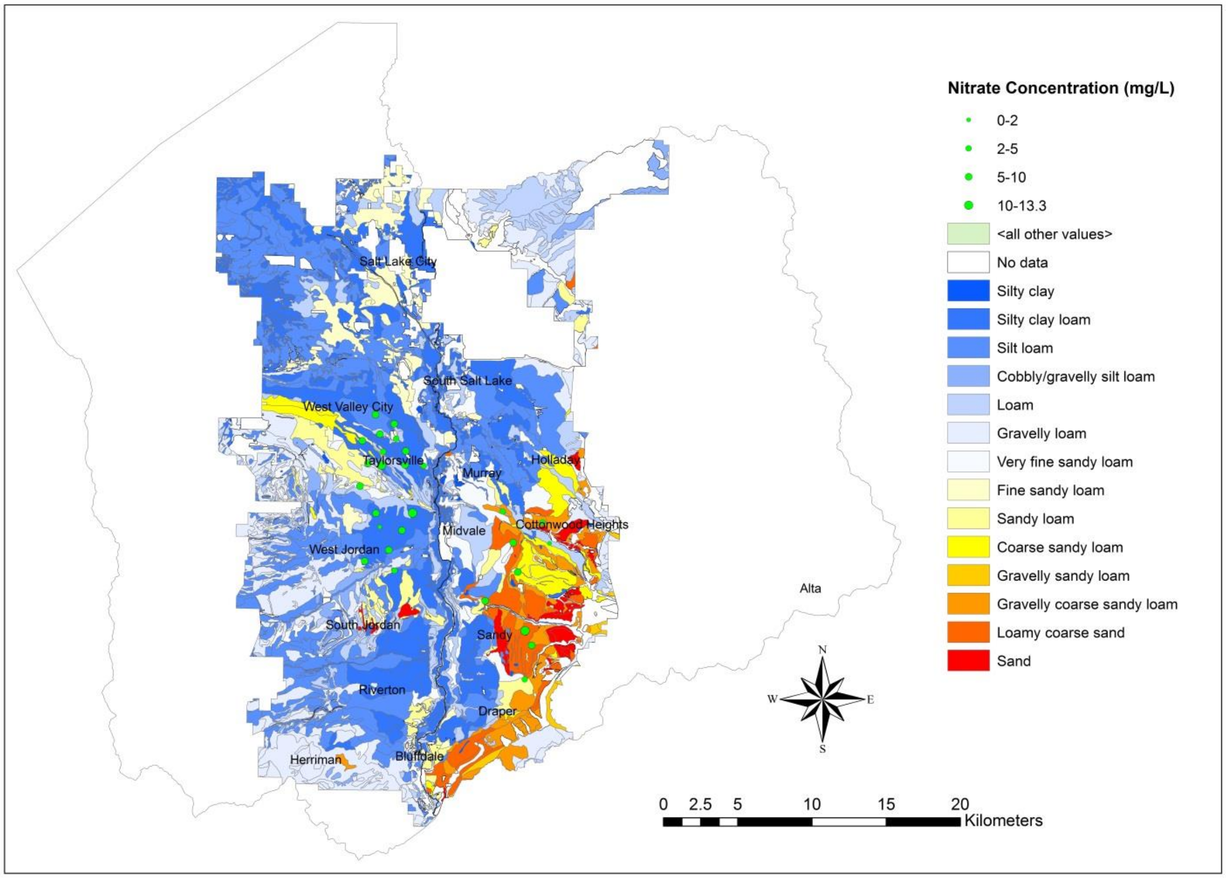

Figure 1. Location of shallow monitoring wells and soil maps in the urban areas of Salt Lake Valley, Utah, USA.

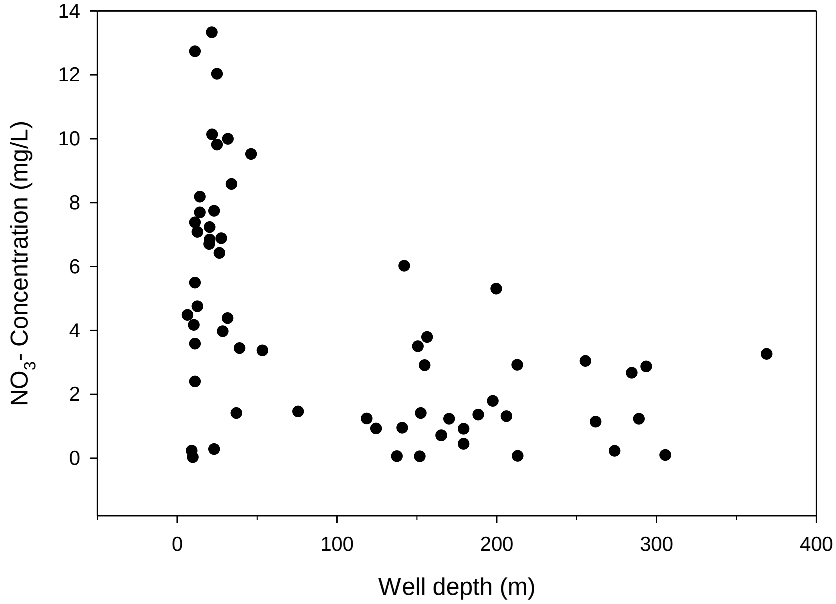

Figure 2. NO_3-N concentration of both deep and shallow wells in the Salt Lake Valley, Utah, USA. Shallow well data were from 1999 and deep well data were from 2001.

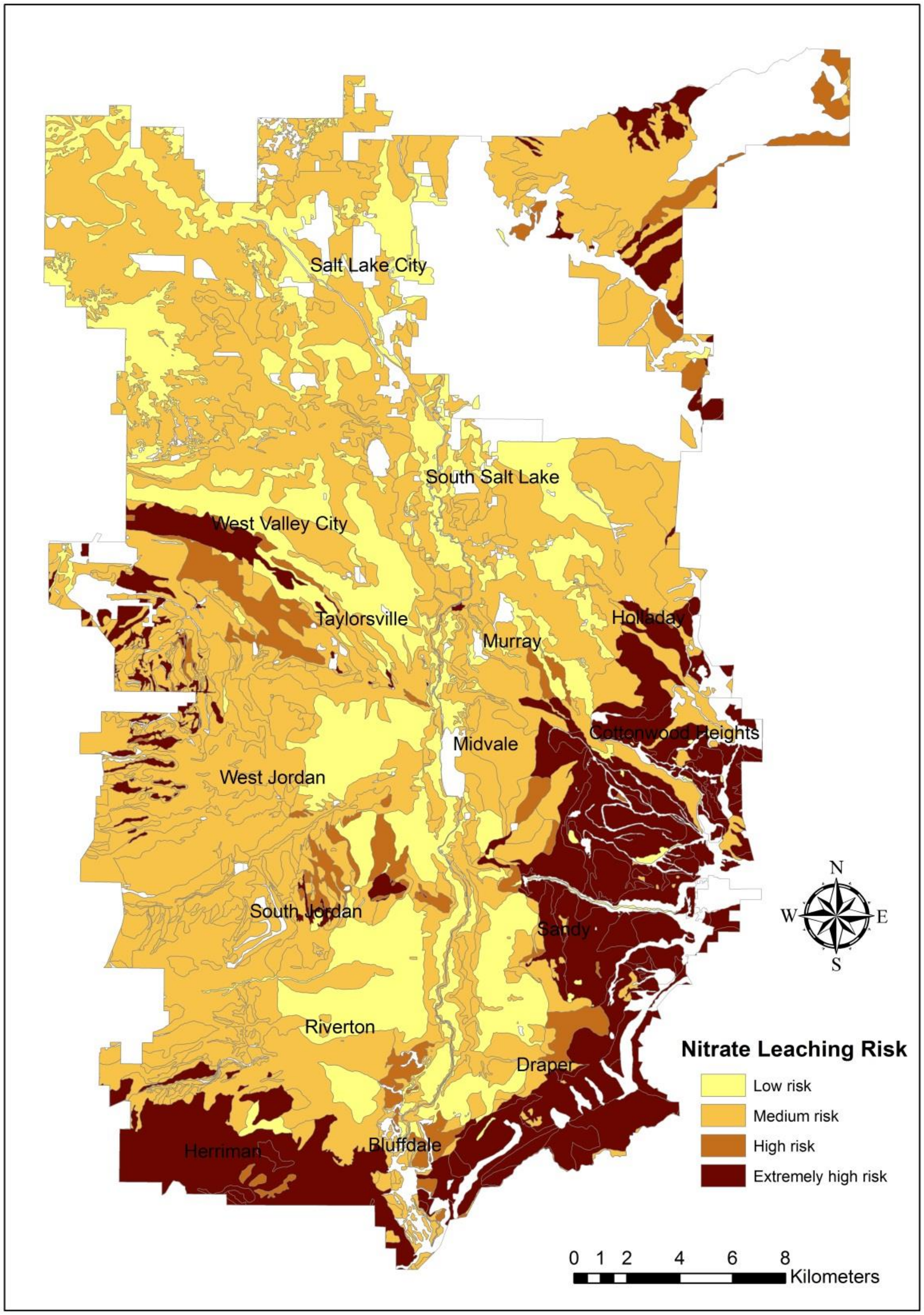

Figure 3. Risk class of urban groundwater being contaminated by NO_3-N leaching from urban landscapes according to soil textures above groundwater under over-irrigation and over-fertilization scenarios in the Salt Lake Valley, Utah, USA.

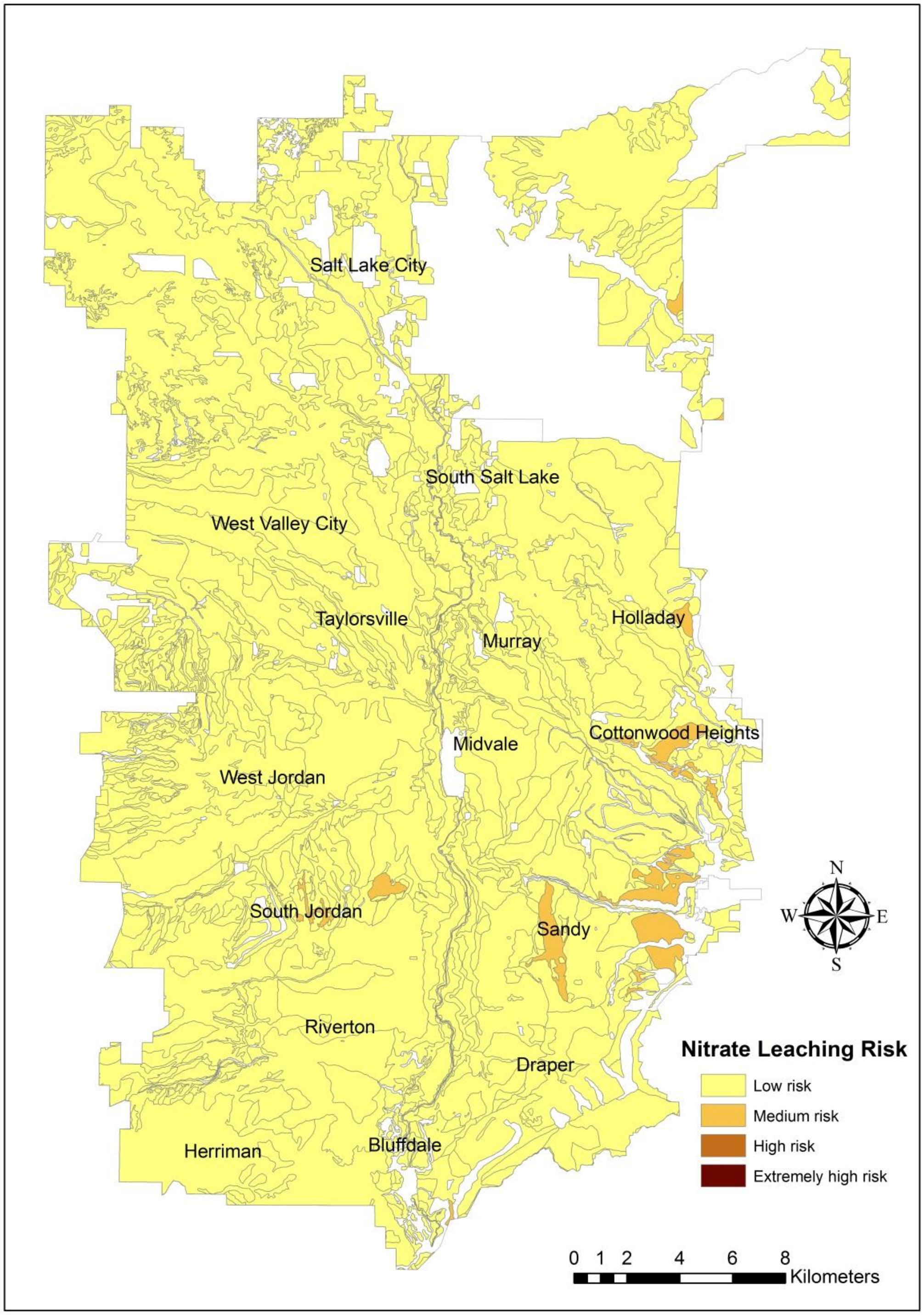

Figure 4. Risk class of urban groundwater being contaminated by NO_3-N leaching from urban landscapes according to soil textures above groundwater under efficient irrigation and fertilization management scenarios in the Salt Lake Valley, Utah, USA.