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An Analysis of Nitrate-Nitrogen in Ground Water Beneath Unsewered Subdivisions

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Abstract

Water samples from private water supply wells in five unsewered subdivisions were tested for nitrate-nitrogen to determine the possible impact of septic systems on ground water quality. Three subdivisions are located in Eau Claire County and two in LaCrosse County, Wisconsin.

The nitrate-nitrogen concentrations in the wells were analyzed in relation to ground water flow direction, the location of septic systems within the subdivision, and the hydrogeologic and physical characteristics of the subdivisions. A comparison of three nitrogen mass balance models helped to identify the possible sources of nitrate-nitrogen in the wells.

The results indicate that nitrogen from septic systems and lawn fertilizer cause nitrate-nitrogen to increase in the ground water beneath the downgradient side of the subdivisions. In three of the five subdivisions the highest nitrate-nitrogen value exceeds the drinking water standard of 10 mg/L.

Introduction

On-site septic-tank soil-absorption systems that serve unsewered subdivisions may cause nitrate-nitrogen levels in ground water to exceed the national drinking water standard of 10 mg/L of nitrate-nitrogen. To evaluate this possibility, water samples from private water-supply wells in five subdivisions in Wisconsin were tested for nitrate-nitrogen. The nitrate-nitrogen values were analyzed for their distribution within the subdivision and for their relationship to the location of upgradient septic systems. In addition, this paper describes the application of a combined nitrogen mass balance model of Wehrmann (1984) and the BURBS nitrogen mass balance model of the Center for Environmental Research, Cornell University (1985) to the five subdivisions.

The fate and transport of nitrate-nitrogen from on-site disposal of domestic waste water is reviewed by Reneau et al. (1989). Models to predict the impact of nitrate-nitrogen from septic systems on ground water are discussed by Perkins (1984) and include nitrogen mass balance models. The application of a nitrogen mass balance model to unsewered subdivisions in Illinois is reported by Wehrmann (1984) and for subdivisions in Wisconsin by Tinker (1986 and 1987) and by Arntson et al. (1988).

Study Sites

Three of the subdivisions are located in Eau Claire County and two in LaCrosse County in west-central

Wisconsin (Figure 1 and Table 1). The subdivisions are situated on sand and loamy sand soils on glacial outwash or river terrace deposits. The soil slope is 0 to 6 percent in the Oak Park and Pine Grove-Deer Park subdivisions and 0 to 2 percent in the other subdivisions. The mean depth to the water table, the mean depth of the water-

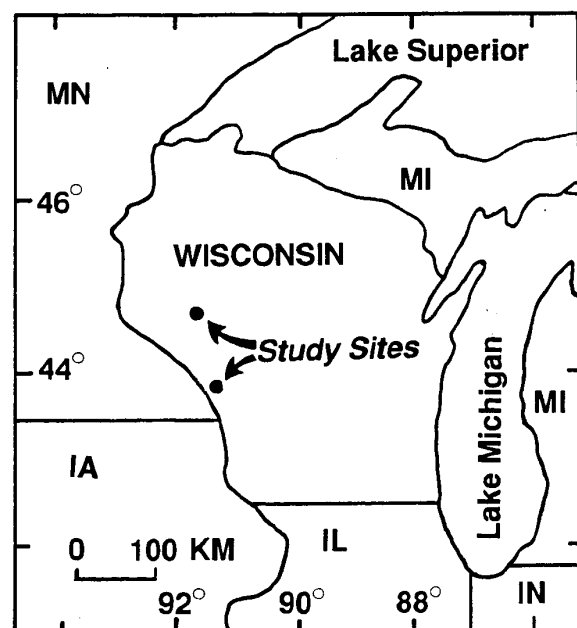


Figure 1. Location of the five subdivisions in Wisconsin.

TABLE 1
Site Location, Soil, Water Table, and Well Construction Information for the Subdivisions

Subdivision	Soils	Mean Depth to Water Table Feet	Mean Depth of Well Feet	Mean Depth of Well Casing Feet
Sandy Knolls NE 1/4, Sec 29, T17N, R7W	Sand Loamy sand	64 ± 3.3*	93 ± 11.3	88 ± 9.1
Pine Grove-Deer Park S 1/2, Sec 22, T27N, R8W	Sand Sandy loam	30 ± 8.4	61 ± 17.4	53 ± 13.9
Oak Park SE 1/4, Sec 29, SW 1/4, Sec 28, T17N, R8W	Sandy loam, loamy sand	75 ± 10.0	120 ± 12.8	116 ± 11.5
Lowes Creek SW 1/4, Sec 15, T26N, R9W	Loamy sand	34 ± 1.9	93 ± 7.2	89 ± 6.7
Briarwood S 1/2, Sec 22 T26N, R9W	Loamy sand	33 ± 6.5	74 ± 15.8	62 ± 21.0

* ± one standard deviation.

TABLE 2
Site Characteristics of the Subdivisions

Subdivision	Initial Construction	Total Area Acres	No. of Septic Systems	Mean Lot Size Acres	Mean No. of People per Home	Mean No. Bedrooms per Home
Sandy Knolls	1981	39	50	0.5	3.9	3.4
Pine Grove-Deer Park	1971	104	70	1.1	3.9	3.1
Oak Park	1972	89	128	0.6	4.0	3.1
Lowes Creek	1975	55	33	1.3	3.3	3.4
Briarwood	1978	81	45	1.2	3.2	2.9

supply wells, and the mean depth of the well casings for each subdivision are presented in Table 1.

All wells in the Sandy Knolls, Oak Park, Briarwood, and Lowes Creek subdivisions terminate in a water-table aquifer composed of sandy sediment. One exception is a well in the Lowes Creek subdivision, which terminates in sandstone under the sandy sediment. In the Pine Grove-Deer Park subdivision, 21 wells terminate in the upper sandy sediment, 17 wells in sandstone under the sandy sediment, and one well in granite under the sandy sediment. The initial construction date, total area, number of septic systems, mean lot size, mean number of people per home, and mean number of bedrooms per home for each subdivision are presented in Table 2. The hydraulic gradient, hydraulic conductivity, average linear velocity of ground water, ground water flow length across the subdivision, and travel time of

ground water beneath each subdivision are presented in Table 3. The hydraulic gradients were determined from water-table maps constructed from data obtained from well construction reports of water-supply wells and elevations of permanent rivers. Hydraulic conductivity values were determined from specific capacity data obtained from well construction reports using the method described by Bradbury and Rothschild (1985). The average linear velocity of the ground water was calculated using Darcy's law with porosity equal to 0.25. The distance across the subdivisions was obtained from aerial photographs, 7½-minute topographic maps, or plat maps.

To reduce ambiguity in the analysis, the five subdivisions selected are located in areas with little or no upgradient agricultural activity or other known sources of nitrate-nitrogen.

TABLE 3
Hydrogeological Characteristics of the Subdivisions

Subdivision	Hydraulic Gradient	Hydraulic Conductivity Feet/Sec	Average Linear Velocity of Ground Water Feet/Sec	Flow Length Feet	Travel Time Years
Sandy Knolls	.0026	5.9×10^{-4}	6.14×10^{-6}	1600	8.3
Pine Grove-Deer Park	.0091	3.30×10^{-4}	1.20×10^{-5}	1100	2.9
Oak Park	.0026	1.10×10^{-3}	1.14×10^{-5}	1400	3.9
Lowes Creek	.0110	5.28×10^{-4}	2.32×10^{-5}	1300	1.8
Briarwood	.0074	4.63×10^{-4}	1.37×10^{-5}	2000	4.6

TABLE 4
Mean and Highest Nitrate-Nitrogen Values for the Subdivisions

Subdivision	No. of Samples Set 1*	No. of Samples Set 2*	Mean Nitrate Nitrogen Set 1 mg/L	Mean Nitrate Nitrogen Set 2 mg/L	Highest Nitrate Nitrogen mg/L
Sandy Knolls	15	14	$5.5 \pm 2.7^{**}$	$6.0 \pm 3.4^{**}$	13.0
Pine Grove-Deer Park	39	44	3.9 ± 2.5	3.5 ± 2.6	11.6
Oak Park	39	35	5.2 ± 3.0	6.3 ± 4.4	21.6
Lowes Creek	18	20	1.9 ± 1.5	1.6 ± 1.6	5.7
Briarwood	15	14	2.2 ± 2.8	1.8 ± 3.3	9.8

* Set 1 samples collected in May, June, or July of 1988.

Set 2 samples collected in September 1988. Samples for each subdivision in sets 1 and 2 were collected within a maximum of a two-day interval.

** \pm one standard deviation.

Nitrate-Nitrogen of Water-Supply Wells

Two sets of water samples were collected from inside or outside faucets of homes in each of the five subdivisions; set 1 was collected in May, June, or July of 1988 and set 2 was collected in September of 1988. The samples for each subdivision within set 1 and set 2 were collected within a maximum of a two-day interval. All water samples were analyzed for nitrate-nitrogen concentrations at the Wisconsin State Laboratory of Hygiene in Madison, Wisconsin. Water samples were collected following standard procedures. For example, samples were collected from taps after flushing, collected prior to any treatment, placed in insulated and cooled containers, and shipped to the laboratory on the day of collection. Duplicate samples differed by no more than 0.5 mg/L of nitrate-nitrogen.

Mean and highest nitrate-nitrogen values for each set of samples for each subdivision are presented in Table 4. The nitrate-nitrogen values for September 1988 for each water-supply well for each subdivision are presented in Figures 2, 3, 4, 5, and 6.

To help determine the source of nitrate-nitrogen in the water-supply wells, it is important to know if the nitrate-nitrogen values increase from the upgradient to the downgradient side of the subdivision with reference to the ground water flow direction. Therefore, an arc with its center point within the subdivision was drawn to encompass the upgradient nitrate-nitrogen values for each subdivision (Figures 2, 3, 4, 5, and 6). The location

of the center point was arbitrarily located within the subdivision. Intervals of 10 degrees were marked on the arc. At each interval on the arc a line was drawn through the center point used to construct the arc. For example, the lines labeled "Distance Across Subdivision" on Figures 2, 3, 4, 5, and 6 are lines through the center point of the arcs. The beginnings of other such lines at each 10-degree interval are also shown on these figures. At each 10-degree interval, the nitrate-nitrogen concen-

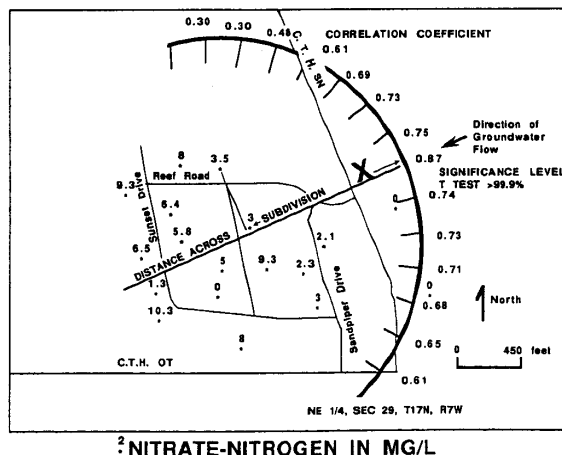


Figure 2. Nitrate-nitrogen concentrations, ground water flow direction and correlation coefficients for distance across subdivision vs. nitrate-nitrogen for Sandy Knolls Subdivision.

tration for each water-supply well was plotted vs. the distance of the well from the arc. For example, the nitrate-nitrogen value of 3.5 mg/L on Figure 2 was plotted vs. the distance "X" for the line labeled "Distance Across Subdivision." This method of measuring the distance from the arc was repeated for each nitrate-nitrogen value for the line labeled "Distance Across Subdivision" and for each line at the 10-degree intervals on the arc. The correlation coefficients and significance levels by Student's t-test (Davis 1986) for the correlation between distance across each subdivision vs. nitrate-nitrogen values are presented in Figures 2, 3, 4, 5, and 6 and Table 5.

The significance level by Student's t-test exceeds 95 to 99.9 percent for the correlation between distance across the subdivision from upgradient to downgradient ground water flow vs. nitrate-nitrogen in the water-supply wells (Table 5). For the Sandy Knolls Subdivision (Figure 2), the highest correlation coefficient is 0.87 in a direction parallel to the ground water flow beneath the subdivision. For the Oak Park subdivision (Fig-

ure 3), the highest correlation is 0.55, which is 30 degrees north of the direction of ground water flow. This differ-

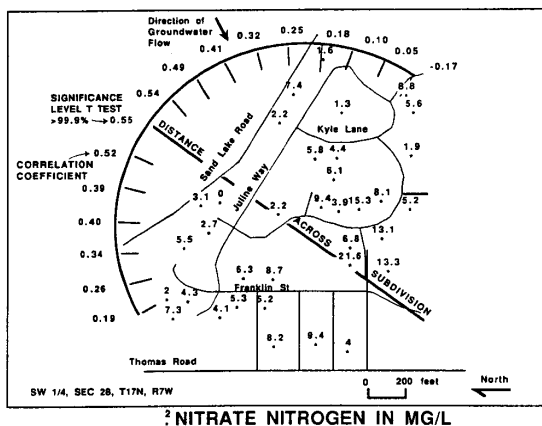


Figure 3. Nitrate-nitrogen concentrations, ground water flow direction and correlation coefficients for distance across subdivision vs. nitrate-nitrogen for Oak Park Subdivision.

TABLE 5
Correlation Coefficients and Significance Level by T-Test for Distance Along Ground Water Flow Line, Nitrate-Nitrogen, and Number of Upgradient Septic Vents

Subdivision	Distance Along Ground Water Flow Line vs. Nitrate-Nitrogen	Nitrate-Nitrogen vs. Number of Upgradient Septic Vents	
		90°	28°
Sandy Knolls			
6/88	0.87 >99.9%	0.58 >99.9%	0.60 >99.0% <99.9%
9/88	0.87 >99.9%	0.62 >99.5% <99.9%	0.63 >99.5% <99.9%
Pine Grove-Deer Park			
5/88	0.57 >99.9%	0.51 >99.9%	0.49 >99.9%
9/88	0.54 >99.9%	0.45 >99.9%	0.49 >99.9%
Oak Park			
6/88	0.40 >99.0% <99.5%	0.39 >99.0% <99.5%	0.46 >99.5% <99.9%
9/88	0.41 >99.0% >99.5%	0.33 >95% <97.5%	0.50 >99.5% <99.9%
Lowes Creek			
5/88	0.44 >95% <97.5%	0.44 >90% <95%	0.59 >99.5% <99.9%
9/88	0.61 >99.5% <99.9%	0.63 >99.9%	0.75 >99.9%
Briarwood			
7/88	0.56 >97.5% <99.0%	0.63 >99.0% <99.5%	0.49 >95% <97.5%
9/88	0.72 >99.5% <99.9%	0.44 >90% <95%	0.71 >99.5% <99.9%

ence is to be expected because the direction of ground water flow indicated from topographic map interpretation is a regional direction and may differ from the local ground water flow paths within the subdivision. For the Lowes Creek subdivision (Figure 4), the highest correlation is 0.61 in a direction parallel to the ground water flow beneath the subdivision. For the Briarwood subdivision (Figure 5), the highest correlation coefficient is 0.74, which is 25 degrees southwest of the direction of ground water flow. Again, the reason for this difference is probably the same as that given for the Oak Park subdivision. For the Pine Grove-Deer Park subdivision (Figure 6), the highest correlation coefficient is 0.54 in a direction parallel to the ground water flow beneath the subdivision. A common characteristic for all subdivisions is the general decrease in correlation coefficients in the direction 90 degrees to the ground water flow direction. Table 5 presents the correlation coefficients and significance levels for the May, June, or July 1988 set of nitrate-nitrogen values for each subdivision.

In general, nitrate-nitrogen values increase from the upgradient side to the downgradient side of each subdivision. This indicates that the source of the nitrate-nitrogen in the water-supply wells may be from land-use activity within the subdivision.

Correlation Between Nitrate-Nitrogen and the Location of Septic Vents

To help determine the possible source or sources of nitrate-nitrogen within the subdivision, the nitrate-nitrogen value in each water-supply well was correlated to the number of upgradient septic vents of soil absorption systems. This was accomplished two ways: (1) by counting the number of septic vents within a quadrant upgradient of each well; and (2) by counting the number of septic vents within a 28-degree angle upgradient of each well. The 90-degree angle was arbitrarily selected and the 28-degree angle was calculated from the size of a contaminant plume from an absorption bed 10 meters (33 feet) square serving a three-bedroom home. The computer model "MYGRT" (Electric Power Research Institute, 1986) was used to determine the size of the contaminant plume. Significance levels by Student's t-test (Davis 1986) exceed 90 percent to 99.9 percent for the correlations between nitrate-nitrogen at a water-supply well and the number of upgradient vents of soil absorption systems (Table 5). The level of significance for the 28-degree angle of the contaminant plume generally equals or exceeds the significance level for the 90-degree angle. This suggests that the septic systems are a source of the nitrate-nitrogen in the water-supply wells. Other sources may include lawn fertilizer applied by homeowners in the subdivision or agricultural fertilizer in the soil beneath the subdivision as a result of past farming practices prior to the construction of the subdivision. The latter source is unlikely for several of the subdivisions because initial construction of the subdivisions began in the early to mid 1970s (Table 2), which would allow sufficient time to remove agricultural fertilizer from the permeable soil in the subdivision and

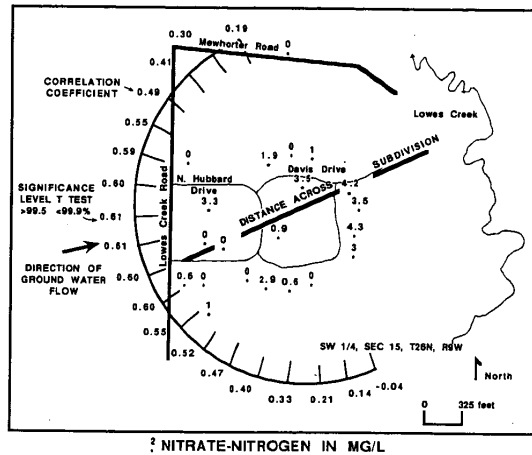


Figure 4. Nitrate-nitrogen concentrations, ground water flow direction and correlation coefficients for distance across subdivision vs. nitrate-nitrogen for Lowes Creek Subdivision.

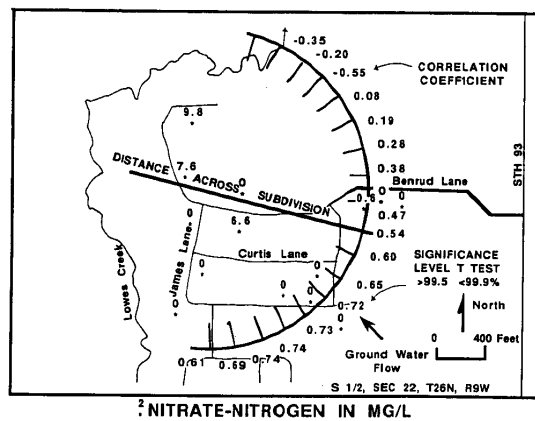


Figure 5. Nitrate-nitrogen concentrations, ground water flow direction and correlation coefficients for distance across subdivision vs. nitrate-nitrogen for Briarwood Subdivision.

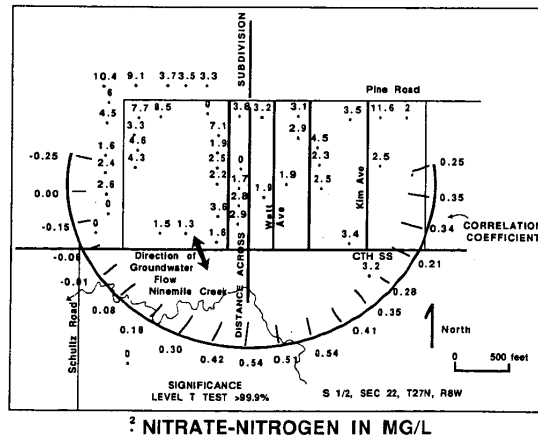


Figure 6. Nitrate-nitrogen concentrations, ground water flow direction and correlation coefficients for distance across subdivision vs. nitrate-nitrogen for Pine Grove-Deer Park Subdivisions.

TABLE 6
Correlation Coefficients and Significance Levels by T-Test for Selected Correlations

	Mean Lot Size per Subdivision Acres	Travel Time Along Flow Length per Subdivision Years	Hydraulic Gradient	Hydraulic Conductivity
Mean Nitrate-Nitrogen mg/L per Subdivision	r = -0.85 >97.5% <99.0%	r = 0.91 >99.0% <99.5%	r = -0.88 >97.5% <99.0%	r = 0.84 >97.5% <99.0%
Highest Nitrate-Nitrogen mg/L per Subdivision	r = -0.83 >97.5% <99.0%	r = 0.56 <90%	r = -0.87 >97.5% <99.0%	r = 0.86 >97.5% <99.0%

from beneath the subdivision through the ground water flow system. For example, the travel times of ground water beneath the subdivisions are from 1.8 to 8.3 years (Table 3).

Correlation of Nitrate-Nitrogen with Other Parameters

Table 6 presents for the subdivisions the correlation coefficients and significance levels for mean and highest nitrate-nitrogen values vs. mean lot size, travel time for ground water across the subdivision, hydraulic gradient of the water table, and hydraulic conductivity of the sediment beneath the subdivisions. The mean nitrate-nitrogen of Table 6 is the average of the mean nitrate-nitrogen for the two sets of nitrate-nitrogen values for each subdivision and includes the mean and highest nitrate-nitrogen values for the Mill Run subdivision in Wisconsin as reported by Tinker (1986). All significance levels are 97.5 percent or higher except for highest nitrate-nitrogen vs. travel time across the subdivision. The high significance level of the correlation between mean and highest nitrate-nitrogen values vs. lot size indicates that mean and highest nitrate-nitrogen values may be predicted for new or yet-to-be constructed subdivisions that are similar in soils and hydrogeology to the subdivisions studied here. For example, the linear regression equation for mean lot size (Table 2) vs. highest nitrate-nitrogen (Table 4) for the subdivisions is $Y = -13.6X + 25.5$. The correlation between mean lot size (Table 2) vs. highest nitrate-nitrogen (Table 4) for the subdivisions is also significant (>97.5 percent <99 percent) for a polynomial regression. The differences between the linear and polynomial regressions are at the low and high range of values for highest nitrate-nitrogen and lot size. For example, the linear regression equation suggests that as lot size (X) approaches zero, the highest nitrate-nitrogen value (Y) is 25.5. Actually, as the lot size approaches the physical size of the absorption field of the septic system, the nitrate-nitrogen value approaches the concentration of nitrogen in the absorption field. Conversely, as the highest nitrate-nitrogen value (Y) approaches zero, the lot size (X) is 1.9 acres (0.77 hectares) by the linear regression equation. Theoretically, as the highest nitrate-nitrogen value approaches zero, the lot size approaches infinity. Of course, any prediction of values outside of the range of input values for the correlation may not be valid.

If the highest nitrate-nitrogen value (Y) equals the

drinking water standard of 10 mg/L, the minimum lot size is 1.1 acres (0.45 hectares) per lot. In the past, the generally recognized minimum lot size for septic tank placement in areas not served by municipal sewerage has been 0.46 acres (0.19 hectares) (Reneau 1979 and Yates 1985). This standard of 0.46 acres (0.19 hectares) per lot is based on engineering rather than environmental considerations (Perkins 1984). A minimum lot size is one approach to control nitrate-nitrogen levels in a subdivision. However, Robertson et al. (1989) report nitrate-nitrogen values in a plume from a septic system at more than 50 percent of the source concentration for a distance of more than 330 feet (100 meters) from the tile bed. Thus, a well located immediately downgradient of a septic system on an adjacent lot may have nitrate-nitrogen exceeding 10 mg/L. A minimum lot size in conjunction with a strategy for the location of wells and septic systems in a subdivision must be a part of the planning process for any subdivision in order to prevent ground water tapped by a well from exceeding 10 mg/L.

The correlation between mean nitrate-nitrogen vs. travel time across the subdivision is greater than 99 percent and may allow the prediction of mean nitrate-nitrogen for future subdivisions in similar soils and hydrogeologic settings. However, the low correlation between highest nitrate-nitrogen and travel time precludes the prediction of highest nitrate-nitrogen levels from travel-time data. The study of additional subdivisions may help clarify the relationship of nitrate-nitrogen concentrations in the well water to hydrologic parameters.

Nitrogen Mass Balance Model

To further identify the source or sources of nitrate-nitrogen in the water-supply wells, three nitrogen mass balance models were applied to the subdivisions.

The nitrogen mass balance equation presented by Wehrmann (1984) is:

$$V_b C_b + V_i C_i + V_s C_s - V_p C_p = (V_b + V_i + V_s - V_p) C_o,$$

where:

- V_b = volume of ground water entering the subdivision from upgradient area
- C_b = concentration of nitrate-nitrogen contained in the ground water entering the subdivision
- V_i = volume of precipitation infiltrating beneath the subdivision
- C_i = concentration of nitrate-nitrogen contained in the infiltrating precipitation

- V_s = volume of septic effluent introduced beneath the subdivision
 C_s = concentration of nitrate-nitrogen contained in the septic effluent
 V_p = volume of ground water pumped by wells beneath the subdivision
 C_p = concentration of nitrate-nitrogen contained in the pumped ground water
 C_o = diluted concentration of nitrate-nitrogen leaving the subdivision.

Some of the input parameters require additional equations as described by Wehrmann (1984). The mixing zone between the recharge from the subdivision and the ground water is determined by the calculation of the transmissivity of the aquifer. The Wehrmann model does not allow for input of nitrogen from lawn fertilizers.

The BURBS nitrogen mass balance equation (Center for Environmental Research, Cornell University, 1985) considers nitrogen input from turf, natural land, and impervious land. Therefore, lawn fertilizer is an input parameter to the model. The BURBS model predicts the nitrogen content recharging to the water table. The modeler must then decide an appropriate mixing zone between the recharge and the ground water.

The "combined" nitrogen mass balance model presented in this paper combines the Wehrmann model with the BURBS model in the mass balance equation: $V_b C_b + (V_t + V_i + V_n + V_s - V_p) C_{BURBS} = (V_b + V_t + V_i + V_n + V_s - V_p) C_o$, where V_b , C_b , V_s , V_p and C_o

are as defined previously for the Wehrmann (1984) model, $V_s = V_p$, and:

- V_t = volume of water recharged from turf
 V_i = volume of water recharged from impervious land
 V_n = volume of water recharged from natural land
 C_{BURBS} = nitrate-nitrogen concentration in recharge to ground water.

All three models were placed on a spreadsheet to calculate the concentration of nitrate-nitrogen. Table 7 presents the input parameters and source of the data for the "combined" nitrogen mass balance model.

Tinker (1987) and the National Association of Home Builders Research Center (1988) reviewed the sensitivity of each parameter for the BURBS model. Wehrmann (1984), Bauman et al. (1985), and Tinker (1986) reviewed the sensitivity of each parameter for the Wehrmann model.

Table 8 presents the mean and highest nitrate-nitrogen for each set of samples and the predicted nitrate-nitrogen from the Wehrmann model, the BURBS model, and two predictions from the model presented in this paper. The first prediction is with a transmissivity based on an aquifer thickness of 100 feet (30 meters); the second with a transmissivity based on the average difference between the depths of the wells and depths to the water table. The 100-foot (30 meter)

TABLE 7
Sources of Input Data to Nitrogen Mass Balance Model

1. Fraction of land in turf	Plat map or aerial photograph
2. Fraction of impervious land	Plat map or aerial photograph
3. Average persons per dwelling	Survey of residents or county planning office
4. Housing density	Plat map or aerial photograph
5. Precipitation rate	U.S. Weather Bureau
6. Water recharged from turf	Thorntwaite and Mather Climatic Water Budget Method by Snowdon (1985)
7. Water recharged from natural land	Same as #6
8. Evaporation from impervious surface	BURBS model (Center of Environmental Research 1985)
9. Runoff from impervious surface	Same as #8
10. Home water use per person	<i>EPA Design Manual</i> by Otis et al. (1980)
11. Nitrogen concentration in precipitation	Berner and Berner (1987)
12. Nitrogen concentration in water used	Nitrate-nitrogen values for water-supply wells in subdivision
13. Turf fertilization rate	UW-Extension, Madison, Wisconsin
14. Fraction of waste water nitrogen leached from turf	UW-Extension, Madison, Wisconsin
15. Fraction of waste water nitrogen lost as gas	Input value of 0. Lack of published research
16. Waste water fraction removed by sewer	Unsewered subdivision
17. Nitrogen per person in waste water	Dudley and Stephenson (1973)
18. Nitrogen removal rate from natural land	Same as #8
19. Transmissivity	Bradbury and Rothschild (1985)
20. Hydraulic gradient	Method described by Blanchard and Bradbury (1987)
21. Flow length across subdivision	Plat map or aerial photograph

TABLE 8
Comparison of Mean and Highest Nitrate-Nitrogen for Each Subdivision to Predicted Values from Wehrmann, BURBS, and "Combined" Nitrogen Mass Balance Models

Subdivision	Field	Wehrmann Model		BURBS Model	"Combined" Model	
	NO ₃ - N mg/L Mean	NO ₃ - N mg/L Kx100	NO ₃ - N mg/L KxMZ* ft	NO ₃ - N mg/L	NO ₃ - N mg/L Kx100	NO ₃ - N mg/L KxMZ* ft
Lowes Creek						
5/88	1.9	1.3	1.5	15.5	1.6	1.9
9/88	1.5					
(Highest)	5.7					
Oak Park						
6/88	5.2	5.0	6.9	49.4	6.4	9.9
9/88	6.3					
(Highest)	21.6					
Briarwood						
7/88	2.2	1.4	2.7	35.7	1.9	3.7
9/88	1.8					
(Highest)	9.8					
Pine Grove-Deer Park						
5/88	3.9	2.7	4.6	18.1	3.6	6.5
9/88	3.4					
(Highest)	11.6					
Sandy Knolls						
6/88	5.5	5.4	12.7	62.2	4.0	11.5
9/88	6.0					
(Highest)	13.0					

*MZ or mixing zone is the average difference between depths of wells and depths to water table.

TABLE 9
Correlation Coefficients and Significance Levels between Mean and Highest Nitrate-Nitrogen Values and the Wehrmann, BURBS, and "Combined" Mass Balance Models
Linear Regression Equation for the "Combined" Model and Mean and Highest Nitrate Nitrogen Values

Field NO ₃ - N mg/L per Subdivision	Wehrmann Model	BURBS Model	"Combined" Model	
	NO ₃ - N mg/L K* x100 ft	NO ₃ - N mg/L	NO ₃ - N mg/L Kx100	NO ₃ - N mg/L KxMZ* ft
Mean	0.99	0.12	0.97	0.90
Correlation Coefficient				
t-Test	>99.9%	<90%	>99.9%	>99.0% <99.5%
Highest	0.75	0.35	0.90	0.83
Correlation Coefficient				
t-Test	>95% <97.5%	<90%	>99.0% <99.5%	>97.5% <99.0%
	X	Y		
	"Combined" Model (Kx100 ft) vs. Field NO ₃ mg/L-highest			
	Regression Equation Y = 1.2X + 4.7			
	"Combined" Model (Kx100 ft) vs. Field NO ₃ mg/L-average			
	Regression Equation Y = 1.1X - 0.02			

* K equals hydraulic conductivity.

*MZ or mixing zone is the average difference between depths of wells and depths to water table.

thickness is an estimate from available data on aquifer thickness. Table 9 presents the correlation coefficients and significance levels of the predicted nitrate-nitrogen levels vs. the mean and highest nitrate-nitrogen levels of the water-supply wells in the subdivisions. The highest

correlation coefficients and significance levels are for the "combined" and Wehrmann models. The benefit of the combined model is that the model is based, in part, on the BURBS model, which indicates the percentage of nitrogen from lawn fertilizer and the percentage from

septic systems. For example, Table 10 shows the amount of nitrogen from septic systems and lawn fertilizer for the subdivisions. The Pine Grove-Deer Park subdivision has more nitrogen from septic systems than from lawn fertilizer, whereas the Sandy Knolls and Briarwood subdivisions have more nitrogen from lawn fertilizer than from septic systems. Table 11 provides information on fertilizer application rates for each subdivision based on a questionnaire sent to the homes sampled for nitrate-nitrogen. Although the fertilizer application rates reported by the residents may be questionable, the combined nitrogen mass balance model indicates that lawn fertilizer may be a source of nitrate-nitrogen. Petrovic (1990) states that the degree of nitrate-nitrogen leaching from a nitrogen fertilization of a turfgrass is highly variable. Petrovic states some researchers report little to no leaching, whereas others suggest that as high as 80 percent of the fertilizer was leached as nitrate-nitrogen. Factors that influence the degree of leaching were found to be soil type, irrigation, nitrogen source, nitrogen application rates, and season of application.

In summary, the value from the combined mass balance model described in this paper correlates to the mean nitrate-nitrogen in the water-supply wells of the subdivisions at a significance level greater than 99.0 percent but less than 99.5 percent and correlates to the highest nitrate-nitrogen in the water-supply wells at a significance level of greater than 97.5 percent but less than 99.0 percent. These correlations may indicate that the main sources of the nitrate-nitrogen in the water-supply wells are from septic systems and lawn fertilizers.

Conclusions

Nitrogen from lawn fertilizer and septic-tank soil-absorption systems has caused nitrate-nitrogen values to increase in the ground water beneath and on the downgradient side of the five subdivisions. In four of the five subdivisions the highest nitrate-nitrogen value equals or exceeds the drinking water standard of 10 mg/L.

Lot size, location and depth of wells, location of septic systems, amount of lawn fertilizer, and the hydrogeology beneath the subdivision are some of the parameters that must be considered to avoid unacceptable nitrate-nitrogen levels in water-supply wells in unsewered subdivisions.

The nitrogen mass balance model described in this paper predicts at a significance level greater than 99.0 percent but less than 99.5 percent the mean nitrate-nitrogen beneath the subdivision; and predicts at a significance level greater than 97.5 percent but less than 99.0 percent the highest level of nitrate-nitrogen beneath the subdivisions.

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TABLE 10
Nitrogen Leached from Turf and Septic Systems for Subdivisions Based on the BURBS Model

Subdivision	Nitrogen Leached from Turf		Nitrogen Leached from Septic Systems	
	Lbs/Acre/Yr	Percent*	Lbs/Acre/Yr	Percent*
Sandy Knolls	92.5	66	46.1	33
Pine Grove-Deer Park	5.4	18	23.6	79
Oak Park	52.1	52	46.7	47
Lowes Creek	10.8	51	9.5	45
Briarwood	37.6	68	17.3	31

* Sum of percent values may not equal 100 because of small input of recharge from non-turf land (natural and impervious land).

TABLE 11
Data on Amount of Fertilizer Applied to Lawns for Subdivisions

Subdivision	Percent of Homes that Fertilize Turf	No. of Times Fertilized Turf per Year*	No of Homes Surveyed	Percent Return of Survey
Sandy Knolls	91	2.4	15	80
Pine Grove-Deer Park	48	1.5	39	54
Oak Park	67	1.6	39	54
Lowes Creek	89	1.7	18	67
Briarwood	77	1.3	15	60

* Assumed an application rate of 3.5 lbs/1000 square feet. Residents indicated they followed fertilizer application instructions on fertilizer bags.

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