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ABSTRACT—Hydrogeologic sensitivity to contamination throughout Winona County in southeastern Minnesota was assessed using the recently developed Trojan-Perry rating method. Sensitivity varied across and within three analysis regions. The Prairie du Chien Aquifer, comprising Region I, showed a wide range of sensitivity, varying from moderate to extreme. Areas of greatest sensitivity were sites where the aquifer was unconfined and overlain by a thin layer of unconsolidated material and karst bedrock. Under these conditions water may rapidly infiltrate through the soil zone and highly dissolved bedrock and into underlying aquifers. The Ironton-Galesville Aquifer, comprising Region II, was protected from surface infiltration by the St. Lawrence siltstone and was not sensitive to contamination unless depth-to-water was less than 25 feet. An unconsolidated surficial aquifer along the Mississippi River comprises Region III, and is highly to extremely sensitive due to large water inputs from adjacent areas. Sites located on sand terraces in this region show the greatest susceptibility due to high permeability throughout the vertical profile.

The accuracy and scope of evaluations made with the Trojan-Perry rating method will improve and expand as data is collected and utilized in the methodology and computer capabilities are employed. The following primary data needs would improve the precision of hydrogeologic sensitivity analysis in Winona County: 1) soil textural classifications and thicknesses to aid in infiltration and depth-to-water analysis, particularly along the Mississippi floodplain; 2) knowledge of land management practices such as tillage and chemical application, which aid in infiltration and contaminant behavior analysis; 3) knowledge of land-use to improve infiltration, permeability, recharge, and contaminant behavior analysis; and 4) soil pH, organic matter contents, and mineralogy, which can be utilized to assess the behavior of specific contaminants or contaminant classes. Evaluating contamination sensitivity to atrazine, a widely used herbicide frequently found in county aquifers, illustrates the need for improved data.

Introduction

The evaluation of groundwater sensitivity at a county level is often difficult because geologic, soil, and land-use data is not available or does not adequately describe the natural variability in those factors. Current methodologies such as DRASTIC and LeGrand's system (1,2) are generally not capable of adequately identifying potential sites of pesticide contamination because of broad scales of analyses, failure to consider specific contaminants, and the potential for rapid changes in the water quality of aquifers, particularly in karst areas.

The analysis of groundwater sensitivity in Winona County in southeastern Minnesota is important because atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine), a widely used herbicide, has recently been found in several wells throughout the county at concentrations of up to 9μg/l (3); the current maximum acceptable limit for atrazine in drinking water is 3μg/l. Because atrazine is considered to be moderately mobile in soils (4), its presence in groundwater indicates that hydrogeologically sensitive areas may exist in the county. In 1984, a hydrogeologic sensitivity analysis of Winona County conducted by the Minnesota Geological Survey (5) indicated that aquifers in the county were at moderate, high, or very high risk. Regions of a given sensitivity were very large, generally greater than 10 sq. mi. and often greater than 50 sq. mi. Sensitivity was determined by geologic conditions in the county. Upland areas underlain by a thin soil mantle and karst bedrock, and sand terraces along the Mississippi River were at highest risk in the county. The remainder of the county was at moderate to high risk, depending primarily on the thickness of the soil and vadose zone. Small scale variations in soil and vadose zone thickness and permeability, topography, and climatology were not considered.

This evaluation is not useful for site-specific estimates of hydrogeologic sensitivity due to the large scale of analysis and limited description of sensitivity. The Trojan-Perry Rating method (6), developed in 1987, offers the potential for flexible, accurate analyses of hydrogeologic sensitivity throughout a large geographic area such as a county. In this paper we report results of an application of the Trojan-Perry method, developing a sensitivity analysis for Winona County, Minnesota.

Winona County was chosen for this sensitivity analysis for several reasons. First, geologic and soil data are available throughout the county. Second, the county has diverse geologic environments in which to apply a sensitivity analysis. Third, the study by the Minnesota Geological Survey

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provides the opportunity to compare two types of analysis. Finally, the presence of atrazine indicates that aquifers in Winona County may be susceptible to contamination.

Materials and Methods

Description of the Trojan-Perry Rating Method

With the Trojan-Perry method, an analysis region is divided into equally spaced sites. The distance between sites is a function of the goals of the analysis and the level of data available for the evaluation. A spacing of one-fourth mile is practical with widely available computer-based data and provides an adequate scale for many analyses. At each site hydrologic, climatologic, water-use, or contaminant characteristics are evaluated as factors that may influence sensitivity. Examples of factors include recharge, depth-to-water, distance to water users, infiltration/permeability of geologic materials, and contaminant attenuation. Values for a given factor are applied to scales such as those shown in Figure 1 to determine a factor score.

Because the scales do not consider all the variables influencing sensitivity, there may be errors in estimates using only factor-based sensitivity. To compensate for these inaccuracies, identifiers and correction terms may be utilized. A correction term is a numerical value which is multiplied by a factor value or score to improve the interpretability of a factor score. An example correction term would be the effect tillage has on infiltration. If a correction term can not be quantified, it may be included in a site index as a qualitative identifier (6).

Rating Score

0	1	2	3	4	5	6	7	8	9	10
10^{-12}	10^{-9}	10^{-8}	10^{-7}	$10^{-6.5}$	10^{-6}	$10^{-5.5}$	10^{-5}	$10^{-4.5}$	10^{-4}	10^{-2}

Permeability/Infiltration (meters per second)

clays,peat clay-loams silt-loams sandy-loams coarse sand
silt loams fine sand gravel
unfractured shale fractured-shale fractured-limestone
igneous/metamorphic rock fractured igneous and metamorphic
siltstone evaporites, basalt

Rating Score

0	1	2	3	4	5	6	7	8	9	10
264	121	78.9	53.9	40.5	30.3	22.5	15.3	9.1	3.8	0

Depth to water/Depth to bedrock (feet

Figure 1. Example scales for Permeability/Infiltration, and Depth-to-Water/Depth-to-Bedrock. Scores ranging from 1-10 are derived by applying values from existing data sources at an analysis site; these scores are then used in Equation 1a.

Site hazard score is determined by the following equation:

Eq. 1a $$HI = A((w_aF_a + w_bF_b + \cdots + w_nF_n)/(w_a + w_b + \cdots + w_n))$$

where HI = hazard index or site score
A = a multiplier
w = weights
F = factor score
a,b, . . . n = factors a,b, . . . n

Site hazard score is an average factor score. The relative sensitivity of two sites may thus be compared even if the data bases used in their respective analyses differ. The multiplier A is designed to increase the range of site scores for easier visual interpretation. Potential recharge, determined by any of a variety of methods, may be used as the multiplier; the use of this term improves the estimate of site sensitivity, and increases the range of site scores. Weighting terms in Equation 1a ($w_a, w_b, \cdots w_n$) give a measure of the importance of a factor in the sensitivity analysis relative to other factors. If all weights are set to 1, the denominator in Equation 1a reduces to **n**, the number of factors used in the analysis (6).

Hazard index, factor scores, correction terms, identifiers, and location are compiled into site indices and stored in data files, which may be computerized. These stored indices can be retrieved to provide descriptions for individual sites; a final sensitivity map can be developed by contouring site scores (6).

The major limitation of the Trojan-Perry method appears to be the lack of statistical correlation between rating scores and actual sensitivity, particularly when correction terms are used. Data from the literature may be utilized to develop rating scales, but these scales remain relatively inexact and untested. However, the method is sufficiently flexible that changes in input data or in scales may be readily incorporated.

Description of the Study Area

Winona County comprises 406,320 acres in southeastern Minnesota, with maximum lengths of 40 and 24 miles at the southern and western borders, respectively. The Mississippi River flows in a southeasterly direction and forms the majority of the northern and the entire eastern border of the county. The county was originally mixed grassland and hardwood forest, but agriculture now accounts for over 50 percent of the total land-use. Steep slopes along the Mississippi River Valley and adjoining stream valleys have been left forested and comprise approximately 25 percent of the total area in the county. Winona, the county seat, is located along the Mississippi River in the east-central part of the county (7).

Bedrock geology in Winona County consists of alternating beds of sandstone, shale, and limestone or dolomite deposited 460 to 525 million years ago. Along the valleys of the Mississippi River and tributary streams (primarily in the eastern third of the county), the geologic profile has been eroded and exposed, creating a steep landscape. Valley floors are relatively flat. Upland areas, located in the western and central part of the county, consist of gently to moderately rolling topography (5).

Bedrock aquifers are the primary source of potable water in Winona County. The three major bedrock aquifer groups are the Prairie du Chien-Jordon Aquifer, the Franconia-Ironton-Galesville Aquifer, and the Mt. Simon Aquifer. The Prairie du Chien Group, consisting primarily of dolomite aquifers, provides yields of 200 to over 1000 gpm for the majority of the upland areas in the county. The aquifer is confined in the extreme west-central part of the County but is unconfined elsewhere. Where it is unconfined, percolating rainwater has eroded the dolomite and created numerous solution channels (5).

The Franconia-Ironton-Galesville Group consists of fine- to medium-grained sandstones and dolomites protected from surface infiltration by the St. Lawrence Formation (a siltstone). Water yields range from 0 to 400 gpm. These aquifers are the primary source of potable water where the Prairie du Chien formations are absent or are too thin to yield adequate supplies of water. These areas are generally found near valley ridges and on valley slopes. The Mt. Simon Sandstone is the primary bedrock aquifer utilized in the valleys, but sand and gravel aquifers, though discontinuous, are used frequently for local water supplies (5).

A thin mantle of unconsolidated material overlies most of the county. This material includes red till, low in silt content, found in the eastern part of the county; a grey till, clay loam in texture, in the west; colluvium, silty to sandy and gravelly, on steep slopes; residual, with variable texture, along valley ridges; and valley fill, ranging from clayey to silty to sandy, along stream and river valleys. A thin layer of loess, generally less than 10 feet thick, overlies these materials. Soils are thin, poorly formed, and generally silt-loam in texture. Agricultural cultivation practices earlier in this century led to severe erosion of topsoil on sloping sites. The thickness of unconsolidated materials ranges from near zero in the west to several hundred feet in the east, with average thicknesses of approximately 5-10 feet in the west and 20-50 feet in the east. Numerous bedrock outcrops exist in the west. Where this bedrock is dolomite, sinkholes are common (5,8).

The study area was divided into three regions (Figure 2) based on the primary source of water supply and, in the case of Region III, the aquifer most likely to be sensitive to hydrogeologic processes. Region I corresponded to those areas underlain by the Prairie du Chien Aquifer, Region II to areas underlain by the Ironton-Galesville Aquifer (when the Prairie-du-Chien Aquifer is insignificant or absent), and Region III to stream and river valleys underlain by surficial aquifers.

Analysis Methods

A 1:200,000 county map was produced and a 40 X 24 grid overlain on that map. (The x,y coordinate system is illustrated in Figure 2.) A total of 691 sites (grid points) were evaluated, each site located at a section corner and therefore 1 mile from adjacent sites.

The Trojan-Perry method was utilized to evaluate sensitivity at each site (see *Description of the Trojan-Perry Method*, and ref. 6). The following equation was used to compute site scores and indices:

Eq.lb HI= R ((sum of factor scores)/(number of factors))

where HI	=	site score or hazard index
R	=	recharge potential (inches)
factors	=	some or all of the following: depth-to-water, depth-to-bedrock, infiltration of the root zone, and permeability of the vadose zone

Although we use inches as units for recharge, the final site scores represent dimensionless, relative sensitivity scores.

In Region I all four factors were assessed. In Region II, depth-to-bedrock was not considered because of the presence of a layer of low permeability above the aquifer. In Region III only infiltration and permeability could be evaluated due to limited data.

Factor scores at each site were determined from the scales shown in Figure 1. Values were determined from county geological maps, a soil atlas, and topographic maps. Scales were developed by compiling scales, tables, and matrices for similar factors in existing rating methods and by incorporating relevant research findings (6). Infiltration factor scores were adjusted for topographic position by use of the following multipliers (9):

Condition		Multiplier
lowlands with slopes 0-6%	—	1.11
uplands with slopes 6-12%	—	0.92
steep slopes > 12%	—	0.65
uplands with slopes 0-6%	—	1.00
bottomland slopes of 0-2%	—	1.61

The recharge multiplier in Equation 1 was computed by subtracting evapotranspiration from precipitation (P-ET). Climatological data were utilized from eight weather stations in or near Winona County. **P** and **ET** were contoured throughout the county. **ET** was computed using the following form of the Blaney-Criddle Method (10):

Eq. 2 u = Ktp/100

where u	=	monthly ET (in)
K	=	monthly ET coefficient for corn (in/°F)
t	=	monthly air temperature (°F)
p	=	monthly percent of daytime hours

The final sensitivity map was prepared by contouring site scores (HI in Eq. 1). Five relative sensitivity classes were established:

Low	—	<30
Low-Moderate	—	30-50
Moderate-High	—	50-60
High-Very High	—	60-80
Extreme	—	>80

The following identifiers were utilized in the analysis:

R,L,G,O,Br	—	topographic position, with R=bottomland slopes of 0-2%, L=lowlands with slopes of 0-6%, G=steep slopes greater than 12%, O=uplands with slopes 6-12%, Br=uplands with slopes 0-6%;
T	—	sand terraces present;
K	—	karst present;
S	—	sinkholes present;
B	—	bedrock at or near the surface;
F	—	site is located on a flood plain.

Results and Discussion

Recharge Analysis

The map of hydrogeologic sensitivity in Winona County, prepared by contouring site scores along the described sensitivity classes (See *Analysis Methods*), is displayed in Figure 3. Site scores were computed with Equation 1b. A score represents the relative likelihood that water will percolate through the soil and vadose zones and into an underlying aquifer at a given site. A particular site score can be compared to other site scores to give a comparison of relative hydrogeologic sensitivity.

Site indices were compiled for each of the 691 sites. Each index gives the location (x,y coordinates), analysis region, site or hazard score, correction terms, and identifiers for a site. Example indices are shown in Table 1. Site indices such as these, used in conjunction with Figure 3, provide insight into the variations in sensitivity within and between regions.

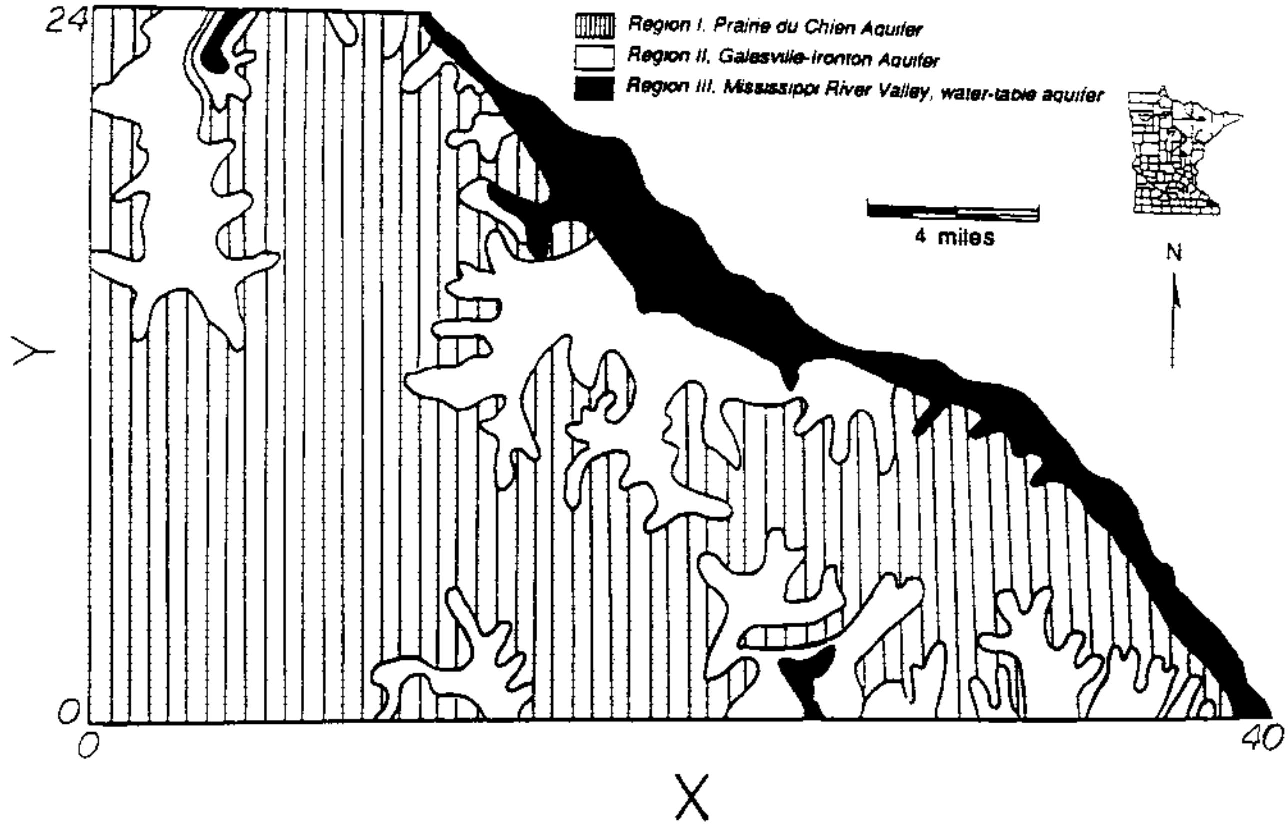

Figure 2. Map of Winona County illustrating the delineation of regions used in the sensitivity analysis. Site coordinates (x,y) are indicated. Each site is located one mile from an adjacent site.

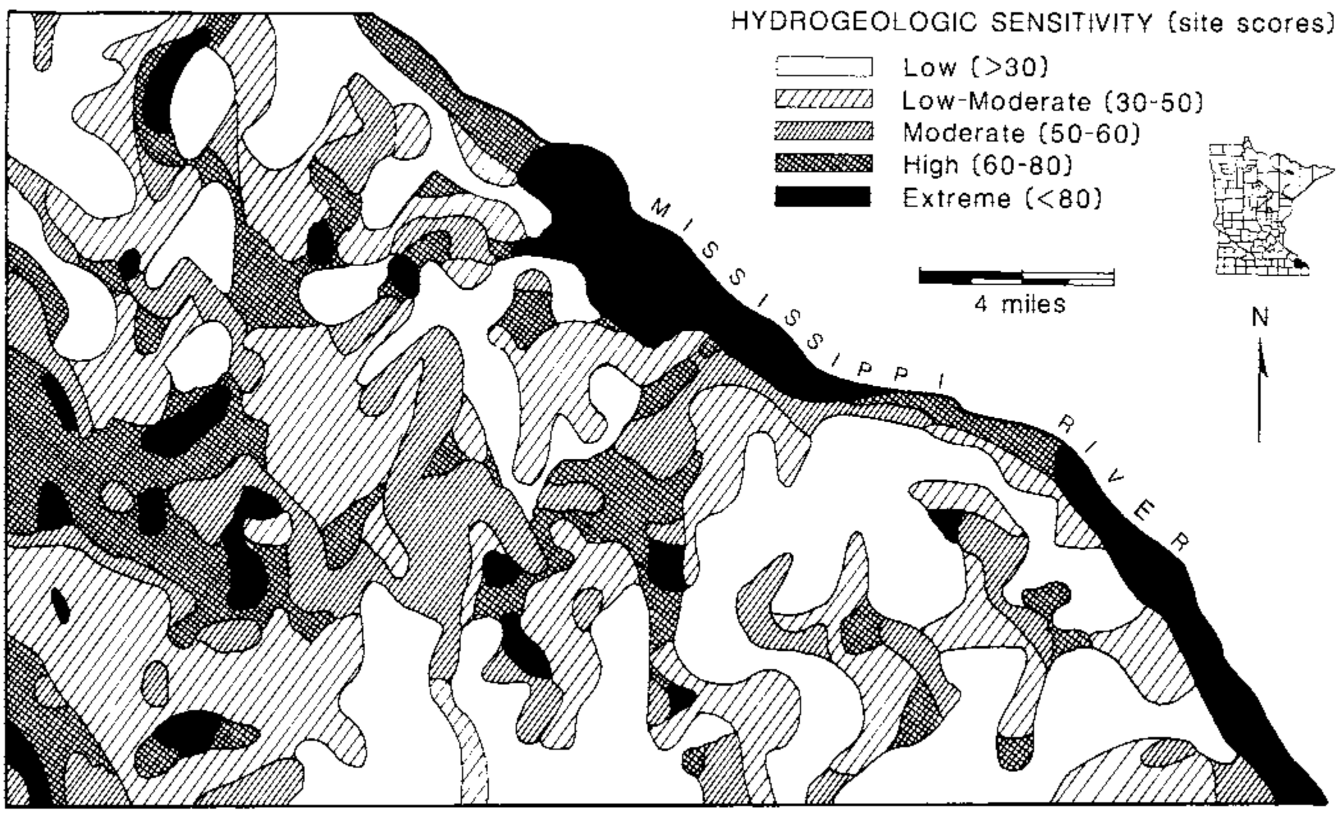

Figure 3. Sensitivity map for Winona County, Minnesota. Site scores were divided into relative sensitivity classes and contoured by sensitivity class.

Table 1. Example site indices for sites in Winona County. Site coordinates are illustrated in Figure 2. Site scores (HI) are computed using Equation 1b. These sites are considered to be representative of sites with comparable site scores throughout a region. Abbreviations represent the following: R = potential recharge (in/yr); DTW = depth to water score; DTB = depth to bedrock score; P = permeability score; I = infiltration score; T = topographic identifier; and ID = identifiers present at a site. Factor scores are determined from scales presented in Figure 1. Identifiers are described in the *Materials and Methods* section of the text.

Region	Site coordinates (x,y)	Score: HI	R	DTW	DTB	P	I	T	ID
III	24:14	46.38	11.36	—	—	4.8	3.4	G	FT
III	23:14	58.37	11.13	—	—	4.8	5.9	R	FT
III	24:12	96.60	10.91	—	—	9.5	7.85	R	FT
II	3:16	93.12	10.87	8.7	—	8.5	8.7	G	K
II	3:19	28.47	10.95	0.8	—	3.6	3.4	G	K
II	4:19	58.51	10.97	5.0	—	4.8	6.2	R	FT
I	6:4	42.24	10.56	1.3	6.1	6.1	2.6	O	K
I	6:6	60.00	10.62	0.5	9.5	8.2	4.4	O	K
I	6:12	83.55	10.78	1.0	10.0	10.0	10.0	G	K

Table 2. Statistical summary for Regions I, II, and III. F- and p values are given from a one way ANOVA test of the hypothesis that site scores between regions were equal.

	Region: I	II[a]	III	Total[b]
Number of sites	262	366	54	682
Minimum	31.83	20.82	31.05	20.82
Maximum	88.10	84.80	99.10	99.10
Mean	55.94	32.78	78.76	45.32
Std. Dev.	12.15	12.28	16.52	12.70

[a] — 9 sites were deleted from the analysis

[b] — ANOVA F-value for Ho: (Mean(Region I = Region II = Region III)) = 318.391; p-value for F < 0.0001

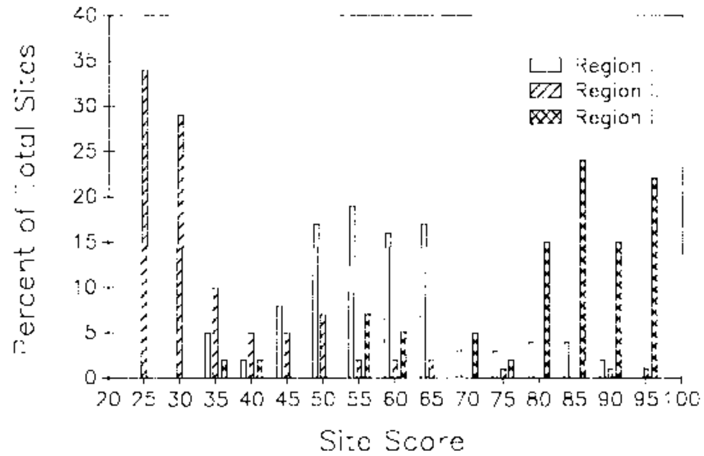

Figure 4. Distribution of site scores for Regions I, II, and III by percent. 691 sites were evaluated, with n=262, 375, and 54 for Regions I, II, and III, respectively.

Figure 4 illustrates the distribution of site scores for each region. A one-way ANOVA test of the hypothesis that all regions have equal sensitivity gives a p-value of less than 0.0001, providing strong evidence that sensitivity varies between regions. A statistical summary within and between regions is provided in Table 2. In Region II, values exceeding 85 were considered as outliers and deleted from the analysis; nine of the 691 sites were deleted. The rationale for defining and deleting these outliers is discussed below.

In Region I, average sensitivity is moderate to high although 35 percent of the total sites in the region have high-very high or extreme sensitivity and 32 percent have low-moderate sensitivity. The example indices for Region I shown in Table I indicate that differences in site score are primarily a function of depth to bedrock, which influences infiltration rate. Permeability of the vadose zone also affects score. At site 6:4, bedrock is 20 feet from the land surface. This relatively thick, unconsolidated layer consists of a clay loam soil underlain by a loamy to sandy-loam material (see Figure 1 for derivation of factor scores). The site score of 42.24 indicates low-moderate sensitivity. The identifier **K** indicates the presence of Karst bedrock at the site, although the first bedrock layer encountered may not be limestone. At site 6:6 poorly cemented sandstone is near the surface. The overlying soil is silt loam in texture. The thinner and more permeable subsoil layer leads to increased sensitivity (score = 60.00) compared to site 6:4. At site 6:12 karst limestone is at the surface, leading to extreme sensitivity despite a depth-to water of 120 feet. Sensitivity in Region I is thus related to the likelihood that water will reach the surface of the karst bedrock, where it has the potential to be rapidly transmitted to the underlying aquifer. The presence of layers of low permeability below the karst bedrock (e.g., site 6:6) or thick soil and vadose zones (e.g., site 6:4) are critical to preventing rapid recharge.

Sensitivity is low for 61 percent of the sites in Region II, with 28 percent having low-moderate sensitivity. Indices in Table 1 indicate that variations in depth-to-water primarily influence variations in site score, with infiltration rate and permeability showing less variation. Site 3:19, with a depth to water of greater than 120 feet, has low sensitivity. The soil texture is silt loam and the underlying bedrock (cemented sandstone or fractured siltstone) effectively reduces water percolation into the aquifer despite the presence of karst limestone. Site 4:19, with a depth to water of 30 feet, has moderate-high sensitivity. The soil texture is silt loam but the topographic position of the site (the base of a stream or river valley) results in a correction term of 1.61 being used for infiltration score. Sensitivity increases dramatically at site 3:16, where a thin layer of coarse material overlies the aquifer. Here depth to water is only 5 feet. Depth to water is the primary influence on sensitivity in Region II; when depth to water exceeds 25 feet, the soil and subsoil zones are able to effectively reduce the potential for water to infiltrate to the aquifer.

Sensitivity in Region III is generally very high, with 88 percent of the sites in the region having scores of 60 or greater. Table 1 indicates that sites in Region III have relatively uniform texture throughout their profile. Unconsolidated materials in the vertical profile are often not highly permeable but the dominating influence on site score is topographic position. Textures range from clay-loam to sand, but the correction term of 1.61 for topographic position dramatically increases the infiltration score for most sites in the region. Sites in Region III are located on a floodplain and receive large inputs of runoff water. Where present, sand terraces show extreme sensitivity due to high permeabilities throughout the vertical profile.

Boundaries between regions are relatively imprecise since we had to use maps of different scale in the preparation of this sensitivity analysis. Manually transferring data from different scale maps (e.g., 1:24,000, 1:100,000 and 1:200,000 scale maps were used) onto a single map incorporates uncertainties at regional boundaries. The problem is exacerbated by the lack of orthophotography for Minnesota, resulting in distortion of vertical scale on planar maps, and the fact that soil data may be available on a ¼ mile scale but accurate on a 1 mile scale.

As an example, site 21:14 reportedly has a slope exceeding 12 percent although it is located on a floodplain. Discrepancies such as this can be smoothed over by comparing adjacent site indices. For example, if site 21:14 is truly located in Region III, the slope is likely to be 0-2 percent. The correction term for infiltration score would then change from 0.65 to 1.61, resulting in a site score of 74.98, considerably higher than the given score of 46.38. As a result of such considerations, site scores over 85 in Region II were considered outliers and deleted from statistical analyses. A grid pattern of 79 X 47 (compared to 40 X 24 used in this analysis) as well as utilizing computer techniques such as Geographic Information Systems (GIS) would provide four times better areal coverage and might improve the accuracy of boundary interpretations.

The sensitivity evaluation for Winona County is limited by available hydrogeologic and soil data. Data pertaining to soil thickness and unconsolidated material are not adequate for the sensitivity we would prefer in this analysis. Broad textural classifications were used, and soil properties that might affect water or contaminant transport were not available. Our depth-to-water analysis was based on a limited number of observations from existing wells in Region II; depth-to-water data were not available for Region I. Data on land-use and management practices that affect water transport were not available at a scale useful for this type of analysis. A more thorough sensitivity analysis would include factors such as locations of tilled land, forest land, native prairie, and mining or excavation activities. An updated soil survey for Winona County has recently been completed and computerized soil survey information will be available soon. Soils information might then be incorporated at the ¼ mile scale to improve the precision of the analysis. Information available in the soil survey, including soil thickness, permeability, and attenuation properties, can readily be incorporated into the sensitivity analysis once appropriate rating scales have been established and Equation 1 appropriately modified.

Contaminant Mobility: Atrazine as an Example

The analysis presented above deals with recharge potential; it does not address the problem of contaminant sensitivity and should not be utilized for this latter purpose without modification. For example, a contaminant such as atrazine, which is widely used and has been found frequently in wells in Winona County, could be assessed in conjunction with the preceding analysis. To accomplish this, the physical and chemical properties of the geologic medium through which atrazine is transported must be evaluated. For such an analysis, data on the root zone (0-4 feet) is critical. This zone represents the greatest opportunity for attenuation and degradation (11). Flow rate, soil moisture content, soil pH, soil organic content and clay type are important factors affecting atrazine attenuation and mobility (4,11-25). Discussion of the specific interactions involving atrazine in soil are beyond the scope of this paper, but a factor scale may be developed relating soil properties and hydrogeologic sensitivity to atrazine contamination. The literature cited above provides an example of the extent of information required when attempting to assess contaminant behavior in the environment.

An example of an attenuation scale for atrazine is shown in Figure 5. This scale primarily considers attenuation of atrazine in the soil zone. It presents options to the user in determining atrazine attenuation and it considers the major factors influencing atrazine mobility. When computerized soil survey information becomes available, soil data may be used in conjunction with Figure 5 to determine sensitivity to atrazine contamination for aquifers throughout Winona County. The following equation could then be utilized in that analysis:

Eq. 3 $HI = R((2I + DTW + DTB + P + A)/(6))$

where HI	=	hazard index or site score
R	=	potential recharge (inches)
I	=	infiltration factor score
DTW	=	depth to water factor score
DTB	=	depth to bedrock factor score
P	=	permeability factor score
A	=	atrazine attenuation factor score

This equation is a modified version of Equation 1, and includes an attenuation factor for atrazine and a weight of 2 for infiltration to account for the influence of infiltration rate on atrazine mobility. An evaluation of hydrogeologic sensitivity to contamination by atrazine must include the attenuation and infiltration factors because they are specifically developed for an atrazine analysis. Other factors may be deleted if information on them is unavailable. Correction terms or additional factors may be added if they can be quantified.

The reader should be cautioned that Equation 3 and the scale shown in Figure 5 are intended to illustrate the methods used in developing an analysis of hydrogeologic sensitivity for a specific contaminant. The interactions of most potential contaminants in the environment are extremely complex and diverse. The simplified model shown here may not represent the actual fate of atrazine in the environment, but it does illustrate the type of analysis that would be required for contaminant-specific evaluations of hydrogeologic sensitivity.

Summary

The preceding analysis of sensitivity in Winona County considers a variety of factors that influence sensitivity in the county. It expands on the analysis conducted by the Minnesota Geological Survey in 1984 (5), combining available soil, geologic, and climatologic data into a relatively small-scale analysis.

Despite the limitations imposed by the availability of soil and geologic data, we believe the analysis prepared with the Trojan-Perry method offers a practical and accurate description of hydrogeologic sensitivity throughout the county. In addition, this analysis can be readily modified to include improvements in data availability, or additions of new information as illustrated with our atrazine sensitivity evaluation.

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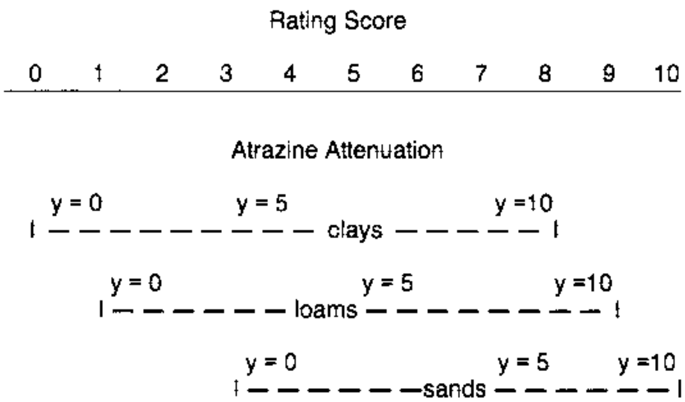

where y = $((2pH + (1/OM)) + 8)/3.29 * k(O/O_{FC})$
pH = average soil pH of the root zone
OM = largest organic matter content of any 1 foot increment in the root zone (g/g soil)
k = constant
O, O_{FC} = average moisture content of the surface 6-inches at time of atrazine application and at field capacity, respectively (cm^3/cm^3)

Figure 5. Attenuation scale for atrazine. The scale was developed from literature and research work. The equation illustrated was determined by a regression of factor score on pH and organic matter content. The constant **k** gives a measure of the decreased absorption of atrazine as water content increases. The value of **k** will generally be 1.0-1.5 (6).