Geological Sensitivity Assessment of Groundwater Systems: A Pilot Study for Scott County, Minnesota?
Summary and Evaluation

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Abstract

Geologic Groundwater Sensitivity Assessments were carried out in a Pilot Study for Scott County, Minnesota, according to DNR Guidelines' Level-1, -2, and -3 specifications. The first objective was to carry out a complete assessment for the entire county as a feasibility study. The second objective was to develop and to test various modifications to the basic guideline methodology. For the Level-1 assessment a modified version (Case #2) involving readily available well information and a surficial geology map is sufficient to meet the needs for a preliminary assessment of a county planning agency and more consistent and useful than the original Level-1 assessment. A modified Level-2 assessment (Case #10) based on more restrictive assumptions, simplified well log analysis, and rapid Geographic Information System (GIS) based areal map interpretation methods gives an internally consistent and conservative result without requiring an excessive investment in preparation time and effort. The third objective was to validate the methodology in general and the modifications in particular. Four methods are used: (1) statistical frequency analysis of relating process based physical-hydrologic decision variables or chemical analyses as dependent variables to areal map distribution of rating classes; (2) checks for internal consistency by an inter-parameter method of correlating and comparing decision variables to percentage occurrence in the sensitivity rating classes; (3) cross-correlation of groundwater chemistry analyses to sensitivity ratings and tritium age classes; (4) inter-parameter cross comparison between relative occurrence of sensitivity rating classes and tritium ages. The validation was carried out on results from 409 well records. The four methods of checking and validating showed the geologic groundwater sensitivity assessment methodology to be reliable, rationally based, and internally consistent.

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List of Abbreviations

BWSR	Board of Water and Soil Resources
CJDN	Cambrian Jordan Sandstone
Cl	Chloride
CWI	County Well Index
DEM	Digital Elevation Model
DNR	Minnesota Department of Natural Resources
DO	Dissolved oxygen
DTW	Depth to water (table)
DTWL	Depth to water level (in well)
EIS	Environmental Impact Statement
EPPL 7	Environmental Planning and Programming Language
GIS	Geographic Information System
H-High	High Sensitivity (rating)
L-Low	Low Sensitivity (rating)
LPU's	Low permeability units
M-Moderate	Moderate Sensitivity (rating)
M – mixed	Tritium age bracket
MATWT	Material at the water table
MDH	Minnesota Department of Health
MGS	Minnesota Geological Survey
MPCA	Minnesota Pollution Control Agency
MPU’s	Moderate permeability units
NO3-N	Nitrate as Nitrogen
OPDC	Ordovician Prairie du Chien Group
QBAA	Quaternary buried aquifer
QWTA	Quaternary water table aquifer
R – recent	Tritium age bracket
STDV	Standard deviation
TIGER-DGT	Digital terrain files
TLPU's	Total thickness low permeability units
TMPU's	Total thickness moderate permeability units
TM&LPU’s	Total thickness moderate and low permeability units
TU	Tritium Units
TVZ	Thickness of the vadose zone
US EPA	U.S. Environmental Protection Agency
US SCS	U.S. Soil Conservation Service
USGS	U.S. Geological Survey
V – vintage	Tritium age bracket
VH-Very High	Very High Sensitivity (rating)
VL-Very Low	Very Low Sensitivity (rating)

Geological Sensitivity Assessment of Groundwater Systems: A Pilot Study for Scott County, Minnesota? *Summary and Evaluation*

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Purpose and Scope

The general purpose of this document is to present the results of a project carried out for the Minnesota Department of Natural Resources Waters Division (DNR) in a summarized form, to discuss the validity of the groundwater sensitivity assessment methodology, to evaluate the proposed modifications, and to formulate recommendations to the lead agency for future modifications.

The scope of the presentation is to review the basic methodology of geologic sensitivity assessments, illustrate the method with examples of sensitivity maps, show the Geographic Information System (GIS) based qualitative assessment of incremental modifications, and to introduce new concepts of geohydrologic sensitivity and anthropogenic hazard assessments as possible future tools for a more comprehensive integrated vulnerability assessment.

The basis for this summary is the findings and data presented in the Final Technical Completion Report (Final Report)[1]. The Final Report consists of a narrative Part I[2], with appendices, and two M.S. Theses, Part II by Sandeep R. Burman[3], and Part III by Mark S. John[4].

The document as presented here was written to stand alone as a summary and analysis of the project. In slightly modified form it also constitutes the last chapter of Part I of the Final Report [2].

Geological Sensitivity Assessment

Assessment Methodology

The results summarized in this section serve three purposes:

[1] Pfannkuch, H.O., (1998, tentative), Scott County, Minnesota, geological groundwater sensitivity criteria and methodology development project, Technical Completion Report submitted to Minnesota Department of Natural Resources Waters Division (in preparation), St. Paul.

[2] Pfannkuch, H.O., (1998, tentative), Geological sensitivity assessment of groundwater systems–a pilot study for Scott County, Minnesota: methodology, criteria, and applications, (Part I of Final Report [1], (in preparation), St. Paul.

[3] Burman, S.R., (1995), Pilot study for testing and refining an empirical groundwater sensitivity assessment methodology, unpublished Master's thesis, University of Minnesota, Minneapolis, 258 pp., (Part II of Final Report [1]).

[4] John, M.S., (1994), Ground-water hazard risk assessment: a preliminary model for Scott County, Minnesota, unpublished Master's thesis, University of Minnesota, Minneapolis, 159p, (Part III of Final Report [1]).

1. To compare, evaluate and discuss the impact of various modifications that have been applied to the original DNR Guidelines[5] using GIS[6] applications to select the most appropriate methodology,

2. To evaluate the basic concept of sensitivity assessment and its underlying assumptions by testing and validating the results of the original guidelines and the modifications through independent checks, and

3. To provide an assessment of the Guidelines and recommendations about the methodology to the DNR.

The basic methodology and the results of the sensitivity assessments and their modifications have been discussed in detail in the Final Report [1]. The results of the various versions of the methods are presented on maps that show the areal distribution of regions of sensitivity ratings from Very Low to Very High sensitivity categories and on difference maps that show the areas where changes in sensitivity ratings have taken place between various levels of modifications. These areas are also summarized in GIS count files.

Assessments were carried out for the three assessment levels (Levels-1, -2, and -3) by applying the methodology described in the DNR Guidelines and introducing various modifications. In the Final Report [1] many cases and variants are discussed.

The general intent of the modifications that have been introduced is to change step by step some of the appropriate decision variables, rating categories and threshold values for rating classes. In general this is done by introducing more internally consistent and inherently logical procedures following a process based approach. It also tends to simplify the methodology and render it more conservative from the point of view of risk management. The results of this approach is shown in Table 5.1, which summarizes the simplifications introduced to classify and rate various geologic materials found in the well log descriptions of the County Well Index (CWI)[7]. The rating index number in the last column of the table is obtained according to 'Step 1' of the DNR Guidelines Level-2 instructions (see Table 5.2).

Table 5.2(a) shows the original DNR sensitivity rating matrix with the following sensitivity classes: VL-Very Low, L-Low, M-Moderate, H-High, VH-Very High. These sensitivity classes are derived from travel time considerations, where the total travel time of a water molecule from the surface to the water table is inversely related to the sensitivity (DNR Guidelines [5], pages 9 and 10).

The decision variables are:

1. Vadose zone thickness (expressed as depth to water later in this report) where the full depth is taken into account without considering a ten foot buffer zone at the top,

2. Barrier units or protective units in the vadose zone, such as moderate permeability units (MPU) and low permeability units (LPU), and

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[5] Geologic Sensitivity Project Work Group, (1991), Criteria and guidelines for assessing geologic sensitivity of ground water resources in Minnesota, Minnesota Dept. of Natural Resources, Div. of Waters, St. Paul, 122 p.
[6] Pfannkuch, H.O., Hunt, S.J., and Burman, S.R., (1993), Pilot project for determination of hydrogeologic sensitivity of Scott County, Minnesota, in: Proceedings geographic information systems and water resources, J.M. Harlin and K.J. Lanfear, eds, March 14-17, 1993, Mobile, Alabama, American Water Resources Association Technical Publication Series TPS-93-1, Bethesda, MD, p.101-111.
[7] Wahl, T.E. and Tipping, R.G., (1991), Groundwater data management–the county well index, Minnesota Geological Survey, St. Paul, 38 p.

3. Geologic material at the water table rated according to its hydraulic conductive properties.

Table 5.1: Geologic Materials Rating Table from DNR Guidelines

Descriptors				
Engineering (ASTM Unified)	Geologic Log	Driller's Well Logs	Pilot Study	Rating
Unconsolidated Materials				
Clayey gravel(CG), silty gravel(GM), Poorly graded gravel(GP), well graded gravel(GW), poorly graded sand(SP), well graded sand(SW)	Outwash, glacial lake silt, fine sand, sand and gravel, terrace deposits, organic material, peat, loess,	Any combination of sand and gravel that does not include the term clay	**Sand/ Gravel**	**2**
Silty sand(SM), Clayey sand(SC)	Sandy loam till, loamy sand till, alluvium, colluvium	Clay sand, sandy clay, hard pan, gravely clay, clay and rock, any other description modified by clay	**Mixed**	**3**
Fat clay(CH), lean clay(CL)	Glacial lake clays, loamy till, clay loam till, clay till	Clay	**Clay**	**4**
Consolidated Materials				
Limestone, dolomite	Karstic limestone, limestone, dolomite	Limestone, limerock, Shakopee, Prairie du Chien, etc. rock	**Bedrock (limestone)**	**1**
Sandstone, igneous or metamorphic rock	Sandstone, igneous or metamorphic rock	Sandstone, sand rock, Jordan, St. Peter, etc. rock		**2**
Siltstone	Siltstone, interbedded sequence or mixed deposits, shaly limestone, sandy shale	Shale modified by limestone or sandstone (seamud), mudrock		**3**
Shale	Shale	Shale		**4**

The shaded areas in Table 5.2(a) represent the rating classes for the materials considered in this report. Scott County does not have obvious karst conditions in the Level-2 sensitivity assessment. Table 5.2(b) summarizes the changes in the matrix of decision variables that have been introduced by the various modification processes in this report and contrasts these with the original decision variable rating matrix from the DNR Guidelines. The shaded area in Table 5.2(b) indicate ratings where the sensitivity has been increased by one level compared to the original rating in Table 5.2(a).

Sensitivity Maps

A total of eleven variants of the sensitivity assessment methodology were retained for this discussion. A detailed description of each is given in Part I [2], Section 4 of the Final Report of the pilot study. The published DNR methodology and various modifications to it are summarized in Table 5.3. Of the 11 Cases, Case #1 (Level-1 assessment) and Case #3 (Level-2 Point Method) follow the DNR guidelines strictly. Case #8 (Level-2 Area Method) also follows the DNR Guidelines, but a lower sensitivity rating class with depth to water (DTW) greater than 100 ft. is introduced as an additional discriminator. This addition only affects a very small area of Scott County by giving it a Very Low rating, and does not change the basic pattern of the DNR area assessment. These three cases, #1, #3 and #8, are used as standards against which the relevant modified maps are compared.

Table 5.2: DNR and Modified Rating Matrices for Level-2 Assessment

5.2(a): DNR Level-2 Rating Matrix

	Water Table Material Rating								
Rating Class	**1** Karst Conditions			**2**		**3**		**4**	
Vadose Zone Thickness	<20'	20-50'	>50'	<20'	>20'	<20'	>20'	<20'	>20'
Barrier Units in Vadose Zone									
Absent	**VH**	**VH**	**H**	**VH**	**H**	**M**	**M**	**L**	**L**
Single MPU >20'	**-**	**H**	**M**	**-**	**M**	**-**	**M**	**-**	**L**
Aggregate LPU's >10'	**-**	**H**	**M**	**-**	**M**	**-**	**M**	**-**	**L**
At least one LPU >10'	**-**	**M**	**L**	**-**	**L**	**-**	**L**	**-**	**L**

5.2(b): Modified DNR Level-2 Rating Matrix

	Water Table Material Rating								
Rating Class	**1** Karst Conditions			**2**		**3**		**4**	
Vadose Zone Thickness	<20'	20-50'	>50'	<20'	>20'	<20'	>20'	<20'	>20'
Barrier Units in Vadose Zone									
Absent	**VH**	**VH**	**H**	**VH**	**H**	**H**	**M**	**M**	**M**
Single MPU >20'	**-**	**H**	**M**	**-**	**M**	**-**	**M**	**-**	**L**
Aggregate LPU's >20'	**-**	**H**	**M**	**-**	**M**	**-**	**M**	**-**	**L**
At least one LPU >20'	**-**	**M**	**L**	**-**	**L**	**-**	**L**	**-**	**L**
Aggregate LPU's >100'	**-**	**-**	**VL**	**-**	**VL**	**-**	**VL**	**-**	**VL**

The modifications that are made to the assessment procedure concern both the criteria and the decision variables. They can affect the qualitative definition of the variable or the quantitative value of thresholds or levels. An example of the first is to use the dominant material in the zone of water table fluctuation, rather than use the single value obtained from the CWI well log. An example of the second is the increase of the threshold value at which low permeability units (LPU's) become significant factors (from 10 ft. of the Guidelines to 20 ft.). A summary of the modifications and the resulting corresponding cases is given in Table 5.3.

Table 5.3: Summary of Modifications to Criteria and Decision Variables of DNR Guidelines

Case No.	Level	Method	Criteria	Modification of Decision Variables
1	1	Area	DNR Guidelines	None
2	1	Area	Surficial geology and vadose zone thickness	Surficial geologic map rating and depth to water
3	2	Point	DNR Guidelines	None
4	2	Point	Existence of very thick Low Permeability Units (LPU) in vadose zone	Add rating class: ΣLPU's >100'
5	2	Point	Dominant material in water table zone of fluctuation	Average material rating in zone of water table fluctuation (±10')
6	2	Point	Increased LPU thickness	Increase LPU thickness threshold from 10' to 20'
7	2	Point	Increase of sensitivity rating of water table material	Sensitivity rating for clay at water table as sole criterion: increased from low to moderate
8	2	Area (CWI)	DNR Guidelines and averaged water table material	Average material rating in zone of water table fluctuation (±10')
9	2	Area (DEM)	DNR Guidelines and averaged water table material	Average material rating in zone of water table fluctuation (±10'), and ΣMPU's >20' rather than one MPU > 20'
10	2	Area (CWI)	Increased LPU thickness and increase of sensitivity rating of water table material	Increase LPU thickness threshold from 10' to 20' and sensitivity rating for clay at water table as sole criterion: increased from low to moderate
11	2	Area (DEM)	Increased LPU thickness and increase of sensitivity rating of water table material	Increase LPU thickness threshold from 10' to 20' and sensitivity rating for clay at water table as sole criterion: increased from low to moderate

Level-1 Sensitivity Maps

For illustration purposes the following cases are shown here. The soils-based DNR Level-1 geologic sensitivity map (Case #1) is shown in Figure 5.1. It displays a variegated areal patchwork of sensitivity map units from which it is difficult to interpret generalized, large scale sensitivity trends. The modified Level-1 map (Case #2) is shown in Figure 5.2. It is based on surficial geology and a more realistic depth to water parameter. It displays larger map features and can be considered a hybrid between the Level-1 and Level-2 methodologies.

Level-2 Sensitivity Maps - Point Method

A number of sensitivity assessments were carried out according to the DNR Guidelines, and several others were modified to various degrees, as discussed below. The results were represented in map form and are a visual representation of the method.

Figure 5.1: Scott County Level-1 Geologic Sensitivity Map (Case #1)

Figure 5.2: Scott County Level-1 Geologic Sensitivity Map (Case #2)

To illustrate the outcome of a Level-2 Point Assessment methodology the modified map representing Case #7 is given on Figure 5.3. The map shows the somewhat arbitrary polygon shapes of the sensitivity areas. These are the result of point ratings expanded to cover the area around a well by using spatial extrapolation functions in the Geographic Information System developed by the Minnesota State Planning Agency[8] (EPPL 7). This representation may be acceptable when it is based on a large number of points. The mapped region on Figure 5.3 shows reasonable coherence and is similar to mapped regions based on the area methods.

Level-2 Sensitivity Maps - Area Method

The Level-2 Area methodology is based on contouring functions and process-based areal interpolation inherent in the GIS methodology. The map based on the DNR Level-2 Area Method corresponds to Case #8 in this report and is shown on Figure 5.4. Its counterpart (Figure 5.5) is the modified Level-2 Assessment (Case #10) which incorporates all of the proposed modifications and uses geologic information, such as a depth to water parameter, obtained from the County Well Index (CWI) database maintained by the Minnesota Geological Survey (MGS). To illustrate the GIS internal difference procedure a difference map is shown on Figure 5.6. It is the result of a GIS overlay and difference operation between the two maps, Case #8 and Case #10. It shows and quantifies the areas that remain in the same rating class and those that either increase or decrease in sensitivity because of the modifications introduced. Quantitative area differences are tabulated in count files such as are summarized in Tables 5.4 and 5.5 discussed later in this section.

Level-3 Sensitivity Maps

A Level-3 assessment evaluates the sensitivity of aquifers below the water table aquifer. The degree of sensitivity is based on the presence of low permeability or confining layers between the water table aquifer and the deeper aquifer that slow down migration and infiltration to the lower aquifer, and result in longer estimated travel times.

Aquifers below the uppermost phreatic (or water table) water bearing unit that are candidates for a Level-3 assessment can be either buried and confined unconsolidated (drift) material or consolidated bedrock units. In the pilot study area (Scott County) buried drift aquifers do not consist of county wide, areally extensive and coherent, tightly confined or hydraulically isolated units. They are rather, relatively small and not well defined units with a high degree of hydraulic connection to the water table aquifer. Therefore this study of a Level-3 assessment considers the bedrock units only.

In Scott County the most heavily used deep bedrock aquifers are Ordovician and Upper Cambrian carbonate and sandstone formations. The first encountered is the Lower Ordovician Prairie Du Chien Group. This aquifer is a major source of drinking water in the county. These formations do not have overlying continuous protective bedrock units at this location. The Eau Claire Formation would be the first low permeability confining unit that is not significantly eroded and that covers the entire study area. It protects the Mt. Simon Sandstone aquifer, the first bedrock unit on which a DNR Level-3 assessment could be implemented. However, the scarcity of wells in the Mt. Simon, 11 out of a total of 1462 CWI wells would make this unfeasible. Of the bedrock aquifers beneath the water table system, the uppermost formations are the most heavily utilized for drinking water and hence are the most important for purposes of sensitivity assessment.

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[8] Minnesota State Planning Agency, (1990), Environmental Planning and Programming Language, Version 7, Release 2.04, St. Paul, MN.

Figure 5.3: Scott County Level-2 Geologic Sensitivity Map (Case #7)

Figure 5.4: Scott County Level-2 Geologic Sensitivity Map (Case #8)

Figure 5.5: Scott County Level-2 Geologic Sensitivity Map (Case #10)

Figure 5.6: Scott County Level-2 Geologic Sensitivity Difference Map (Case #10 Minus Case #8)

This study developed an entirely new approach to assess the sensitivity of such deeper aquifers. Although they underlie the water table aquifer, they do not have a distinct confining unit that isolates them hydraulically from the upper formation. The concept used in this approach is that sensitivity of the deeper aquifer should also be proportional to the vertical travel time of a water borne conservative contaminant from the land surface to the deeper aquifer, including its travel time through the water table aquifer. This is a simple extension of the travel time concept that a Level-2 Assessment is based upon. It adds the movement of the contaminant downward from the water table to the top of the next lower aquifer, and is the basis for additional protection. Thus in this system, the Level-3 sensitivity assessment incorporates the Level-2 sensitivity assessment with the protection provided by the saturated zone. The travel time to the deeper aquifer is the sum of travel time to the water table and the travel time within the water table aquifer itself. Hence the deeper aquifer would have at least the same degree of protection and therefore the same sensitivity rating as the portion of the water table aquifer immediately overlying it. Any additional protection gained by virtue of presence of low permeability units within the saturated zone would translate into a further lowering of the sensitivity rating.

Due to the scarcity of well data in the study area for most of the deeper aquifers in the pilot study area, application of the DNR Level-3 assessment method would not be feasible. However, this modified method provides a conservative estimate of the sensitivity of all the deeper aquifers in a single procedure. The results of the Level-3 assessment study for this report according to this modified approach are shown in map view on Figure 5.7.

GIS Analysis of Maps and Discussion of Results

A quantitative way to assess the differences between the various methods and modifications is to compare the cumulative areal extent of mapped sensitivity rating classes produced by GIS generated and manipulated count files.

Table 5.4 is a summary of the results from the count files showing the percentage of area falling into the five sensitivity rating classes for each of the cases. These results are discussed in detail below for each standard and each modified methodology. Figure 5.8 is a graphical representation of the information from Table 5.4.

Table 5.4: Summary Table: Percentage of Area in Rating Class

	Level-1		Level-2 Point Method					Level-2 Area Method			
Rating	Case Number										
Class	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11
Very Low				7.6	7.6	7.6	7.6			2.8	2.8
Low	21.1	71.1	63.3	55.7	55.3	50.7	44.8	77.3	79.3	57.4	57.8
Moderate	38.7	13.2	14.6	14.6	15.7	19.2	25.1	8.0	7.1	20.1	19.8
High	7.4	4.6	14.4	14.4	13.8	15.0	15.0	7.4	8.0	12.4	14.1
Very High	32.8	11.1	7.7	7.7	7.5	7.5	7.5	7.3	5.5	7.3	5.5

Figure 5.7: Scott County Level-3 Geologic Sensitivity Map: Area Method Based on Level-2 Assessment and LPU's in Saturated Zone

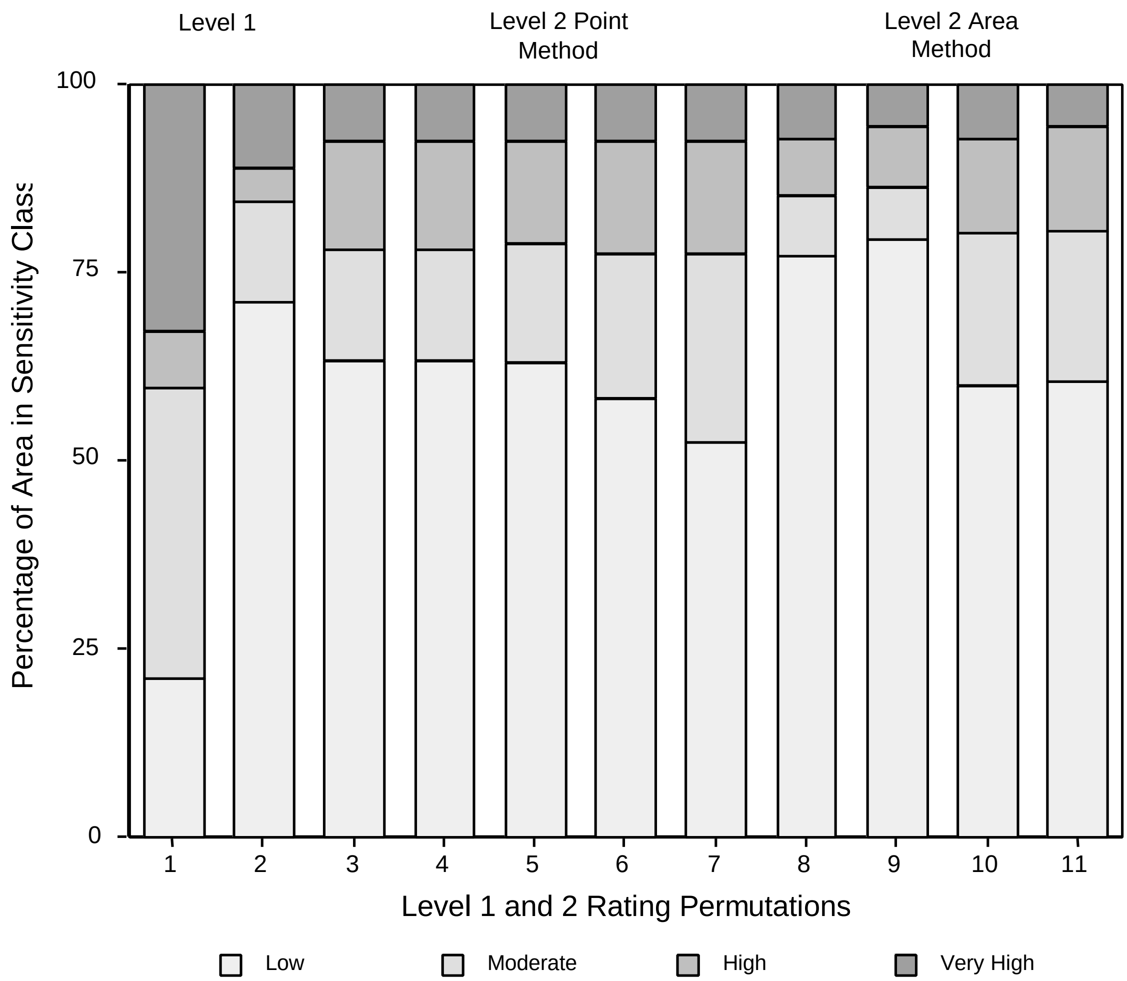

Figure 5.8: Summary Diagram of Areal Change in Sensitivity Class by Assessment Methodology

Discussion of Level-1 Sensitivity Maps

For this level, results show a striking difference between the DNR method (Case #1) and the modified method (Case #2). The original method results in a high percentage of Very High and High ratings (40%) and a low percentage of Low sensitivity rated area (21%) compared to a Low rating of 71% for the modified Level-1 method. This is because the original method relies on soil atlas information that has a tendency to fragment the sensitivity mapping units and to overestimate the extent of the High and Very High sensitivity rating categories. This is based on inadequate information about the depth to the water table and the thickness of the vadose zone. The depth to water in soil atlases is given as either larger or smaller than 6 ft. The less than 6-ft. category produces the higher sensitivity ratings. Most likely it does not represent the real geohydrologic water table, but a seasonal transitional feature linked to slow drainage or a temporarily perched water table condition.

The modified method, Case#2, results in areal rating distributions of the combined High and Very High categories (15.7%) that are comparable to those of the DNR Level-2 Area method, Case #8 (14.7%). They are slightly less than that of the areal rating percentage of the two most sophisticated Level-2 area method modifications, Cases #10 and #11 (19.7% and 19.6%, respectively). However, knowledge or map information about the surficial geology and depth to water or water table elevation is required for the Modified Level-1 method, Case #2. This information may not be readily available, or it may be expensive to produce.

Discussion of Level-2 Sensitivity Maps - Point Method

The several applied variations (Cases #3 to #7)show a very consistent areal percentage of the High and Very High rating categories (21.3% to 22.5%) even including the original DNR method (Case #3). As more conservative modifications are made (Cases #5, 6 and 7) the areal percentage of the Low rating category decreases, the difference is taken up by the Moderate rating.

The Level-2 Point Method and its variations were used in this study because the density of the information base (409 located and verified wells from the CWI database) was high enough to produce credible map representations. These results were comparable to the results from the more sophisticated and internally consistent methods, namely Cases #6, #10 and #11. However, once the data base density is below the one available for this study (approximately 1 well/square mile) GIS produced map renditions in the form of extrapolated polygons around wells (tessellations) become less and less realistic to be useful. This is discussed in more detail on page 31 in Reference [3]. For assessments of smaller areas or localized situations the point method still serves a valuable purpose.

For counties with a limited well database the area method is more appropriate because a process based approach of extrapolating and interpolating values of decision variables can be carried out. When based on reasonable professional expertise these results are more realistic than the statistically generated interpolations of the point method.

Discussion of Level-2 Sensitivity Maps - Area Method

The Level-2 Area Method variations (Cases #8, #9, #10 and #11) produce areal percent ratings for the Very High and High categories of 14% for the method closest to the original DNR guidelines and the least conservative of the modified approaches. The two more conservative approaches and internally consistent methods, Cases #10 and #11, give areal distributions of these two ratings of 19%.

Case #11 is based on a very elaborate method to obtain the depth to water map for the county. It is the difference between a water table map representing a high position (worst case scenario) and a digital elevation model of the land surface (DEM). A large effort went into the construction of the water table map, based on CWI well log data, evaluation of time series data from state operated observation wells, and mass measurements of accessible water table wells during the data gathering phase of this project.

Case #10 represents modifications that are based on a depth to water map obtained by the difference of a simplified CWI water table interpretation and a simplified topographic surface. Surprisingly the two modifications show practically the same areal percentage distribution of rating categories. The reason for this is that the decision variable ‘depth to water’ is reduced to a partitioning depth contour line (isobath) separating areas with DTW of more than 20 ft and less than 20 ft. This oversimplification results in a map resolution that is too coarse for the refinements of the more sophisticated water table and DEM procedure to be perceived. The method is applicable for Scott County, or in general where the error introduced by extrapolating the depth to water data from individual well information is negligible compared to the value obtained by the true difference between the mapped water table elevation and the topographic elevation. This would generally be the case for areas with low or subdued topographic relief.

The most sophisticated method (Case #11) would only be warranted if a finer definition of the DTW values into more classes is needed. Under the present conditions Case #10 which shows approximately the same map and areal distribution of sensitivity areas as Case #11, is sufficient.

Comparison between Methodologies of Level-1 and Level-2 Assessments

The differences between various methods and modifications expressed as changes in the percentage of area in the rating class are summarized in Table 5.5 and visualized in Figure 5.9. The results again show the large discrepancy of the original Level-1 methodology with all of the other methods and modifications.

Table 5.5: Evaluation of Rating Class Difference Between Methods and Criteria

Criteria/ Method	[1-2]		[5-4]	[6-5]	[7-6]		[7-4]	[8-4]	[11-4]
Class									
Low	50.0		-0.3	-4.7	-5.9		-10.9	14.3	-2.4
Moderate	-25.5		1.1	3.5	5.9		10.5	-7.7	4.1
High	-2.8		-0.6	1.2	0.0		0.6	-6.4	0.3
Very High	-21.7		-0.2	0.0	0.0		-0.2	-0.2	-2.0
Change	50.0		1.1	4.7	5.9		11.1	14.3	4.1

Criteria/ Method	[8-4]	[9-8]	[10-8]	[10-9]	[11-10]	[11-9]	[11-4]	[11-7]
Class								
Low	14.3	2.0	-17.2	-19.2	0.5	-18.7	-2.4	8.2
Moderate	-7.7	-0.9	12.1	13.0	-0.3	12.7	4.1	-5.3
High	-6.4	0.6	5.0	4.4	1.7	6.1	0.3	-0.9
Very High	-0.2	-1.8	0.0	1.8	-1.8	0.0	-2.0	-2.0
Change	14.3	2.7	17.1	19.2	2.1	18.8	4.1	8.2

Table 5.6 gives an overview of how successive levels of increasing conservative modifications produce sensitivity changes. Using the Point Method as demonstration it shows that all modifications produce a change of 13% and for the area method it is 19%. The modification that seemed to introduce the greatest change is the change of the rating criterion for the decision variable ‘material at the water table’ from Low to Moderate when clay is present at the water table (6%). Increase in the low permeability units' thickness threshold from 10 ft. to 20 ft. produces a change of 4.6%.

In conclusion it has to be pointed out that although the modifications produce variations in the sensitivity ratings, the two most critical rating categories, Very High and High sensitivity (corresponding to travel times of less than a year) remain remarkably constant throughout all of the variations of the methods (19.37% ± 3.29%) except for the original DNR Level-1 Method (40.2%). This result is reassuring in that all methods provide a certain consistent safety margin. It also indicates that the methods are acceptable for general planning and groundwater management purposes on a County scale.

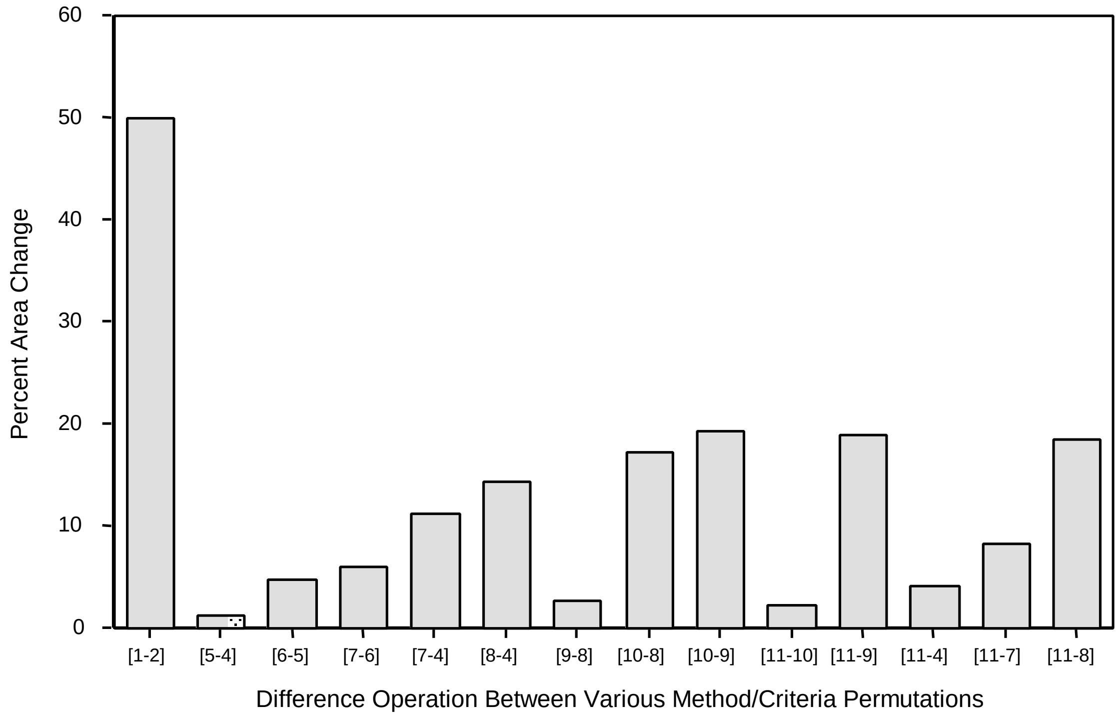

Figure 5.9: Summary of Total Area Change from Table 5.5

Discussion of Level-3 Sensitivity Maps

The philosophy behind the preparation and presentation of a Level-3 geologic sensitivity map has been described in detail above. The quantitative results are summarized in Table 5.7. Since the Level-3 approach used here is based on an area assessment its findings are compared to the Level-2 assessment by the area method, original DNR Guidelines, Case #8, and the modified area method based on CWI depth to water information (Case#10), respectively.

It shows a dramatic shift to the Very Low rating class, as one would expect. At the other end of the spectrum there is no significant change. This result is due to the fact that a mapped area that already has a low percentage or absence of low permeability units (LPU's) in the vadose zone, producing a High or Very High rating, is unlikely to have significant thickness' of LPU's below the water table.

Conversely, a unit that already is rated Low or Very Low has a high probability that further protective units are to be found below the water table and that there would be a general decrease in the sensitivity rating. In the example of this study the shift has been mainly from the Low rating class into the Very Low rating class.

One other important finding from this study is that the areas classified as High and Very High remain approximately the same for Level-2 and Level-3 assessments. This means that the results of a Level-2 assessment for the High and Very High rated areas have transfer value to the assessment of underlying deeper aquifer systems.

Table 5.6: Summary of Sensitivity Rating Changes Due to Modifications

Decision Variables Added	Difference Operation	Sensitivity Change		Cumulative Change
	Modifications	Percent	Area(km^2)	Percent
Point Method				
Averaged water table material in zone of fluctuation	[4] -[5]	-1.76 +1.1	16.76 10.5	2.86
Increase LPU thickness threshold from 10' to 20'	[5] -[6]	+4.64	44.3	7.5
Sensitivity rating for clay at water table as sole criterion increased from Low to Moderate	[6] - [7]	+5.93	56.55	13.43
All modifications	[4] - [7]	-1.76 +11.67	16.76 111.3	
		13.43	128	
Area Method				
DNR-CWI / DNR-DEM	[8] - [9]	-6.0 +3.0 9.0	56 29 85	
DNR-CWI / Mod. CWI	[8] - [10]	-0.04 +17.12 17.16	0.33 162.5 162.83	
Mod. CWI / Mod. DEM	[10]- [11]	-5.15 +3.0 8.15	49 29 78	
DNR DEM / Mod. DEM	[9] - [11]	-0.04 +18.8 18.84	0.33 178 178.33	

Table 5.7: Level-3 Sensitivity Ratings

	Level-3			Level-2			
	Area Method			DNR (#8)		Modified (#10)	
		Percent of County Area in Rating Class					
Rating	Area (km^2)	(%)	Cum. (%)	(%)	Cum. (%)	(%)	Cum. (%)
Very Low	501.4	52.6	52.6			2.79	2.79
Low	187.5	19.7	72.3	77.3	77.3	57.43	60.22
Moderate	108	11.3	83.6	8.04	85.34	20.09	80.31
High	105.7	11.08	94.68	7.37	92.71	12.42	92.73
Very High	51.1	5.36	100	7.28	100	7.28	100
Total	953.7	100		100		100	

Geohydrologic Susceptibility Assessment

Geohydrologic Recharge Potential

Geohydrologic Parameters

The methodology for assessing groundwater sensitivity to surface generated contamination is based on factors that control the travel time from the land surface down to the aquifer of interest. The one major factor it does not directly account for is surficial recharge, which in many cases can provide a significant driving force for the vertical migration of contaminants. In the following the major factors that govern recharge at the surface are identified, first by using GIS to describe the spatial distribution of these factors across Scott County, and then by using GIS map algebra to combine these factors into a model of the potential for recharge over the county. The more detailed description of the methodology and findings is presented in Chapter 8, "Correlating Sensitivity with Recharge Potential" in Reference [3], pages 189 - 209**.** For the present summary of findings the representation of the recharge potential is compared with the distribution of groundwater sensitivity at the Level-1, -2, and -3 assessments over the same area. This provides an analysis of how well the sensitivity methods account for recharge, which plays a major role in determining how rapidly contaminants will be mobilized and transported downwards. Thus the potential for groundwater contamination in an area of high sensitivity is further increased if the recharge potential over the same area is also high. Another region with the same rated sensitivity will be at less risk if the recharge potential is lower.

The recharge module is based on the assumption that infiltration and downward migration of water is strictly vertical; it ignores upward flow and discharge areas such as wetlands and springs. The four component layers used to develop the recharge module were as follows:

1. Drainage density. Expressed as length of surface drainage per unit area, in this case miles per square mile. This quantity has long been used to quantify overall runoff potential versus infiltration potential of any given region.

2. Precipitation. The precipitation received by an area obviously has marked influence on the recharge to groundwater. Mean annual rainfalls based on long-term records of the three nearest recording stations in and around Scott County were used to obtain a Thiessen type polygon distribution for the study area.

3. Land use based runoff. The Scott County land use maps were digitized into EPPL 7 and presented as a map. Each of these land use areas has a different runoff potential, which can be quantified according to the SCS curve numbers for various urban, suburban and agricultural land uses[9]. Based on the SCS curve numbers available for the land use categories themselves or very similar ones, their runoff potential was rated for this study from *Very High* to *Very Low*. These runoff potential ratings are inversely related to recharge potential.

4. Surface slope. The slope of the land surface plays an obvious role in determining the relative importance of runoff versus infiltration. Higher slopes are conducive to faster runoff and lower infiltration, and conversely. The topographic map created by EPPL7 from the digital elevation model (DEM) files for Scott County was used to create a slope map.

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[9] USDA, (1992), Hydrology guide for Minnesota, USDA Soil Conservation Service, Saint Paul, Minnesota, 8 chapters, October 1992.

Recharge Potential Rating Classes

The runoff ratings expressed by these four components were reclassed according to a scheme in which the individual parameter classifications were transformed into compatible rating classes. This produced scores of the relative recharge potential across the county. By further EPPL7 map arithmetic and reclassification operations on these first results a final score could be produced. A more detailed description of this procedure is found in chapter 8 of Reference [3], cited above. The resulting final recharge potential map (Figure 5.10) has five classes of relative recharge potential, ranging from 'Very Low' to 'Very High'. These have been assigned numerical values from 1 to 5 corresponding to increasing recharge potential classes.

Recharge potential rating classes do not correspond exactly to geologic sensitivity rating classes as developed for the Level-1, -2 and -3 assessments. They do, however, present a relative ranking of conditions that correspond to an increased likelihood that contaminants will be mobilized and transported towards the water table. In this respect they can be qualitatively linked with the geologic sensitivity classes to at least give some warning where increased transport activity can be expected.

The previously developed sensitivity assessment maps also are based on a division into five classes, with the Very Low rating having a value of 1 and Very High corresponding to 5. A simple EPPL 7 operation obtains the difference between this recharge potential map and the Level-1, -2, and -3 sensitivity maps.

The map algebra was designed such that the difference maps had five classes:

1. Areas where the numerical value of the sensitivity rating is greater than that of the recharge potential. In such areas also, the sensitivity does not need to be modified by the recharge potential since there is no underestimation of the overall risk to the groundwater.

2. Areas where the sensitivity rating value was the same as the recharge potential value (congruence). In these areas the relative groundwater sensitivity coincides with the relative recharge potential and hence there is no apparent need to modify the sensitivity rating.

3. Areas where the recharge potential value is higher than the sensitivity rating by 1 class value. Here there is a need for further evaluation to ensure that the sensitivity analysis has not underestimated the risk to groundwater.

4. Areas where the potential recharge rating is two classes higher than the sensitivity class. Here the discrepancy between geologic sensitivity and recharge potential has increased, and so has the likelihood that the geologic sensitivity may be enhanced by greater recharge.

5. Areas where the recharge potential is three classes higher than the sensitivity rating. This obviously reduces the confidence in the degree of protection afforded to the groundwater in the area as implied by the sensitivity rating alone, and further evaluation and accounting for this high recharge potential in regional/local planning is advisable.

The results of these operations are summarized in Table 5.8. More detailed comparisons of areal distributions are discussed and shown in Chapter 8 in Reference [3], Table 8.3 , page 203.

Figure 5.10: Scott County Geologic Sensitivity Map: Relative Recharge Potential

Table 5.8: Difference of Relative Recharge Potential and Level-1, -2, and -3 Sensitivity Ratings

Class	Level-1		Level-2		Level-3	
	Percent of County Area Affected					
	(%)	Σ(%)	(%)	Σ(%)	(%)	Σ(%)
Sensitivity > Recharge	25.38	23.38	12.05	12.05	10.0	10.0
Congruence	20.43	43.81	9.9	21.95	6.12	16.12
Recharge > by 1 class	21.5	65.31	27.66	49.61	15.04	31.16
Recharge > by 2 classes	22.2	87.51	29.77	79.38	25.56	56.72
Recharge > by 3 classes	4.8	100	20.64	100	43.3	100

Analysis and Comparison to Geologic Sensitivity

Review of the area differences produced by introducing the recharge potential rating from Table 5.8 seems to indicate that the Level-1 geologic sensitivity ratings are least affected or most in line with the recharge criteria. The Level-2 and Level-3 ratings differences get progressively worse as the recharge potential increases. Part of this evaluation is real and should be taken into account. Part of it, however, is an artifact of the methodology, the criteria and the decision variables used in the various Level-1, -2, and -3 assessment approaches.

The Level-1 assessment rates geologic sensitivity according to the geologic materials present at or near the ground surface based on soil surveys. It therefore is soils specific, and different soils series are distinguished on the basis of properties such as geology, parent material, physiography, drainage and relief. Furthermore the depth to water as obtained from soil surveys is really the depth to a seasonal high saturation depth for the soil horizons. It is more likely to be intimately linked to variation in precipitation, topography and near surface infiltration capacities. Since these also are the factors that were used in deriving the recharge potential ratings, it seems reasonable that the distribution of Level-1 sensitivity ratings will come closest to corresponding with that of surficial recharge potential. The importance of near surface properties in determining geologic sensitivity is lost in moving towards the Level-2 and Level-3 assessment, where geologic variations deeper in the vadose zone and a more realistic representation of the water table come into play.

Due to the considerable area in all three levels of sensitivity assessment for which the relative recharge potential exceeds the relative sensitivity rating, it appears that some efforts should be made to assess the recharge potential to avoid serious underestimation. It should be used as a valuable supplement and to refine the geologic sensitivity assessments. However, this approach needs more study and validation before it can be incorporated into the sensitivity assessment process, especially in the areas of weighing the various potential recharge criteria and in the assigning of realistic threshold values for the classification ranges. It is introduced here to draw attention to the important factor of recharge potential and its influence on the geologic sensitivity rating.

Anthropogenic Hazard Assessment

Objectives and Approach

The previous discussion in this section dealt with purely geologic and hydrologic parameters that affect the time of travel criterion and thereby the sensitivity of the groundwater. Regardless of the physical rating parameters the actual threat of contamination to groundwater is also determined by the likelihood of release of harmful substances into the environment.

The basic objective of this part of the pilot study is therefore to identify human activities that have a potential to negatively affect groundwater quality. In particular, it is to identify and locate specific sources of hazard and utilize them in a decision tree based on an Integrated Risk Framework approach. This chapter is based on a M.S. Thesis by Mark John, which appears as Part III of the Final Report [1]. The details of the Integrated Risk Framework are discussed in Part III (Figure 1.2: *Integrated Risk Framework*, p.9 and Figure 1.3: *Hazard Potential Rating*, p.10) [4].

The present analysis is not a risk assessment for which likelihood of occurrence of an adverse event (groundwater pollution) and its public health, economic and ecological consequences would have to be specified. A hazard assessment looks at identifying the sources of risk and the description and nature of the potential of adverse effects emanating from a source.

Furthermore, the basic idea of this pilot project is to gather information about the methodology on how to integrate cultural information into the geologic sensitivity assessment of the Level-1 methodology via GIS procedures. Its purpose is to identify problems with handling data structures, data pedigrees from various sources, and developing the appropriate GIS functions and operations for combining, weighing and displaying data on thematic and combined layer and map presentations.

Hazard Source Inventory

An ideal procedure would consist of an exhaustive inventory of potential hazard sources, their location, areas affected, degree of hazard involved and the potentially affected targets. With appropriate contouring and interpolation algorithms these parameters could be transformed into areal coverage to produce potential hazard rating maps or layers. These combined with the geologic sensitivity and geohydrologic recharge potential layers would produce a sensitivity assessment within an integrated potential hazard framework.

This type of map goes beyond a simple geologic sensitivity assessment, which is based on geologic factors alone. It explicitly takes into account the likelihood or possibility of contaminants being released from the surface and propagated to the groundwater body. This type of assessment is more properly called a vulnerability assessment, including geological, contaminant specific transport characteristics and anthropogenic factors.

Point Method Applied in this Study

In the absence of an extensive database an areal coverage or map representation of hazards in the county becomes less feasible and a point method has to be introduced. This approach is somewhat similar to the point method of DNR Guidelines Level-2 assessments discussed earlier. This approach is the inverse of the area method that assigns a hazard score for each sensitivity map unit. Rather, with this point method, sites that are potential sources of contamination occupy a pixel or entire cell within the raster system of the EPPL 7 GIS, regardless of their actual areal extent.

The corresponding geologic sensitivity rating at that point is attached to the site and the two (or more, depending on the situation) are combined via a GIS algorithm. The resulting new rating will give an indication on how the introduction of a hazard rating affects the geologic rating on a point by point basis.

The result of this pilot project is a point hazard rating combined with the geologic sensitivity rating, a Level-1 assessment in this case, and a methodology to evaluate the influence or effect that introduction of hazard rating scores for various factors will have on the overall sensitivity rating.

Limitations

This part of the study was carried out under time and funding limitations. Therefore only a limited set of new data could be generated: five different potential hazard sources were represented as thematic layers. Only point and line objects were identified, no areal sources were identified. At the time this study was carried out the only digital geologic sensitivity assessment available was the Level-1 DNR Guidelines sensitivity map (Case #1) for Scott County, which had to serve as the basis for comparison and analysis.

However, these limitations do not impair the main objective of this study, which is to develop and demonstrate a methodology to integrate the hazard potential with the geologic sensitivity assessment. The study proposes recommendations about how easily accessible hazard information can be used to determine the level of detail necessary to prepare commensurate geologic sensitivity assessments.

Methodology

Theory and Assumptions

The basic idea behind this study is very simple: (1) the greater the number, density, volume and strength of potential sources of contamination in an area the greater the likelihood of failure and emission into the environment, and (2) the closer these sources are to sensitive targets the greater the impact. Therefore this study makes a distinction between sources and targets and treats them as different elements in the GIS model.

The presence of a potential source or generator of contamination is noted and its location into one cell is recorded as a site address. Three source categories considered are municipal/community, industrial, and agricultural generators. Where feasible the volume, strength and likelihood of failure (age of installation) were noted as attributes.

The three targets considered are population and population density, surface hydrologic features and water bodies, and groundwater.

Source Factors

Five groups of hazard source objects were selected on the basis of accessibility and availability of the database. The sources are represented as points (one point per single raster cell) or lines (strings of raster cells).

Three generators produce the five types of potential hazards as follows:

1. Municipal/Community Sources: Landfills (14 sites), large community septic tank systems (9 sites),

2. Industrial/Commercial Sources: Pipelines (approximately 70 miles occupying 1683 cells), storage tanks (20 sites), and

3. Agricultural Sources: Feedlots (168 sites).

The total number of cells that contain a potential hazard site for this particular study is 1894, out of a total of 214,000 cells, or 0.89% of the covered area. This is not an exhaustive study inclusive of all potential sites, but rather a work to develop methodologies on how to incorporate hazard factors in an assessment study. In a full scale hazard identification project it is expected that the number of sites would be much higher.

For each member of the five newly generated information groups a separate GIS layer is created. Each potential hazard source is a discreet spatial object, either a point or a line (pipeline information). Each site on the thematic layers has a location and associated attributes such as identification or description, characteristics and a hazard score.

Target Factors

The three principal targets used in the GIS model are population, surface hydrography and surface water bodies, and groundwater.

Population numbers, densities and distribution have been obtained and reconstructed from land use data compiled by the Metropolitan Council, a regional government planning agency. Population can actually be considered both a target as well a possible source of contamination. As a target, which is the main emphasis of this study it is sensitive to contamination of groundwater as consumer of water, the denser the population the more of the resource will be used and the larger numbers will be affected. On the other hand, large numbers and high densities of population may constitute a threat to the groundwater environment as generators of pollution. Three layers of land use data representing dwellings were combined into one representing population.

For the second target layer, hydrographic information in the form of major rivers and lakes in the county were extracted from existing TIGER DGT files, a digital terrain file. Information on smaller creeks, agricultural drainage systems and wetlands are not contained in these files and therefore are not considered in this study. For a complete assessment they would have to be included.

The accessibility of the uppermost aquifer as a target for surface generated contaminants is expressed by the sensitivity ratings obtained in the various geologic sensitivity assessments as described in the DNR Guidelines and in this report.

The hazard assessment study had the Level-1 sensitivity assessment as a map available in useable digital format. This Level-1 map and its sensitivity ratings serve both as a comparison standard against which the potential hazard source sites are evaluated, and as a component in determining the rating of each site.

GIS Operations

Spatial Analysis Functions

The objective of the GIS operations is to evaluate the spatial relation between the source sites and the targets by spatial analysis functions, to quantify the degree of hazard or threat associated with each source site, and to obtain a hazard ranking or score for each site by combining site scores from the five source layers in an overlay procedure. The elements of the analysis functions included: population, distance to surface water, cumulative site density and interference, and geologic sensitivity (Level-1 DNR Guidelines).

Population density was determined within a 1-mile radius of each source cell in the raster representation of the county through a GIS focal analysis and neighborhood procedure.

A GIS connectivity and distance operation produced the determination of the distance of surface water bodies to every identified source site

The cumulative site density and interference GIS proximity operation counts the number and identifies the nature of potential hazard source sites within a one-mile radius of a site. It is a measure of the diversity of activities and the density of hazardous sites in a given area. If a site is relatively isolated there is less of a risk to the environment in the area than if there are several sites within the area. This assumes that all sites have an equal impact and likelihood to fail.

For all three of the above operations the resulting counts, raw scores and numeric values are normalized and reclassed to form ranges of interval classes that can be used to rank the hazard potential of each site.

The geological sensitivity layer is imported directly from the Level-1 assessment (Case #1) with its established sensitivity ratings: Low, Moderate, High and Very High.

Hazard Rating of Source Factors and Analysis

The hazard rating of source factors layer is not based on GIS operations as the above items, but simply on assignments of hazard ranking scores to each class of source factors. The requirements of an acceptable rating system are that it be consistent within a given class of source factors and between classes of different source factors. The basis for assigning hazard scores is patterned after US EPA guidelines for the evaluation of contamination potential of surface impoundments[10]. From it the number of interval classes (9) and numerical score values have been taken. A value of 9 represents the highest hazard potential. They are given below in Table 5.9.

Table 5.9: The Source Site Hazard Scores

Class	Potential hazard source	Ranking
1	Abandoned municipal landfills (dumps)	9
2	Feedlots	5
3	Large septic tank systems	3
4	Pipelines: petroleum products	9
	Pipelines: liquid propane	5
	Pipelines: natural gas	3
5	Tanks: based on volume, content and age scores (range)	1 to 9

[10] U.S. Environmental Protection Agency, (1978), A manual for evaluating contamination potential of surface impoundments, EPA/570/9-78-003, June 1978, Office of Drinking Water, Washington, D.C.

Spatial Modeling

The purpose of a GIS analysis is to show spatial relations between sites and their attributes and to produce combination of site attributes (hazard ranking scores) by overlay operations across layers. Spatial modeling carries out these analyses for a number of combination algorithms and for various configurations of decision trees. Evaluation, reclassification and ranking operations are inherent in the GIS algebra. Model runs were carried out for each layer individually and for all layers combined to produce a final summary score of all source factors.

In the first series of model runs the Level-1 sensitivity for each source site was examined. For each layer of source factors a reclassification into four equal interval classes of hazard ranking was carried out. It had to be compatible with the Level-1 rating intervals. Areal mapped distribution of the potential hazard source site and their hazard ranking were correlated with the Level-1 sensitivity score assigned to the cell in which the source site was located. No other operations were carried out. The results served as a comparison basis to evaluate the influence of various model conditions on the rating score of each source site classification.

In the second series of model runs hazard assessments were conducted for individual layers. Combined hazard scores are obtained by modifying the scores for the target factors. These modifications incorporate the various proximity analyses (population, hydrography, neighborhood density and diversity), Level-1 sensitivity, and the site hazard scores and manipulating them according to EPPL 7 criteria and reclassification algebra to obtain a hazard rank for the site in question and the source factor. Two models were run: (1) the unweighted assessment in which each factor has equal weight, and (2) the weighted assessment where the hydrogeologic sensitivity and the site hazard are each weighted by a factor of 3. Results of both models were reclassed into four equal interval classes: Low, Moderate, High and Very High sensitivity.

The outcome of each model run for each layer or factor can be represented in the three following formats: (1) three-way count files generated by GIS algebra, (2) percentage allocation of source sites falling into the four hazard classes, and (3) map representation of sites and hazard scores as points or lines.

In this summary chapter only the results for the combined layer model are presented in the site ranking and percentage distribution of hazard rating classes across the total number (1894) of potential hazard source sites. The results are summarized in Table 5.10 and illustrated on Figure 5.11.

Table 5.10: Hazard Ranking for All Layers

	1	2	3	4	5	6
Ranking	Level-1 no. of sites	Level-1 % of sites	Unweighted no. of sites	Unweighted % of sites	Weighted no. of sites	Weighted % of sites
Low	377	20	1538	81	788	42
Moderate	664	35	240	13	405	21
High	66	3	37	2	234	12
Very High	739	39	79	4	467	25
Marsh	31	2				
Water	17	1				
Total	1894	100	1894	100	1894	100

Columns 1 and 2 present the potential source sites located in a Level-1 mapped unit that has the sensitivity rating class as indicated. These serve as comparisons to unweighted and weighted model results in columns 3 and 4, and 5 and 6, respectively. It can be seen that the introduction of the hazard score factors tend to decrease the sensitivity of the hazard source cells when compared to their geologic sensitivity assessment based on the Level-1 rating of the cell in which they are located.

Between the unweighted and the weighted methods a general increase in sensitivity occurs, although not to the degree of increase of the geologic sensitivity. This is due to the fact that the Level-1 ratings and the site hazard scores are tripled in weight; instead of contributing 40% they now contribute 67% of the final score.

Some explanation of this seemingly contradictory result is in order; one would have expected that the addition of hazard factors would in general increase the sensitivity for all sites. The two categories that have the highest hazard ranking (9) are the storage tanks and the oil pipeline. However only a small number of tanks are present (20) and they are clustered in the northern part of the county, and the oil carrying pipeline occupies only a small portion of the county in the northeast. These are regions where the geologic sensitivity already is high and where population densities also are high, so they already combine to give a relatively high vulnerability rating.

The low number of the other factors, septic tanks and landfills, decreases the influence of the neighborhood diversity and density operation, and the more or less evenly spaced and distributed feed lots fall mostly into areas of low density farm population so that the influence of the population and the neighborhood diversity and density operations are diminished and offset by lower geologic sensitivity ratings. This is to be expected. If population density is a factor, then the overall vulnerability in an area of low population density or absence of potential contaminant sources is decreased even if the originally established geological sensitivity is high.

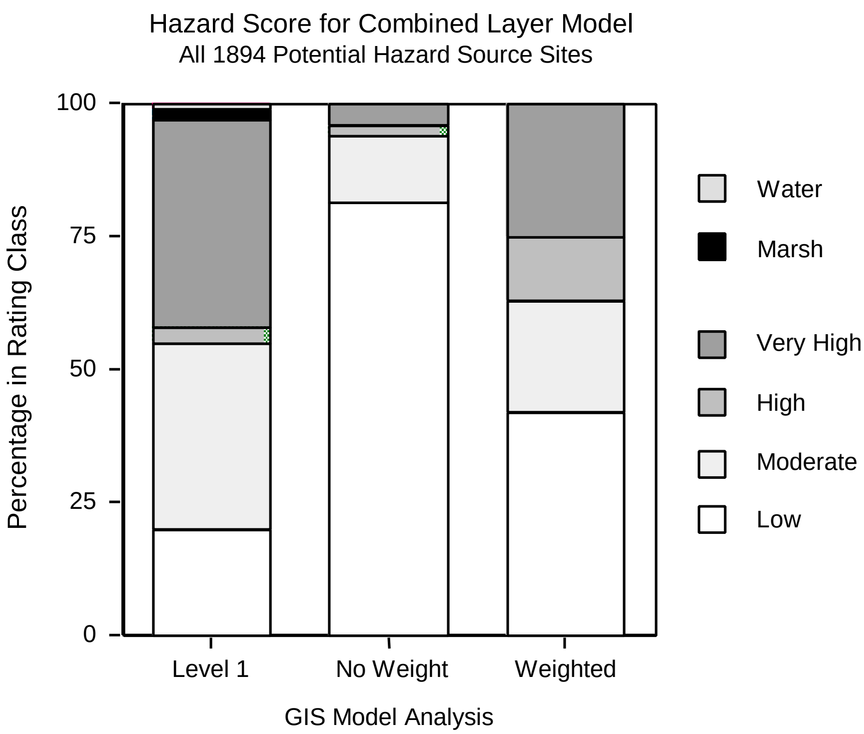

Figure 5.11: Comparison Between Level-1 Sensitivity and Hazard Scores

Results for this Study

The main importance of this aspect of the study is the development of a methodology to introduce potential sources of hazard into the groundwater sensitivity assessment. Besides developing the appropriate GIS models and syntax it also dealt with the methodology of combining data from various sources and coordinate reference systems to make them compatible with the raster cell GIS coverage of the county.

This aspect of the study has resulted in recommending additional factors to assist in decision making, especially when to initiate in-depth, detailed vulnerability assessments. These factors are: (1) population density, (2) land use as an indicator of economic activity and potential threat to underlying groundwater, and (3) an inventory of identifiable potential sources of hazard, their location, density, and areal distribution.

Validation of Rating Methodology

Methodology

In the original DNR guidelines the basic principles, methodology, criteria, decision variables, their values and ranges of threshold values and their modifications have been derived from a consensus process of experts (Delphi type approach) and are physical process based. The following analysis and discussion is intended to evaluate the internal consistency of the methodology and to evaluate the validity of the assumptions about the definition of decision variables and the reasonableness of their assigned numerical values. This validation is carried out through independent approaches.

Four methods are used: (1) frequency analysis of rating classes in benchmark wells and comparison to areal distribution of rating classes, (2) check for internal consistency by an inter-parameter method of correlation and comparing decision variables to areal sensitivity ratings, (3) correlation of groundwater chemistry analyses to sensitivity ratings, and (4) correlation of tritium age dates to sensitivity ratings

The basic idea is to evaluate the sensitivity for a number of wells for which the pertinent information is available on an individual basis (a 'point method'). Next, to compare these results with the rating of the earlier area sensitivity assessment in the mapping unit or raster in which the well is found. This allows comparing assessment procedures where several variations of the point and area methods are based on DNR Guidelines modifications. For this validation study, 409 well records from across Scott County were analyzed. From these wells 100 were selected for chemical testing, and 30 for tritium age dating. The results from these independent studies were correlated with the ratings obtained in the preparation of sensitivity maps for Scott County.

Statistical Frequency Analysis (Method 1)

Information from the 409 wells has been used as described earlier in the preparation of Level-2 sensitivity assessments by the area and the point methods. A more detailed description is given in Reference [3], Chapter 5: "Influence of the geohydrologic parameters on the sensitivity rating", page 137 ff. In this step the wells were rated individually and the results compared to the results of the area methods (DNR area method cases #8, #10 and #11).

The relative frequency of the sensitivity rating classes for the individual wells is compared to the percentage distribution of rating classes on the maps obtained by the area method of sensitivity assessment. If a large enough number of wells is rated by the point method then the statistical distribution of the frequency of occurrences of the sensitivity rating classes should be the same as the relative distribution of these sensitivity ratings on an areal basis. This holds strictly if the number is statistically significant, if there is no bias in selecting the wells or in assigning sensitivity ratings to the map areas, and if the ensemble is statistically stationary and homogeneous.

Table 5.11 shows the frequency of occurrence of wells in a respective rating class expressed as a percentage of total wells in this study. This is compared to the percentage of wells in a given rating class based on three area sensitivity assessment methods. These three DNR methods are: (1) Level-2 Areal Method (Case #8), (2) Level-2 Modified Areal Method based on CWI depth to water values (Case #10), and (3) Level-2 Modified Area Method with DEM and water table difference for depth to water (Case #11).

In Table 5.11 over 40% of the wells attained a Low rating. Moderate wells constitute the next most frequent class, accounting for over 26% of the studied wells, with High wells constituting a little over 20%. The relatively sparse distribution of Very Low and Very High wells, 5.62% and 7.33% respectively, indicates that only select areas of the county possess features such as very deep or very shallow water tables, great thickness of low permeability units or a vadose zone comprised primarily of high permeability material. These are all extreme situations whose presence can be established fairly unambiguously.

Table 5.11: Frequency Analysis of Well Sensitivity Ratings

	Wells in Rating Class		Areas in Rating Class		
	Individual/Point		Case #08	Case #10	Case #11
Rating Class	No.	%	%	%	%
Very Low	23	5.62		2.8	2.8
Low	167	40.83	77.3	57.4	57.4
Moderate	107	26.16	8.0	20.1	19.8
High	82	20.04	7.4	12.4	14.1
Very High	30	7.33	7.3	7.3	5.5
Total	409	99.98	100	100	99.6

The agreement between the statistical frequency analysis and the actual relative areal extents of mapped rating classes is as reasonable as one can expect under the circumstances. Comparison with the two modified area method results is shown on Figure 5.12.

The distributions of the various physical parameters among the different sensitivity classes are examined below, as well as the geological makeup of the areas with different sensitivities.

Internal Consistency of Decision Variables and Ratings (Method 2)

In this method the decision variables that are at the basis of the sensitivity rating approach are compared one by one, and correlated to the sensitivity rating classes. The four decision variables used are: (1) depth to water (DTW), (2) total low permeability units (TLPU's) in the vadose zone, (3) total moderate permeability units (TMPU's) in the vadose zone, and (4) representative (hydrologic) nature of averaged geologic material at the water table (MATWT). The average is established over a zone of fluctuation of ±10 ft. around the recorded water table position in the CWI as interpreted from the well water level listed in the CWI, not the actual water table in the strict sense.

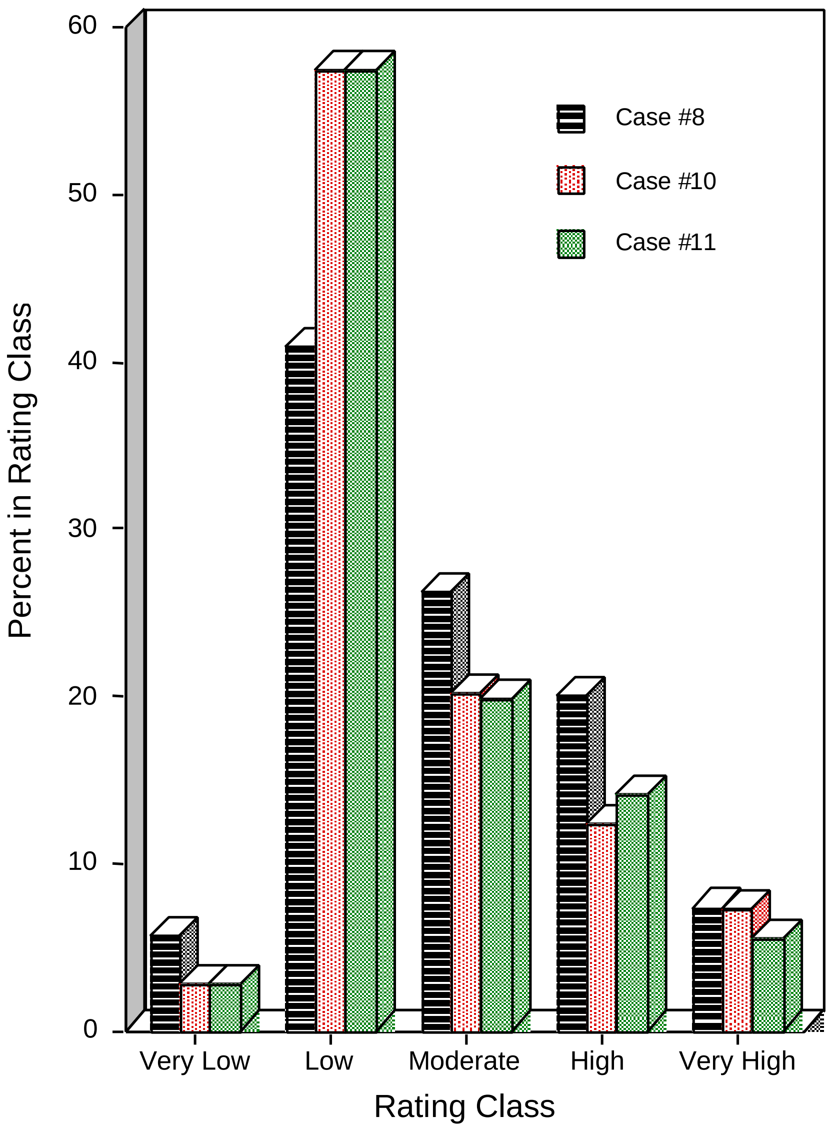

Figure 5.12: Frequency and Areal Percentage Distribution of Rating Classes

One of the most important decision variables in determining time of travel down to the first encountered groundwater body is the depth to water. Its numerical value also coincides with the thickness of the vadose zone. It is important because the depth to water is equivalent to the path length along which a contaminant has to flow to reach the water table and thereby determines its travel time.

The thickness of the vadose zone influences the likelihood that protective, low permeability layers of geologic materials may be present, and the greater the thickness the greater the possibility that protective layers actually exist.

The depth to water (DTW) is a dynamic quantity based on the transient changes of the water table which varies with a daily, seasonal and annual pattern in response to recharge and discharge. It is the difference between a static topographic surface and a dynamic water table or potentiometric surface. For the kind of assessments discussed here a true dynamic DTW is not a feasible decision variable to be used. Therefore, a surrogate variable has to be introduced. A fictitious water table surface has to be constructed which takes into account the natural fluctuations about some average quasi-equilibrium position, and that also introduces some safety factor related to the maximum height of the water table in a given recurrence period. The difference between the static topographic surface and this fictitious surface gives a conservative estimate of the areal distribution of the 'depth to water' parameter. This method of establishing the DTW was used in the most sophisticated modification (Case #11) of the DNR Guideline Level-2 assessment. It is described in great detail in Reference [3], Chapter 5: "Implementation of the Level-2 Assessment methodology", p.58 ff. Because the discrimination criteria and threshold values applied in the DNR Guidelines for DTW criteria are rather coarse (greater or less than 20 ft.), the fine detail of the dynamic depth to water is lost in establishing rating classes. Therefore, it is acceptable to use a surrogate in the form of depth to water level measurements in wells (DTWL) at the time they were constructed and recorded as shown in the CWI. This measurement may not even represent the position of the water table at the time of the measurement, it certainly does not represent the position of the water table at some later date (or only in some fortuitous fashion at one moment in time). Nevertheless, this measure is taken as a representative workable surrogate for the depth to the water table, for the reasons given above and explained in more detail in Chapter 5 of Reference [3]: "Preparation of the corrected Water Table Map", p. 61 ff.

For this discussion the decision variable 'depth to the water table' (DTW) is represented by the depth to water level (DTWL) in CWI wells, or wells used for level measurements in connection with this particular study. Given the threshold criteria of the Level-2 procedure according to the DNR Guidelines this is considered an acceptable and a conservative approximation of the 'depth to water' and 'thickness of the vadose zone' parameters, and the decision variable DTW in subsequent discussions of this report has to be understood in these terms unless otherwise and explicitly indicated.

One more point needs to be made in this context: The DNR Guidelines mention at one point in the description of the methodology that the properties of the geologic materials in the first 10 feet of the vadose zone are not to be considered in the rating procedure for Level-2 assessments because this zone most probably has additional flow spaces due to weathering, root propagation and burrowing. However, this restriction is not explicitly specified and carried through the rating matrices and the decision trees that lead to a final global rating. This has lead to some uncertainty and confusion in the application of the methodology and to uneven application in practice. The present work does not take this restriction into account. Therefore, the entire thickness of the vadose zone is used for determining the decision variables, including the top ten feet.

Depth to Water and Geologic Material in the Vadose Zone

Figure 5.13 shows a cumulative frequency curve of depth to water levels (DTWL) observed and measured in the 409 in wells under consideration for this study. The average DTWL of water supply wells in Scott County based on this analysis is 65 ft.

The next illustration, Figure 5.14, is based on an analysis of the combined thickness of moderate and low permeability units (TM&LPU's) in the vadose zone as established from CWI information for the 409 wells used in this study. It shows these values plotted as a function of the thickness of the vadose zone on a semi-log plot. Here the thickness of the vadose zone is assumed to be, and is set equal to, the depth to water as measured in the wells and recorded in the CWI data base (TVZ = DTWL). The heavy curve is a power law fit through the 409 points. The thin line is for illustration and represents the line where DTWL is equal to TM&LPU's, hence no points exist to the left of it. The plot shows the expected thickness (34 ft.) of TM&LPU's at the average thickness of the vadose zone, or DTWL, of 65 ft., as established from Figure 5.13. The graph shows that, on average, for depths greater than 30 feet one half or more of the thickness of the vadose zone contains either moderate or low permeability units, or combinations thereof. This percentage increases with depth as can be seen by the location of the majority of the points that are situated between the fitted curve and the 1:1 line for the larger DTWL values. For example, for a DTWL of 65 ft., 52.6% of the vadose zone is occupied by TM&LPU's. Corresponding TM&LPU's percentages for DTWL's of 100 ft. and 200 ft. are 54% and 56%, respectively.

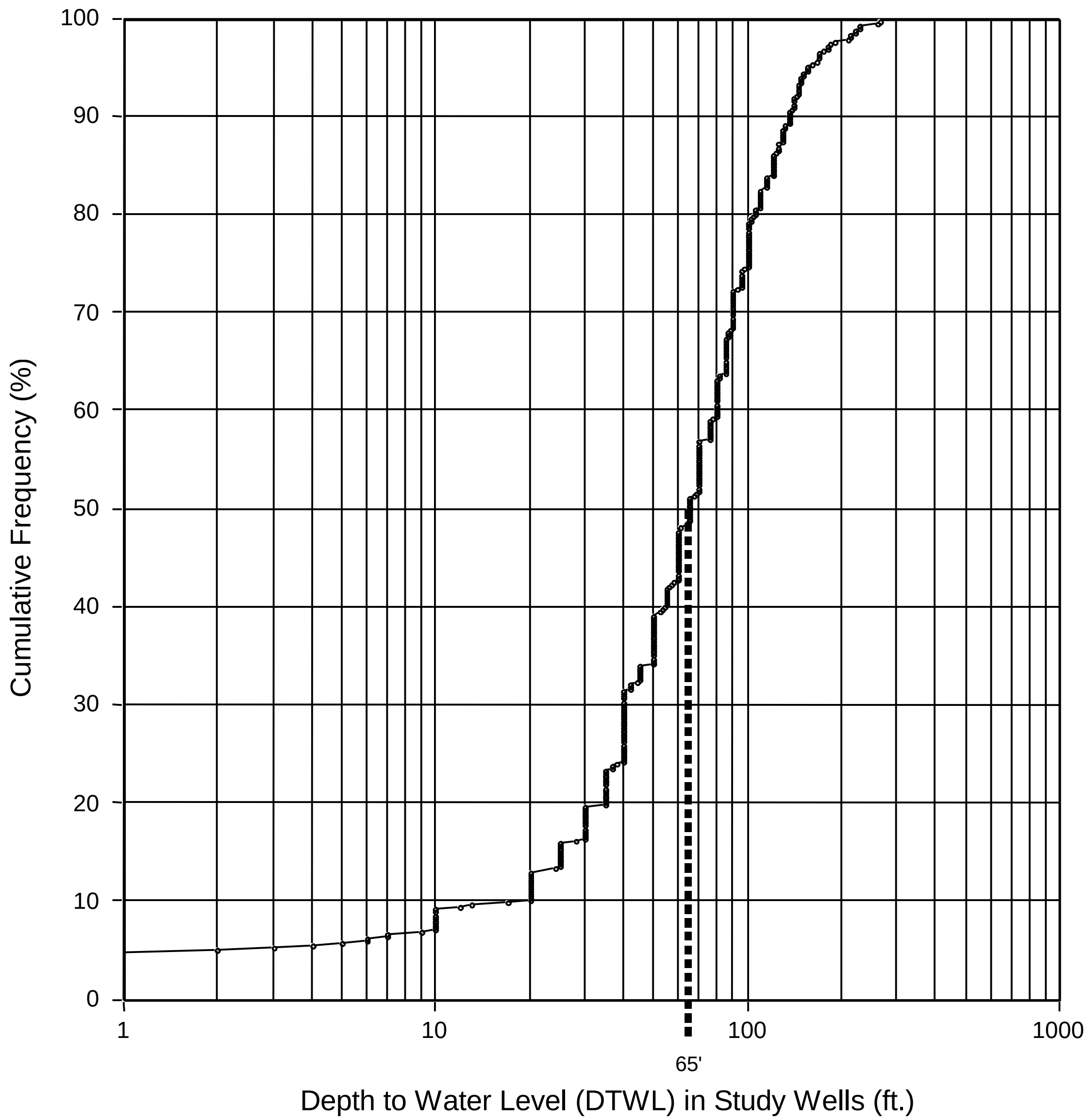

Figure 5.13: Cumulative Frequency of Depth to Water Level (DTWL)

The two rectangular areas at the bottom of the graph enclose all the well data found to the respective depths of 20 and 30 feet as points. The 20 ft. DTWL-rectangle has a y-coordinate (TM&LPU's) of 9.85 ft.; the 30 ft. DTWL-rectangle has one of 15.1 feet. The larger (30-foot) rectangle contains 22 data points. Eleven of these show values of TM&LPU's greater than zero, and of these only six that are greater than ten feet. The 20 ft. DTWL-rectangle has nine data points with zero TM&LPU's, and three with TM&LPU's greater than zero. By definition none can be equal to or greater than ten feet in this rectangle.

Hence, the number of shallow depth wells expected in these DTWL ranges is actually very small compared to the total number of wells completed in the rest of the water table aquifer. This would hold true in the type of glaciated terrain characteristic of the pilot study area. This indicates that the DNR Guidelines choice of the 20-ft. isobath, or the 30-ft. isobath (if one wants to exclude the top ten feet as a buffer zone) as a discriminant threshold or partitioning line between deep and shallow DTWL is a very valid and workable assumption. By extension, the same rationale for the discriminant value of the 20-ft. or 30-ft. isobath can also be applied to the case where the thickness of the vadose zone is obtained as a result of more refined and conservative water table elevation averaging and well log interpretation procedures, for example Case #11.

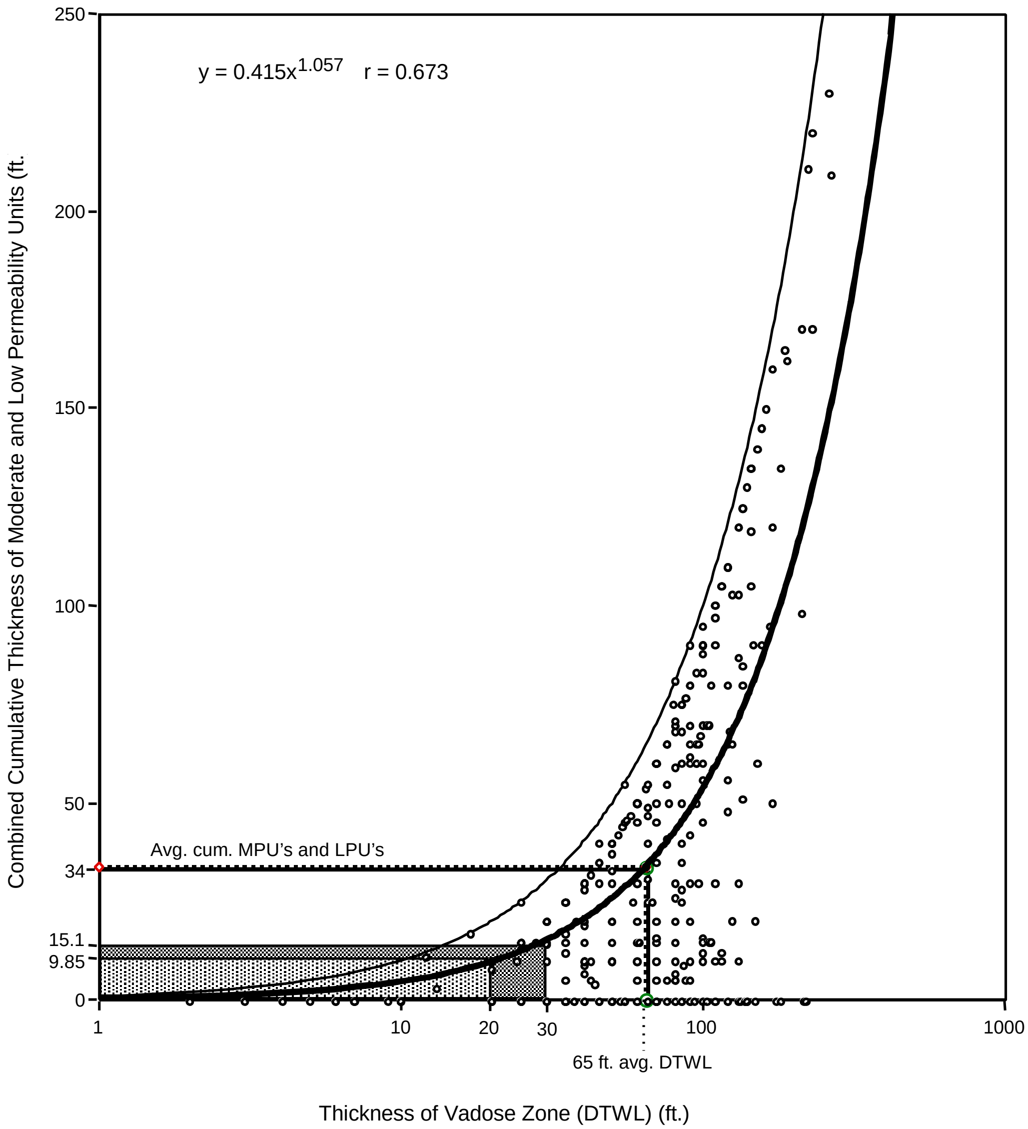

Figure 5.14: Cumulative Moderate and Low Permeability Units in the Vadose Zone

Correlation of Decision Variables to Sensitivity Rating Class

Average values for the decision variables DTWL, TLPU's, % LPU's,. TMPU's, and % MATWT have been extracted from the data set of the 409 wells. Their occurrence in each respective rating class, Very Low, Low, Moderate, High, and Very High is summarized on Table 5.12 showing average values, standard deviation and coefficient of variation.

Table 5.12: Summary of Physical Decision Variables and Rating Classes

5.12(a): Depth to Water in Feet as Established by Observed Water Level in Wells (DTWL)

Rating Class	Very Low	Low	Moderate	High	Very High
Average	148.04	77.55	58.18	77.71	14.5

Standard deviation	35	40.44	44.45	43.10	18.01
Coefficient of Variation	0.24	0.52	0.76	0.55	1.24

5.12(b): Total Thickness in Feet of Low Permeability Units in Vadose Zone (TLPU's)

Average	131.48	45.6	6.71	2.72	0
Standard deviation	31	21.32	15.62	5.0	0
Coefficient of Variation	0.24	0.47	2.33	1.84	0

5.12(c): Percent Thickness of Low Permeability Units in Vadose Zone (%LPU's)

Average	89	63	16	5	0
Standard deviation	8	23	23	9	0
Coefficient of Variation	0.09	0.36	1.44	2.02	0

5.12(d): Total Thickness in Feet of Moderate Permeability Units in Vadose Zone (TMPU's)

Average	1.61	6.07	24.08	1.48	0
Standard deviation	6	22.51	38.42	9.2	0
Coefficient of Variation	3.6	3.71	1.6	6.24	0

5. 12(e): Percent Averaged Material at Water Table (%MATWT)

Bedrock	0	1	0	4	10
Sand/Gravel	13	22	10	95	90
Mixed	4	28	67	1	0
Clay	83	49	22	0	0

The three decision variables depth to water, thickness of low permeability units in the vadose zone and thickness of moderate permeability units in the vadose zone, all in feet, have been plotted against the rating classes on the graph in Figure 5.15.

As determined from the CWI well logs, the wells rated Very Low sensitivity have an average depth to water of 148 feet, distinctly greater than any of the other classes. In contrast, wells rated in the Very High class have an average depth to water of only 14.5 feet, illustrating the validity of this rating as well (Table 5.12(a)).

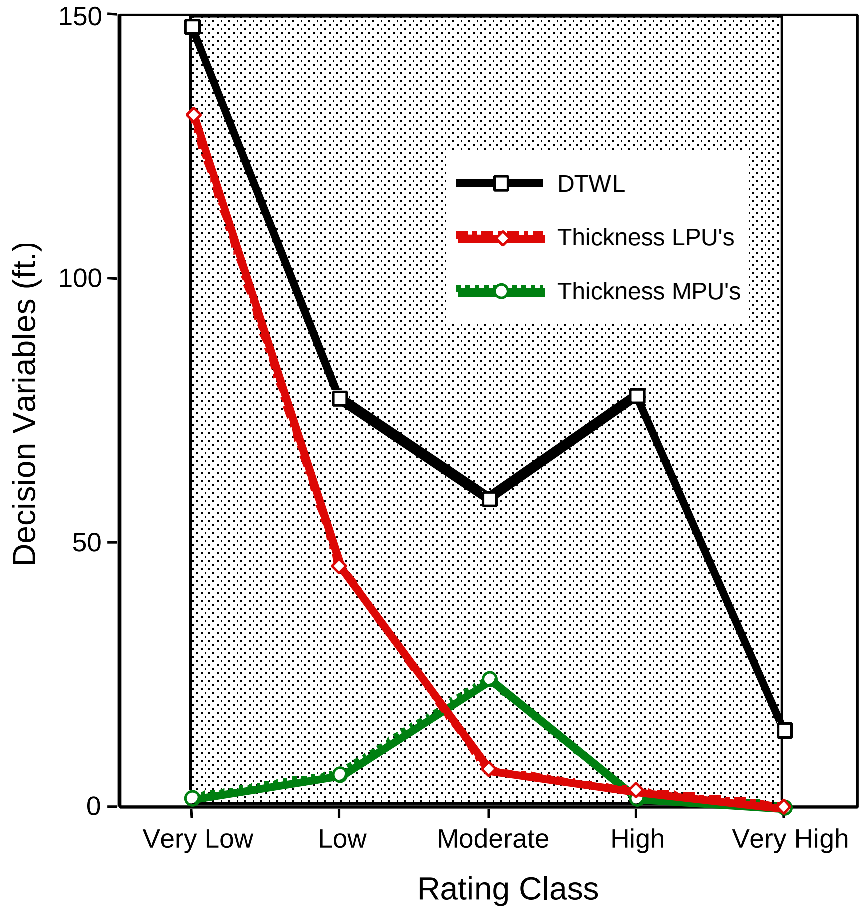

Figure 5.15: Correlation of Physical Decision Variables to Sensitivity Rating Class

The Low and High classes have almost identical average depths to water, which would indicate that thickness of the vadose zone is not the primary difference between these ratings. Moderate wells have an average depth to water that is actually lower than that of the High wells, again pointing to the role played by other physical properties that correlate with other protective parameters within the extent of the vadose zone other than the length of the traveled pathway. These would modify the sensitivity indicated by thickness of the vadose zone alone. Thus, depth does not appear to be a sole driving factor behind sensitivity, but rather a complement to other more critical geological conditions.

Figure 5.15 shows the correlation of the average depth to water with the sensitivity class, and the trend in the curve for this single parameter comparison demonstrates that this variable is a viable decision variable.

The validity of the Very Low rating, and the distinction between the Low and High classes is illustrated by the variation of the thickness of Low permeability units (Table 5.12(b)). The average thickness is over 130 feet for the Very Low class and 45.6 feet for the Low rating. It continues to decline, averaging 6.71 feet for the Moderate wells and 2.72 feet for the High rating. None occur in the Very High rating category. Thus, even though Low and High wells have very similar average depths to water, it is obvious that the vadose zone composition has greater influence on the groundwater sensitivity determination. Figure 5.15 shows the expected inverse relationship between thickness of low permeability units (LPU's) in the vadose zone and sensitivity ratings.

The percent of total thickness of the vadose zone composed of low permeability units was obtained and analyzed to evaluate the vadose zone composition from a more process oriented perspective. The high degree of heterogeneity and lack of lateral continuity of the glacial till that underlies much of Minnesota is well established. It is a natural consequence of the variability of glacial transport and depositional mechanisms. The thickness of low permeability units as determined from a well log may therefore not be extrapolated to subsurface conditions even a relatively short distance away from the well. However, a certain amount of episodic consistency may be expected in the depositional products of various glacial events, i.e. it may be possible to determine some broad trends in the relative proportions or percentage of different textural classes in the lithologic column given a similar glacial regime and depositional environment. As shown in Table 5.12(c) the various sensitivity classes are characterized by distinctly different composition of the vadose zone itself. In the Very Low wells, on the average almost 90% of the entire vadose zone consisted of low permeability material. This fell to 63% in the Low wells, still a very significant proportion. The relative occurrence of low permeability material then declined to16% for Moderate wells, 5% for the High ratings, and this textural class was absent from areas that attained a Very High classification.

In all likelihood there were variations in the geologic processes that operated during the deposition of the present day vadose zone materials, which is manifest in the spatial variation of the groundwater sensitivity over the study area. This apparent interrelationship based on percentage distribution of textural classes for a given area rather than an extension based on neighboring local lithology allows a much greater degree of confidence to be placed in the spatial extrapolation of geohydrologic data that is essential for completing a Level-2 Assessment on an area of any size in this diverse glaciated setting.

The trends in the thickness of moderate permeability units are also shown in Table 5.12(d) and Figure 5.15. It demonstrates that the existence of the Moderate rating class is due mostly to the occurrence of MPU's in the vadose zone, because only in this rating class do MPU's attain a thickness of any consequence. This, along with a predominance of mixed material at the water table (discussed below) are what distinguish the Moderate rating class from the Low and High sensitivity classes, with which they otherwise share considerable similarity of geological setting.

The term 'water table' in the subsequent discussion is a fictitious concept of a free surface that is inferred from static water levels measured in wells. This point was discussed in greater detail earlier in this section, but needs to be restated to avoid confusion.

From Table 5.12(e) it can be seen that in the Very Low rating class, the predominant material at the inferred water table is clay in 83% of the wells. This would be an obvious complement to the deep water tables typical of these areas. The difference between the Low and High sensitivity areas becomes apparent here. Even though both areas on an average possess the same depth to water, the High areas have an overwhelming occurrence of sand/gravel at the inferred water table, in 95% of the wells as compared to only 22% in wells that rate Low. The Moderate wells, even though they have an average depth to water that is less than the High wells, are dominated by mixed material and clay at the water table, with sand/gravel only in 10% of the wells. The Very High wells have no occurrences of mixed material or clay at the water table at all. Their typically shallow depth to water seems to be accompanied by the presence of high permeability sand/gravel or limestone bedrock at the water table. The geologic material at the inferred water table is thus an important modifying factor in sensitivity, and plays an especially important role in the three middle ratings. The two extreme classes, i.e. Very Low and Very High, possess other properties that are distinct and decide their rating fairly independently of the material at the water table. Figure 5.16 shows the variation in relative occurrence of the different classes of water table material with the sensitivity rating.

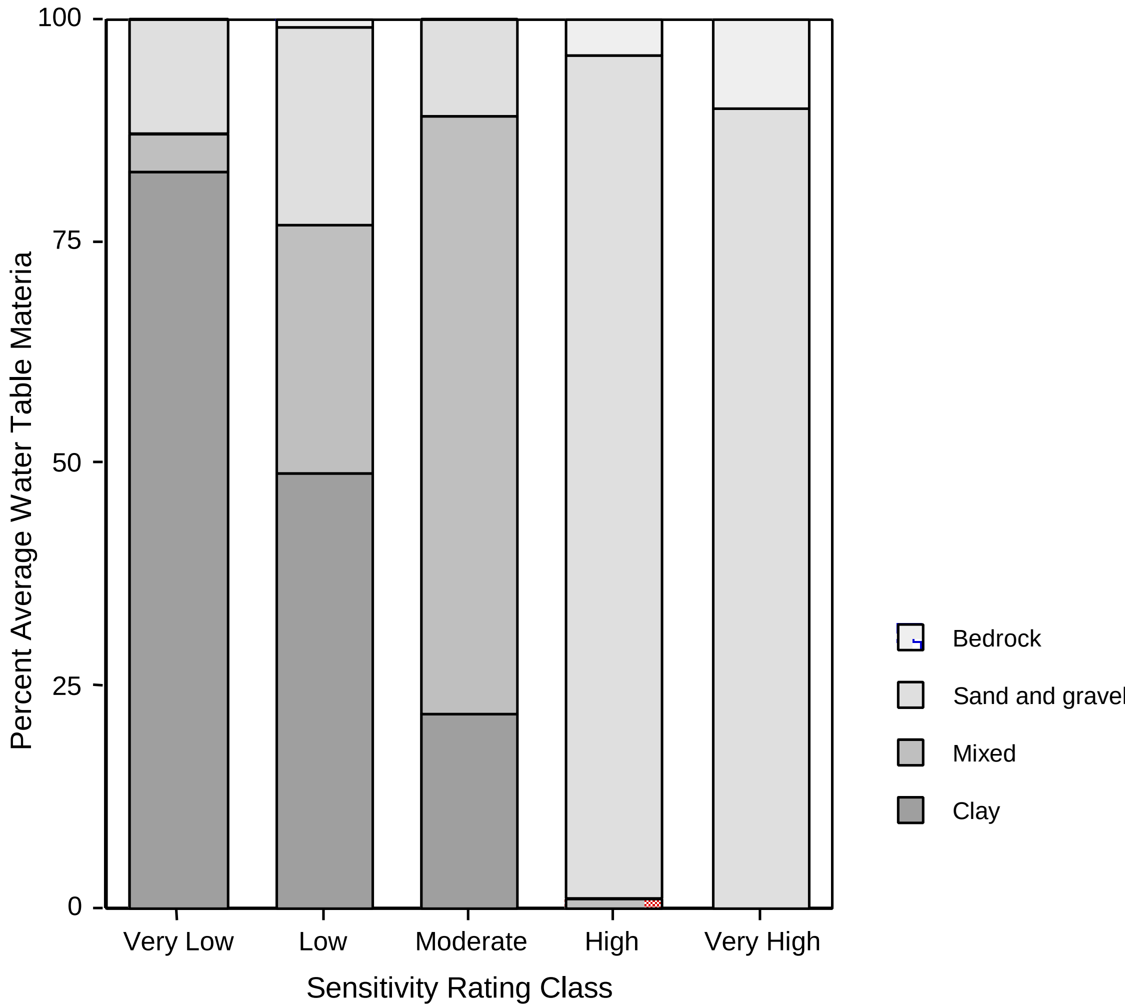

Figure 5.16: Correlation of Material at Water Table to Rating Class

The method of comparing individual sensitivity parameters from individual wells with the overall areal rating has shown that the decision variables chosen and their values are consistent with the rating system. This method does not provide a totally independent check, because the wells on which the frequency analysis was carried out were also used for the areal sensitivity rating methods. Consistency of these parameters with the rating method is a necessary though not sufficient condition of acceptability. On the other hand, had the outcome lead to inconsistencies, grave doubts about the validity of the method would have been raised.

Two independent methods of checking the validity of the approach and the underlying assumptions are discussed below.

Correlation of Chemical Analyses and Rating Classes. (Method 3)

Groundwater chemistry of portions of the Quaternary aquifer in Scott county were compared to different sensitivity ratings in order to correlate the major ion chemistry and dissolved oxygen to sensitivity rating classes. The sampled wells were selected to obtain a uniform spatial distribution across the county area, and to eliminate spatial bias as far as possible, in order to identify the differences in chemistry that are attributable mainly to differences in degree of interconnection with the surface. One hundred wells were sampled for this purpose.

The field procedures and analytical methods including sampling, sample preservation, transport storage and analysis in this study followed rigorous protocol and quality control (QC) and quality assurance (QA) procedures. Details are given in Reference [3], Chapter 7, “Field Methods”, p.169 ff. The complete data compilation, showing well unique numbers, aquifer, sampling date, and the complete list of physical and chemical parameters obtained is included in the appendix of Reference [3] as Appendix B: ”Geologic Parameters and Level-2 Ratings from the Study Wells”, and Appendix C: ”Geochemical Data from the Sampled Scott County Wells”. A summary of the data, which presents the average value of every parameter sampled for each of the sensitivity categories, is given in Table 5.13. Of the twenty analytical parameters shown only three are significant to establish links between groundwater chemistry and its sensitivity rating. These are: chloride (Cl), nitrate (NO_3) and dissolved oxygen (DO). These parameters are highlighted in Table 5.13. Their values are normalized against their concentration for the Very High rating class which by definition has a value of 1. These normalized non-dimensional values are plotted against the five rating classes in a summary graph on Figure 5.17.

Table 5.13: Average Values of the Sampled Chemical Parameters for Each Sensitivity Class

Rating Category	Units	Very Low n=14	Low n=36	Moderate n=30	High/Very High n=20
Stabilization Time	minutes	30	32.98	29.67	30
Temperature	°C	10.55	10.18	10.32	10.45
Conductivity	µS	560	530	500	510
pH	pH units	7.32	7.23	7.38	7.23
Eh	mV	-86.57	-86.36	-56.96	-70.9
Alkalinity (as $CaCO_3$)	mg/L	394.57	381.99	369.26	365.48
DO	mg/L	0.09	0.61	1.00	0.78
F	ppm	0.40	0.23	0.21	0.22
Cl	ppm	2.49	7.46	10.74	16.33
NO_2-N	ppm	0.01	0.01	0.01	0.0063
Br	ppm	0.00657	0.01	0.01	0.02
NO_3-N	ppm	0.23	0.35	0.74	1.13
PO_4-P	ppm	0.02	0	0.001	0.0065
SO_4	ppm	64.58	32.89	32.96	28.90
Al	ppm	0.009	0.007	0.008	0.01
Si	ppm	12.06	14.51	13.42	13.50
P	ppm	0.27	0.10	0.07	0.04
Fe	ppm	1.14	3.00	5.56	3.36
Mn	ppm	0.12	0.26	0.29	0.38
Sr	ppm	0.24	0.370	0.28	0.28
Ba	ppm	0.08	0.21	0.15	0.17
Ca	ppm	79.23	95.30	84.62	93.16
Mg	ppm	31.77	37.53	33.51	35.48
Na	ppm	88.58	17.66	17.66	8.76

K	ppm	3.00	4.37	3.67	3.66

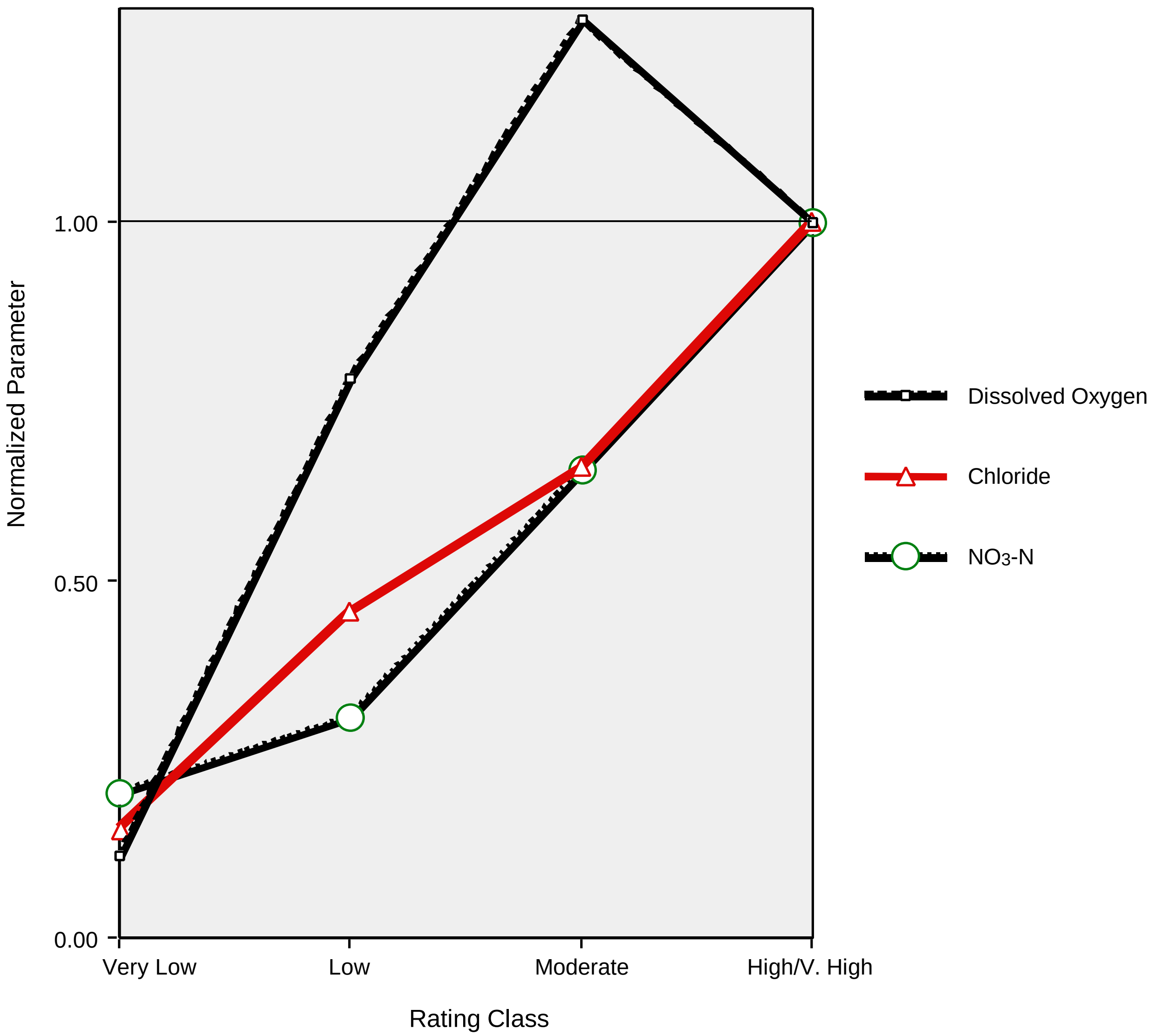

Figure 5.17: Correlation of Normalized Chemical Parameters to Sensitivity Rating Class

Chloride

The average concentration of chloride increases from 2.5 ppm in wells with Very Low sensitivity to 16.33 ppm in wells that are rated High or Very High, this trend is expected and follows the pattern due to anthropogenic contaminant loading from the surface.

Figure 5.18 shows the distribution of chloride concentration in each sensitivity class plotted against concentration ranges of = 10 ppm, 10 to 50 ppm, and = 50 ppm, respectively. In the Very Low category, 100% of the wells have chloride $\leq$ 10 ppm. For the Low category, this proportion falls to 88%, with the other wells equally divided in the 10 to 50 ppm and > 50 ppm intervals. In the Moderate class of wells, 75% of the wells have chloride concentration in the = 10 ppm interval, accompanied by a significant increase in the proportion of wells that fall into the 10 to 50 ppm interval. In the High and Very High sensitivity class of wells, the proportion of wells with > 50 ppm chloride rises to 20%, while the wells with = 10 ppm chloride fall to 70%.

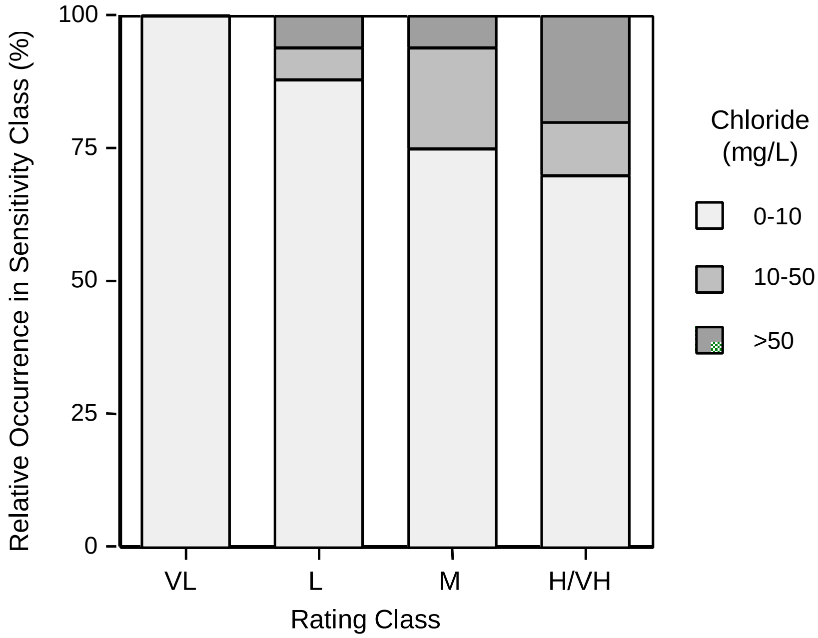

Figure 5.18: Correlation of Chloride Concentration with Rating Class

Nitrate

The nitrate (NO_3-N) sensitivity correlation is equally good. As evident from Table 5.13, and Figure 5.19, there is a distinct increase in nitrate levels also with increasing sensitivity. The average nitrate increases from 0.23 ppm in Very Low sensitivity wells to 1.13 ppm in the wells classed High and Very High. Of greater importance is the relationship brought out in Figure 5.19, which shows the distribution of nitrate levels ranges = 1 ppm, 1 to 5 ppm, and > 5 ppm, within the various sensitivity classes. In the Very Low class, 100% of the wells have nitrate = 1 ppm. In the Low class of wells, this proportion falls to 94%, with 2% now having nitrate levels in the 1 to 5 ppm interval, while the remaining 4% have nitrate levels > 5 ppm. In the Moderate sensitivity class, only 87% of the wells remain in the = 1 ppm nitrate interval, while the proportion of wells in the > 5 ppm nitrate interval increases to 10%, with 3% falling in the 1 to 5 ppm nitrate interval. In the High and Very High sensitivity classes, the proportion of wells with =1 ppm nitrate falls to 50%, while that with > 5 ppm increases to 20%, with 30% of the wells in the 1 to 5 ppm nitrate interval.

Dissolved Oxygen

The dissolved oxygen measurements also show interesting trends, with potential implications for groundwater sensitivity. As can be seen from Table 5.13, and Figure 5.20, the average dissolved oxygen content steadily increases from the Very Low class of wells until the Moderate class, before dropping slightly for the High and Very High classes, which is somewhat of an anomaly. However, when the distribution of dissolved oxygen concentration within each sensitivity class is examined, it is evident that the proportion of wells with high dissolved oxygen concentration, i.e. > 1 mg/L, also increases from the wells with Low sensitivity to those with High sensitivity. This was shown earlier in Figure 5.17. The dissolved oxygen data should be used with caution, since the measurement is carried out in the field and is subject to contamination with atmospheric oxygen. However, the results obtained from this study do complement the correlation displayed by the nitrate and chloride concentrations with the sensitivity ratings.

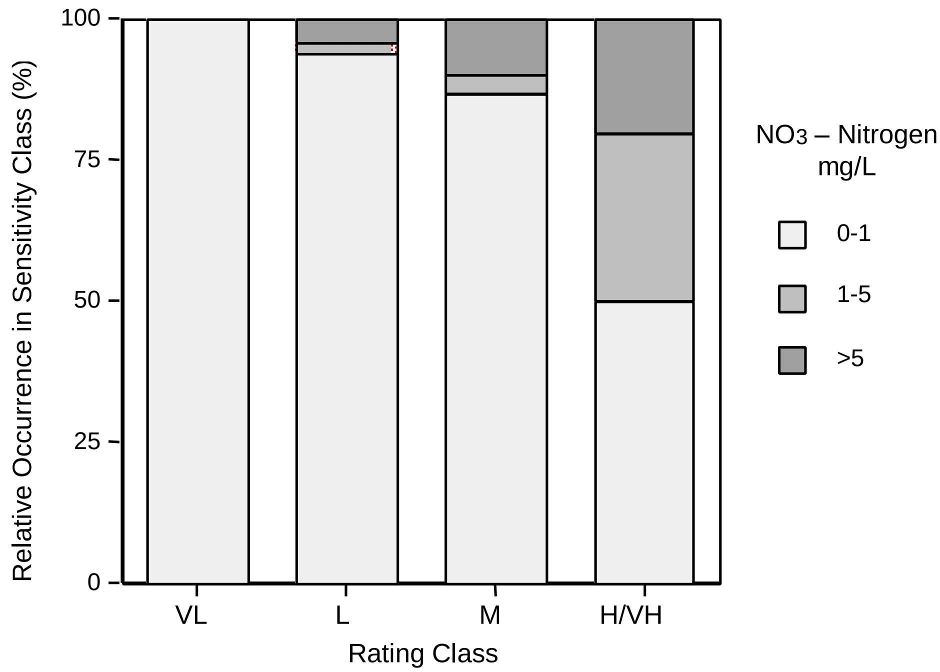

Figure 5.19: Correlation of Nitrogen Concentration with Rating Class

Correlation of Tritium Ages and Rating Classes (Method 4)

A rough age bracket or residence time of groundwater can be estimated from its tritium content measured in Tritium Units (TU). Tritium produced by cosmic rays in the atmosphere and found in recharge water only has a few TU's. With its short half-life of 12.4 years the rate of decrease in tritium sequestered in groundwater reservoir gives an indication of natural residence times in the subsurface flow system. The atmospheric nuclear testing in the 1950's and 1960's producing TU values in the order of 1000 to 2000 upset this normal sequence. Tritium is therefore a very sensitive indicator of water that has entered groundwater systems since 1954. It is equally useful in the converse, i.e., as an indicator of long residence times in the absence of any such water.

The following tritium groundwater age divisions, established in the Department of Geology[11] were used for interpreting the results of this study: (1) If the water sample contained more that 10 TU, that water was considered as having entered the ground since 1954 and was classified as Recent; (2) If the water sample contained less than 1 TU, that water was considered as having entered the ground before 1954, and was classified as Vintage; (3) Water samples that contained between 1 and 10 TU were

[11] Alexander, S.C. and Alexander, E. C.Jr., (1983), Residence times of Minnesota groundwaters, Journal Minnesota Academy of Science, Vol. 55, No.11, p. 48-52.

considered either a mixture of older and younger waters, or entirely of intermediate age, and were classified as Mixed.

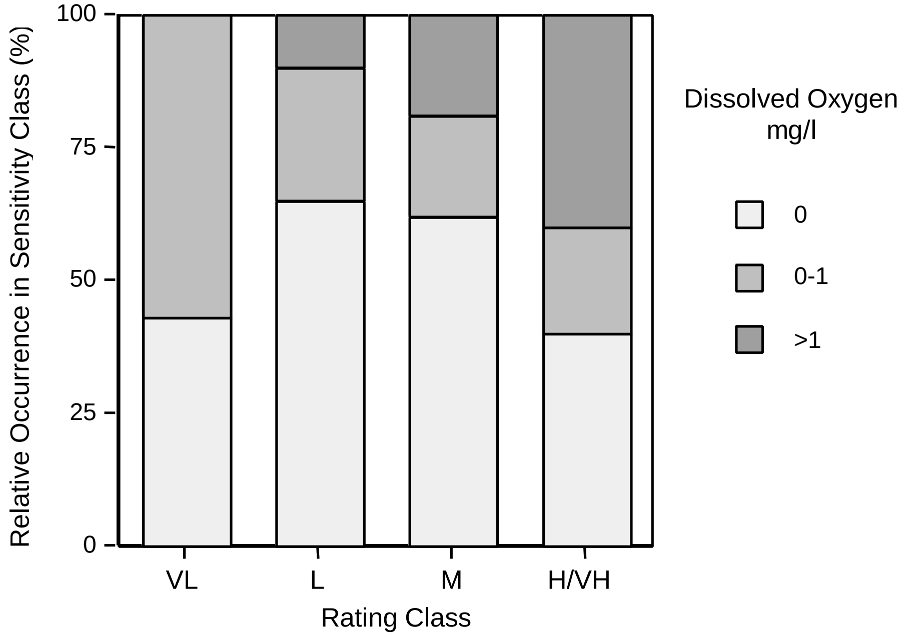

Figure 5.20: Correlation of Dissolved Oxygen Concentration with Rating Class

All groundwater age or residence time interpretations require a certain degree of caution since groundwater systems inevitably involve mixing of water from different reservoirs as well as mixing of water of differing ages within the same reservoir. Therefore, a groundwater age or residence time cannot really be considered to be entirely specific, but instead should be interpreted as being an average for that flow system.

Budgetary constraints permitted only 30 of the 100 well water samples to be actually analyzed for tritium. These were selected to be uniformly distributed across the county, and an effort was also made to ensure that a representative cross section of different sensitivity areas was sampled.

Table 5.14 shows the results of the tritium ages as Vintage, Mixed, and Recent of 30 samples, including well information, sensitivity rating, and chemical parameters dissolved oxygen (DO), chloride (Cl), and nitrate (NO_3-N) which are averaged for each tritium age class. Excellent correlation is apparent from Table 5.14 between the tritium ages and the groundwater sensitivity ratings of the 30 wells sampled.

Of the 7 samples that were found to be of Recent tritium age, i.e. > 10 TU, 3 had a High sensitivity rating, 2 had a Moderate rating, and 2 had a Low rating. The latter need some explanation. The two Low rated wells with static water levels of 40 and 50 ft. below land surface attained a Low score based on an interpreted thickness for the overlying low permeability protective units, in the order of 20 feet. This is about the limit for which reliable values can be established from well logs and this thickness could in reality be less. The independent chemical parameters, DO, Cl, and NO_3-N, are the highest of the entire set of analyses. This implies a high degree of hydraulic connection with the land surface, a significant lateral flow component, or a nearby permeability window. But the last two are not included in the DNR assessment methodology and their influence can therefore not be evaluated. This analysis based on chemical data indicates, however, that the two wells should have a rating of High. With this explanation in mind, the Recent Tritium age corresponded very well to either a lack, or small thickness, of protective units.

Table 5.14: Summary of Well Information and Tritium Age of Samples

Site number[1]	Unique well no.[2]	Aquifer code[3]	DO[4] (mg/L)	Cl (ppm)	NO_3-N[5] (ppm)	Rating[6]	Tritium age[7]
4	207329	QBAA	0.70	1.05	0	Low	V
16	212315	QBAA	0.02	1.785	0.386	V. Low	V
20	502714	QBAA	0.11	0.728	0	Low	V
37	207375	QBAA	0.00	1.872	0	Low	V
43	102284	QBAA	0.05	1.15	0.067	V. Low	V
47	211713	QBAA	0.00	8.639	0.027	V. Low	V
50	466153	QBAA	0.00	1.981	0	Low	V
62	211891	QBAA	0.00	2.082	0.014	V. Low	V
64	424679	QBAA	0.54	2.473	0.09	Low	V
65	215784	QBAA	0.08	2.731	0.533	Low	V
66	102255	QBAA	0.24	1.5	0.765	Low	V
101	407110	OPDC	0.00	0.497	0	V. Low	V
102	502702	OPDC	0.00	0.626	0	V. Low	V
103	215761	CSTL	0.40	0.826	0	V. Low	V
104	212303	CJDN	0.38	0.421	0.026	V. Low	V
105	212438	OPDC	0.00	0.587	0	V. Low	V
Average			0.15	1.809	0.119		V
24	207329	QBAA	0.70	1.05	0	Mod.	M
49	221375	QBAA	0.00	3.98	0	Low	M
94	207696	QBAA	0.37	5.32	0	V. Low	M
96	207390	QWTA	0.18	2.354	0.067	Low	M
106	211960	OPDC	0.18	5.347	0	Low	M
107	420033	OPDC	1.15	16.88	0.025	Low	M
109	206814	CJDN	2.45	3.491	0.04	Low	M
Average			0.72	5.48	0.02		M
10	207931	QBAA	0.00	2.69	0	High	R
31	212540	QBAA	0.00	14.8	0.035	Mod.	R
67	207566	QWTA	6.17	59.89	5.223	Low	R
69	207564	QWTA	6.15	60.47	5.356	Low	R
77	221326	QWTA	0.00	6.95	0	High	R
83	212298	QBAA	0.00	12.08	0.121	High	R
108	100988	OPDC	0.03	5.63	0	Mod.	R
Average			1.76	23.21	1.533		R

[1] Reference number for site in the sampling program; [2] Minnesota Geological Survey Unique Well Number; [3] Aquifer codes: QBAA, Quaternary buried aquifer, QWTA, Quaternary water table aquifer, CSTL, Cambrian St. Lawrence Formation, CJDN, Cambrian Jordan Sandstone, OPDC, Ordovician Prairie du Chien Group; [4] Dissolved oxygen, [5] Nitrate as nitrogen; [6] Sensitivity rating; [7] Tritium age bracket: V-vintage, M-mixed, R-recent.

At the other end of the scale, all the 16 wells that were found to have water of Vintage tritium age, i.e. < 1 TU, had sensitivity ratings of Very Low or Low. Nine of the wells had a Very Low rating, the other

7 were Low. Significantly, the Low rated wells had a Low rating based on an interpreted protective thickness of at least 50 feet for the overlying low permeability units. For this sample set, the effects of the physical properties that result in Low sensitivity ratings are thus clearly reflected in the tritium ages.

The sensitivity ratings of the 7 wells that were found to be of Mixed tritium age, i.e. 1 < TU < 10, also fit in well with these findings. Five of the wells had Low ratings, based on a CWI interpreted thickness of 30 feet for the low permeability protective units. One had a Moderate rating. Only one well can be considered to be an anomaly as it had a sensitivity rating of Very Low and a Mixed tritium age.

Thus, the geologic protection and hence sensitivity of the Mixed tritium age wells seem to represent an intermediate position between those of the Recent and Vintage age wells, with minor overlaps. The Recent wells are all rated Low and higher. The Vintage wells on the other hand are rated Low and lower. Thus a very clear distinction exists between the geologic properties and corresponding sensitivity ratings of Recent and Vintage waters, with no overlap at all in this sample population.

The geologic properties required for Low sensitivity ratings grade into those that result in Moderate ratings, which in turn are transitional into those resulting in higher sensitivity. Therefore it is to be expected that the tritium ages show the same trends, the finding of real significance being the sharp distinction between the Recent and Vintage end members. These relationships are shown in Figures 5.21, 5.22 and 5.23.

The tritium ages also correlate well with the chemical signatures of surface connection, as can be seen from Table 5.13 and Figure 5.21. It shows a plot of the chemical parameters versus the tritium age ratings. The concentrations are normalized to their highest value that corresponds to the Recent rating. Both the average dissolved oxygen and chloride levels show a clear increase from the Vintage waters to the Recent waters. The average nitrate for Recent waters is also significantly higher than that for the Vintage waters. The average nitrate value for Moderate waters is the only apparent anomaly, being less than that for Vintage waters.

Figure 5.21: Correlation of Tritium Age and Chemical Indicators

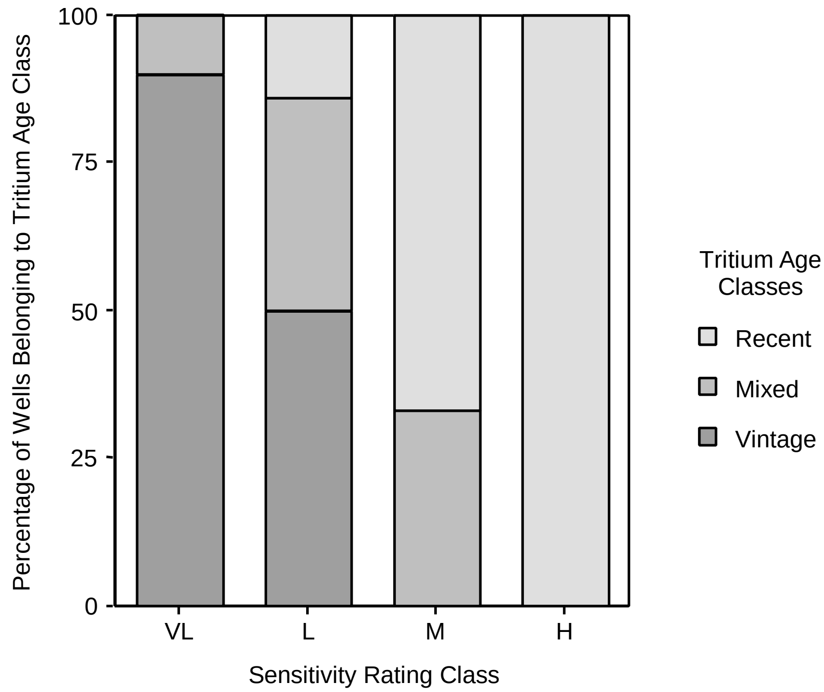

Figure 5.22: Correlation of Tritium Age of Groundwater to Level-2 Sensitivity Rating Class

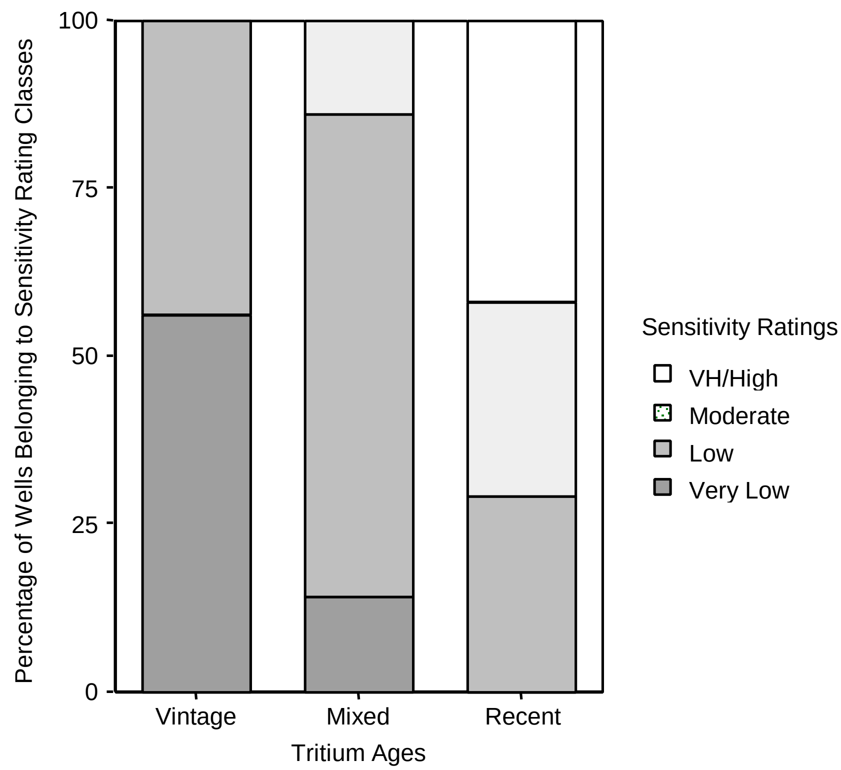

Figure 5.23: Distribution of Sensitivity Ratings Among the Three Tritium Age Classes

Discussion of Results

If land use policies based on sensitivity maps are to have any credibility the underlying methodologies to designate and outline sensitive and less sensitive areas have to be internally consistent, reproducible and reliable. The principal concern of the preceding section was to establish the validity of the methodology, criteria, decision variables, and threshold values developed in the DNR Guidelines and subsequent modifications to carry out a geologic groundwater sensitivity assessment for a county.

This study focused on the analysis of Level-2 Assessments. These are the centerpiece and the most important phase in geologic sensitivity assessment procedures. They involve the sensitivity rating of the first encountered water bearing unit based on the depth or inferred depth to the water table. This is an example of a sensitivity assessment based on a point of compliance or compliance surface, the water table, as a reference. Other bases for assessment exist where the reference is the resource, the groundwater body. This would be a resource-based approach. A mixed approach is to take as the travel time reference depth zones within an aquifer below the water table.

But these options are not part of the discussion in the original DNR Guidelines which only deals with compliance surfaces, and therefore are not considered here. However in sensitivity assessment work it is necessary to state the type of approach, compliance, resource or mixed very clearly to avoid confusion.

The Level-1 Assessment according to the Guidelines is only a preliminary step in the assessment procedure and it is based on decision variables that are not readily comparable to those important at the Level-2. The modified Level-1 assessment is a hybrid between the Level-1 and Level-2 methods. Level-3 Assessments involve the sensitivity of the aquifers below the first encountered water bearing units dealt with in Level-2. The pattern and distribution of the mapped sensitivity units mimic those of the Level-2 assessment. Since by definition there has to be some lower permeability unit separating the surficial and the deeper aquifers the corresponding mapped sensitivity rated areas in general rate one or two classes lower than the Level-2 ratings. Because of the scarcity of pertinent data and no clear aquifer separation between near surface and deeper units in Scott County the validity of the Level-3 assessments could not be tested.

For these reasons the Level-2 Assessments were used as the basis on which the validity of the methods was tested. Four sets of data were analyzed: Two semi-independent sets of physically and geological based statistical data, and two truly independent sets of chemical and isotope data that indicate the degree of connection between the aquifer and the surface and the ease of vertical travel to the water table.

Four methods of comparing and correlating the data were presented:

1. The first consisted of relating process based physical-hydrologic decision variables or chemical analyses as dependent variables to the rating classes (Figures 5.15 and 5.17). The purpose was to check whether the correlation produced consistent trends for the expected inverse relation for the physical decision parameters and a positive relation for the chemical parameters plotted against increasing rating class values from Very Low to Very High.

2. The second method establishes the proportional or percentage occurrence of each critical parameter for each one of the rating classes. It compares the relative distribution of the parameter in question in each one of the rating classes (Figures 5.16, 5.18, 5.19, 5.20, and 5.22).

3 The third cross-correlation method plots relative occurrence against tritium age (figure 5.21).

4. The last method is an inter-parameter cross comparison between relative occurrence of rating classes and tritium ages (Figure 5.23).

Not all parameters showed perfect behavior in the trend and distribution analyses, but the general tendency, and corroboration across classes of decision variables and rating distributions confirm that the ratings and their areal distribution based on the DNR Guidelines and modified methodologies in this report are consistent with valid findings of process based approaches. Therefore the assumptions and methodology in developing the criteria, decision variables and threshold or range values that allow a clear discrimination between rating classes are valid for Level-2 Sensitivity Assessments. The recommendations that follow are based on this assumption of validity.

Recommendations

This section contains the recommendation of two methods for assessing geologic sensitivity for the Minnesota Department of Natural Resources (DNR) Guidelines, and refers to the basis on which these recommendations are made. The two different methods are recommended for two levels of involvement. The basic recommendation is that a Modified Level-1 assessment (Case #2) may be sufficient for most preliminary planning purposes at a county scale, and that it represents a reasonable balance between effort and the usefulness of the outcome. For a more complete assessment of complex conditions a Modified Level-2 assessment (Case #10) is proposed. It involves a much more extensive information and database, requires greater expertise and professional guidance.

Basis and Scope

The bases for these recommendations result from the present Pilot Study, summarized in the present document and elaborated in the three-part, complete final technical report with appendices (Reference [1]). The originally proposed levels and methods according to the DNR Guidelines were applied and various modifications and combinations thereof were introduced, studied and compared. Cases #1, #3, and #8 refer to the original Level-1, the Level-2 Point Method, and the Level-2 Area Method, respectively. Other case numbers refer to variations and modifications of the methodology of the Guidelines and are described in the pilot study (see summary Table 5.3).

The present pilot study was carried out for a glaciated area with a surficial geology consisting predominantly of mixed glacial features. These consist of moraine complexes, with outwash features and lake sediments, and alluvial terraces and river deposits. Bedrock aquifers are secondary (in extent, use and volume withdrawn) and at greater depth under glacial covers. The area is of moderate surface relief and low slopes except for the bluffs descending from the uplands to the Minnesota River valley. Surface drainage is dendritic and lakes and wetlands are concentrated on ground moraine. These recommendations may have to be modified or revised in other regions that have not been studied in this pilot project such as regions dominated by a single glacial process (outwash plains, lacustrine deposits) or by extensive geomorphic features such as plains, high relief, or bedrock dominated systems.

Although it has been mentioned before it needs to be repeated that a sensitivity study and the resulting map representations do not replace detailed investigations at the scale of a project, irrespective of the sensitivity rating at the county or regional scale.

The scope of the recommendations extends to relatively shallow regional groundwater systems in unconsolidated geologic materials involving the first encountered water bearing unit whether a producing aquifer or not. This does not include perched systems. Hence it uses a compliance surface approach.

As the original DNR Guidelines establish, these recommendations are based on the concept of total travel time and the simplifying assumptions about flow conditions which are geology based, represent a simplified hydrology in the vertical direction through the vadose zone, and are based on the assumption of a conservative tracer chemistry. The criteria of travel time calculation are transformed into surrogate variables: thickness of vadose zone, vertical saturated hydraulic conductivity in the vadose zone, and a unit vertical hydraulic gradient. The surrogate variables are further transformed into decision variables: depth to water, low and moderate permeability units in the vadose zone, and the hydrologic characteristic of the geologic material at the water table.

The source of information for the preparation of the assessments under ordinary conditions relies on existing data and only a minimum of new and supplementary information is generated for a typical assessment project.

Recommendations for Methodology

DNR Guidelines Level-1 (Case #1) Assessment Methodology as described in the DNR Guidelines and in earlier sections of this report is based on interpretation of soils descriptions. These are provided in the Natural Resources Conservation Service's "State Soil System Database" from which the DNR has produced a statewide interpretation and sensitivity-rating matrix using the Level-1 assessment methodology. The drawback of this method is that it produces small and scattered sensitivity mapping units closely resembling the patchwork-like soil mapping units. It also overrates the sensitivity of an area. It is therefore proposed to use a Modified Level-1 assessment procedure instead, where appropriate.

DNR Guidelines Level-2 Point Method (Case #3) is valuable for local assessments, but does not produce a realistic areal coverage or realistic map representations, i.e. especially in areas where the density of data points is limited.

DNR Guidelines Level-2 Area Method (Case #8) is the most realistic and internally consistent representation of groundwater sensitivity. The recommendations below include modifications of the Level-2 Area Method.

Modified Level-1 (Case #2)

The two elements needed to use this method are a realistic depth to water map based on an interpretation of well logs contained in the County Well Index (CWI) data base maintained by the Minnesota Geological Survey (MGS) and the Minnesota Department of Health (MDH), and a surficial geology map of the area under consideration. Where no surficial geology maps exist at an appropriate scale they may have to be prepared from various sources, including field work or field checking by a competent geologist. Rough, large unit surficial geology maps can be constructed from existing information at a larger scale, such as USGS hydrologic atlases, soils association maps, or other reports and existing information from the MGS, other state agencies, or the private sector.

The more recent County Atlases prepared by the MGS and the DNR usually contain surficial geology maps, CWI-based depth to water information, and usually a plate with groundwater sensitivity representation as a Level-2 assessment or similar prepared using a variety of pollution sensitivity assessment methods. In this particular case a modified Level-1 (Case #2) assessment would only be warranted if the original County Atlas sensitivity plate is based on considerations other than using the water table as a compliance surface, or if very special conditions need to be met.

A surficial geology map gives a more credible, although not complete, representation of the nature of geologic material expected to exist at greater depth below the surface than maps created based on soils information only. They also provide larger mapping units over areas where extreme detail only serves to fragment and obscure the larger picture.

The depth to water map (DTW) can be constructed from well log information contained in the database of the County Well Index (CWI). The definition of this map clearly depends on the density of data points in the CWI for the area under consideration. CWI information can be supplemented with interpretation of the position and elevation of the water table based on hydrographic features such as lakes and rivers on topographic maps. One such map and the methodology has been developed for the Seven County Metropolitan Area by the USGS[12]. From the combination of the CWI and topographic information the isobath line separating areas of DTW less than 20 ft. and more than 20 ft. can easily be established.

It needs to be pointed out that the relatively good agreement between sensitivity maps according to the less time consuming modified Level-1 Method and the more elaborate DNR Level-2 approach or its modified versions is due to a more realistic evaluation of the DTW factor. But, more importantly it is also due to the fact that in the type of glaciated terrain present at this study site there exists a direct relationship between thickness of the vadose zone and the occurrence and thickness of low or moderate permeability units.

The Modified Level-1 methodology requires a certain level of expertise that may not be expected to exist at all levels of county government. This is especially true of preparing surficial geology information and its interpretation and translation into sensitivity ratings. Like the statewide sensitivity rating matrix based on the soils database a similar type of statewide modified Level-1 rating matrix should be prepared by the DNR. A consistent approach for using hydrologic characteristics of surficial materials, and depth to water, where available would assure consistency across the state. Furthermore, for consistency reasons, interpretation of the well logs from the CWI data base, analysis of the topographic and hydrographic information, and the establishment of the 20 ft. or 30 ft. DTW isobaths, or depth contour lines, should also be done in coordination with the DNR.

If the necessary data base is insufficient and only soils information is available for an unmodified Level-1 DNR Guidelines approach the problem of getting larger, more uniform mapping units could be solved by using appropriate GIS methodology on digitized soils maps at the county level. It would consist of an algorithm that absorbs small patches of sensitivity units into the surrounding larger, lower sensitivity areas, given certain size and sensitivity criteria. This approach would alleviate one part of the problem of overestimating sensitivity ratings. However, the problem of the ill defined DTW and its insufficient threshold value would still remain.

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[12] Larson-Higdem, D. C., Larson, S.T. and Norvich, R. F., (1975), Configuration of the water table and distribution of downward leakage to the Prairie du Chien and Jordan Aquifer in the Minneapolis-St. Paul Metropolitan Area, Minnesota, USGS Open File Report 75-342, 33 p.

The Modified Level-1 Method (Case #2) as described in this report should be sufficient for the preparation of sensitivity maps for planning if no problems are foreseen. However, a number of triggering situations may make it necessary to go to the next level of assessment, Level-2. A few of these triggering levels are discussed below to help staff decide the appropriate level of effort.

Modified Level-2 Area Method(Case #10)

The Modified Level-2 Area Method recommended is the Case #10 from the discussion in the present pilot study above. This modification involves minimal variations in the original DNR Level-2 Area Method from the Guidelines (Case #8). No fundamental changes in the methodology or the basic assumptions are made. The database used remains the same: a surficial geology map and information from the well logs contained in the CWI. Changes with respect to the guidelines deal only with:

1. An increase of the threshold values for the decision variables:
   a. Thickness of low and moderate permeability units (LPU and MPU's) in the vadose zone, and
   b. Thickness of the zone defining ‘material at the water table’ to the zone of fluctuation of the water table position, rather than a single point depth value.

2. A change of the rating category of clay materials at the water table to a higher sensitivity rating.

3. A more consistent method to define the depth to water based on establishing a ‘high water table’ from statistical analysis and extrapolation of CWI data and hydrographic information.

These modifications result in a conservative rating scheme.

Much of the information needed to generate the Modified Level-2 assessment such as the surficial geology map and the water table map or the depth to water contour lines (±20 ft. isobaths) are in principle already available if a Modified Level-1 (Case #2) map has been generated. Both may need some refinement to meet the standards for a Level-2 investigation. The only additional work is to evaluate hydrologic characteristics of the geologic material in the vadose zone and at the water table from the well logs in the CWI.

The Modified Level-2 Area Method (Case#10) is recommended because the areal assessment method is internally consistent, and it is based on physical principles governing the shape and evolution of the water table surface, not on purely statistical extrapolation as is the case with the Level-2 Point Methods. It is recommended over the Level-2 Point Methods for the reasons stated above and because it results in smaller areas of Low or Very Low sensitivity ratings, hence it is also more conservative. In addition, it is recommended over the Modified Level-2 Area Method (Case#11) because the results show very little difference in the sensitivity ratings of the mapped area such that the added effort to produce a map according to the more sophisticated method does not seem warranted. The Modified Level-2 Area Method (Case#11) makes use of true depth to water map based on the difference between a DEM topographic map and a very elaborate water table map.

To reiterate: Even a more detailed Level-2 study gives only a general overview of the sensitivity of the groundwater resource to potential groundwater contamination, but does not substitute for an in-depth study and sensitivity assessment at the project scale.

Potential Hazard Inventory Map

The first step in evaluating whether a sensitivity assessment or a higher degree of refinement in a sensitivity assessment is necessary, is to identify and locate potential threats to the groundwater and the affected populations on a hazard inventory map. This type of map represents an areal evaluation of potential threats and affected populations. It should show:

1. Population density distribution, and the location and magnitude of groundwater withdrawal for municipal, agricultural or industrial purposes.

2. Land cover and land use (present and projected) with an indication of potential diffuse sources of agrochemical pollution.

3. Source identification and location of point sources of potential contamination threats.

The resulting areal presentation on a map would be a simple binary representation of presence, or absence of a threat without a detailed ranking system. The results would be overlain onto the Level-1 map either physically or by GIS algorithm. If significant overlap between areas of threat and High or Very High sensitivity exist a more precise definition of these areas through a Level-2 analysis would be warranted.

Other triggering mechanisms for a Level-2 assessment could be the same criteria that are used to determine if an Environmental Impact Statement (EIS) is needed on a countywide basis. Among these are project size and value, large-scale changes in land use, development pressure, preservation of natural resources, etc.

Administrative Recommendations

Both recommendations, Modified Level-1 Method (Case #2), and Modified Level-2 Area Method (Case#10), require a certain minimum data base, and a minimum amount of expertise in preparing the information base, and sophistication in the interpretation, designation and application of sensitivity ratings to the sensitivity maps. It is unlikely that this expertise exists at an even level in county government throughout the state.

It is therefore recommended that in order to maintain adequacy in the application of the methodology, sufficiency of the database, and consistency in the rating, the DNR be involved in setting state-wide guidelines and assist in the preparation of county sensitivity maps.

First, site visits and an evaluation of the database for each county project should ascertain the adequacy of existing information and answer the question whether a sensitivity evaluation can be carried out on the basis of it. If the database is found lacking, the DNR should assess the amount of new information that needs to be generated. The relatively low cost sources of information are the generation of geophysical data for filling in and supplementing at critical points, and geochemical data for residence time estimation. If none of these complete the database sufficiently, the county may have go to a full-scale preparation of a County Atlas.

Second, the preparation of the following documents for sensitivity mapping purposes only, should be supervised by the DNR:

1. Surficial geology maps based on information from soil association maps, USGS Hydrologic Atlases (Series HA), County Atlases and MGS reports,

2 Surficial material textural information into rating categories for large surficial landform units (such as already has been done in a Level-1 rating matrix for small soils units), and

3. Interpretation of CWI well logs and depth to water maps and construction of the 20 ft. isobath lines.

Finally, DNR should act as a central clearinghouse for pertinent information that is generated by other agencies for inclusion in sensitivity assessment projects and to avoid duplication of effort. Other agencies that are involved in activities related to sensitivity assessments are the Minnesota Department of Health (MDH), in charge of wellhead protection programs, the Minnesota Pollution Control Agency (MPCA) in modeling large aquifer systems, and the Board of Water and Soil Resources (BWSR) in aiding counties in the preparation of water plans, to mention a few.

Summary List of Bibliographic Footnotes

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