Criteria and Guidelines for Assessing Geologic Sensitivity of Ground Water Resources in Minnesota

Minnesota Department of Natural Resources
Division of Waters

June 1991

Criteria and Guidelines for Assessing Geologic Sensitivity of Ground Water Resources in Minnesota

June 1991
Updated December 2003

developed by the
Geologic Sensitivity Project Workgroup

prepared for the
Legislative Commission on Minnesota Resources

Minnesota Department of Natural Resources
Division of Waters

The DNR Information Center phone numbers:
Twin Cities: (612) 296-6157
MN Toll Free: 1-800-652-9747 (ask for the DNR)
Telecommunication Device for the Deaf:
(612) 296-5484

Department of
Natural Resources
Division of Waters

Printed on Recycled Paper

ACKNOWLEDGEMENTS

The criteria and guidelines for assessing geologic sensitivity in Minnesota described in this report were developed by members of the Geologic Sensitivity Project Workgroup:

Fred Bergsrud, Minnesota Extension Service
Jan Falteisek, Minnesota Department of Natural Resources
Jeff Green, Minnesota Department of Natural Resources
John Hines, Minnesota Department of Agriculture
Howard Hobbs, Minnesota Geological Survey
Eric Mohring, Minnesota Board of Water and Soil Resources
Bruce Olsen, Minnesota Department of Health
James Piegat, Hennepin Conservation District
Eric Porcher, Minnesota Pollution Control Agency
Carl Schenk, Metropolitan Council

Additional information was provided by Ted Geier, graduate student, University of Minnesota.

Within the Department of Natural Resources, Division of Waters, Sarah Tufford was the program administrator. Jim Zicopula drafted many of the figures. Katie Gorres assisted with word processing and mailing.

This project was funded by the Legislative Commission on Minnesota Resources.

Sincere thanks to all reviewers of earlier drafts; while not all comments could be accommodated, this report was substantially improved by your timely and thoughtful critique.

Jan Falteisek
Project Coordinator
Division of Waters
Department of Natural Resources

Note: In December 2003 this document was scanned by staff of the Minnesota Pollution Control Agency in collaboration with DNR Waters. Minor changes were made to several pages to improve useability and correct technical inconsistencies overlooked in the original document. The scanned document is available in electronic format on the DNR Waters web site.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (cont.)

LIST OF FIGURES (cont.)

LIST OF TABLES

CHAPTER I

INTRODUCTION

Prevention of ground water contamination is a major component of wise resource management. One approach to help prevent ground water pollution is to recognize where ground water is especially vulnerable, or sensitive, to pollution. Water resource managers can use this information to develop and implement appropriate ground water protection strategies.

This report presents the general approach and criteria for determining relative ground water sensitivity throughout Minnesota. The Minnesota Ground Water Protection Act of 1989 defines a sensitive ground water area as "a geographic area defined by natural features where there is a significant risk of ground water degradation from activities conducted at or near the land surface." The Act, among other things, requires the Minnesota Department of Natural Resources to develop sensitivity criteria and map sensitive areas and indicate the "type of risk of ground water degradation that may occur from activities at or near the surface." To be able to consistently identify and discriminate more sensitive areas from less sensitive areas requires a set of criteria for decision-making.

This report is the result of project funded by the Legislative Commission on Minnesota's Resources (LCMR) to develop criteria and a general approach for assessing the geologic sensitivity of ground water in Minnesota. The criteria were developed through the cooperative efforts of staff from: the Department of Natural Resources, Department of Health, Hennepin Conservation District, Board of Water and Soil Resources, Minnesota Geological Survey, Pollution Control Agency, the Metropolitan Council, the Department of Agriculture, and the Minnesota Extension Service. Representatives of these agencies utilized previous work of their agencies as well as personal experience in ground water research and management to develop the criteria and approach. In addition, comments were solicited from a broad group of interested persons.

The criteria, general approach and guidelines for application were developed to encourage a consistent approach to assessing geologic sensitivity in Minnesota. Potential users of this report include federal and state agencies, local governments, and research organizations in Minnesota colleges and universities.

These criteria for assessing geologic sensitivity allow the preparation of maps. However, the prepared maps are interpretations of known or estimated subsurface conditions. They are intended for use as screening tools and guides to indicate where additional information or other special requirements might be desirable to support land use or resource protection decisions.

The criteria for assessing sensitive ground water areas are based on the properties of the geologic materials overlying the ground water. The sensitivity of the material is indicated by the known or estimated "time of travel" for a water-borne contaminant to travel vertically from its source at or near the land surface to the aquifer. The most sensitive ground water areas would have the shortest estimated time of travel. These areas have the least potential to retard the vertical movement of contaminants into an aquifer. The time of travel varies with the distance and nature of the geologic materials through which the contaminant must travel. The permeability, thickness, mineralogy, and number and type of different geologic layers underlying the area also affect the time of travel.

Users of the criteria and guidelines may find this approach satisfactory for many needs. However, users should be aware of the limitations of the approach, which is intended to be only a first step. The criteria describe geologic sensitivity and are based solely on the physical and geologic conditions in an area. The complex effects of human activities, lateral movement of ground water, the physical and chemical properties of a particular contaminant, or the chemical and biological characteristics of the soil and underlying geologic materials are beyond the scope of this report. Other methods which can be used to evaluate the effect of these factors on ground water sensitivity are described in the report.

The Legislative Commission on Minnesota's Resources (LCMR) funded related projects to assist the development of criteria for delineating sensitive areas. This report is part of a larger project that also included several aquifer and watershed studies. The results of these studies of the Prairie du Chien - Jordan aquifer and in Dakota County, Olmsted County, Winona County and the Twin Cities Metropolitan Area were used to modify earlier drafts of this report.

It is recommended that the criteria and methods presented in this document be further evaluated, and modified as needed, through future application to activities related to ground water protection and management in the fields of planning, regulation and education.

CHAPTER II

A GROUND WATER PRIMER

The geologic materials that make up the earth's crust contain pore spaces, voids, cracks, and other openings which are capable of storing and transmitting water. Precipitation or surface water becomes ground water when it seeps or infiltrates into the ground. As the water moves downward, some is retained in the **unsaturated zone** or **vadose zone** (Figure II-1) where the pore spaces or fractures contain both air and water. Some of the water in the unsaturated zone will be taken up by plants and returned to the atmosphere, and some becomes attached to soil and rock particles. Some of the infiltrating water eventually reaches the **saturated zone**, where all voids and cracks are completely filled with water. The surface separating the unsaturated or vadose zone from the saturated zone is called the **water table**. Water stored in the saturated zone is called **ground water**. A saturated geologic formation capable of yielding water to wells or springs is called an **aquifer**. The **static water level** or **head** of an aquifer is the level to which water will rise in an unpumped well constructed into that aquifer.

Two properties of geologic materials determine their ability to store and transmit water: **porosity** (the amount of space to store water) and **permeability** (a measure of the relative ease with which water can move through the material due to the connections between the spaces). Geologic materials with high porosity and permeability typically yield large amounts of ground water.

WATER TABLE AQUIFERS

A **water table aquifer** is the uppermost aquifer in which a water table is present. The water table exists everywhere in a variety of geologic materials. Some of these such as sand, gravel, limestone, and sandstone readily store and yield water to wells. Other geologic materials such as clay, shale or dense bedrock do not readily yield or transmit ground water. However, if high yielding aquifers are not present, even low-yielding materials such as clay-rich glacial till can be used as a water source. There is no clear definition of the minimal yield required to designate a geologic formation an aquifer. In some areas of Minnesota, wells are supplied by water table aquifers that yield less than one gallon per minute to continuous pumping.

In a broad sense, the water table roughly parallels the land surface. The water table in Minnesota is usually within fifty feet of the land surface, and is exposed in lakes, perennial streams, and some wetlands (Figure II-2). Elsewhere, it is covered by the vadose zone. When water infiltrating from the surface reaches the water table, it begins moving toward points of ground water discharge, particularly streams, springs, lakes, and wells.

Perched water is a term used to describe ground water that is not part of the water table aquifer. Perched water occurs in isolated lenses above a continuous water table. Perched conditions result when surface water or infiltrating water encounters geologic materials of low permeability such as clay or shale. These materials prevent or retard the vertical movement of water to the water table and create water saturated conditions above them. Thus, the water is contained or perched above the actual water table. Sometimes it is very difficult to distinguish

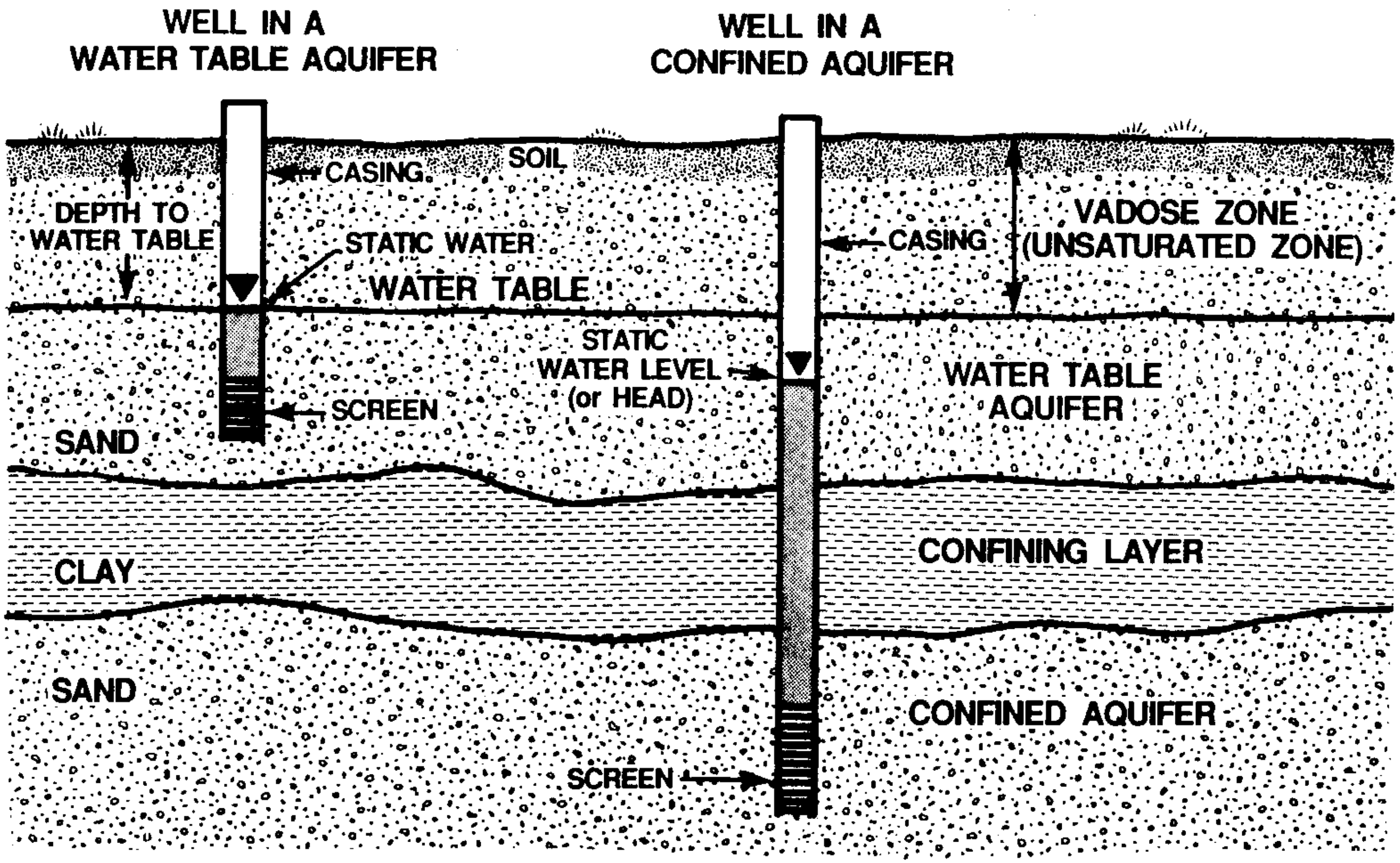


Figure II-1. Cross-section diagram showing general ground water terms.

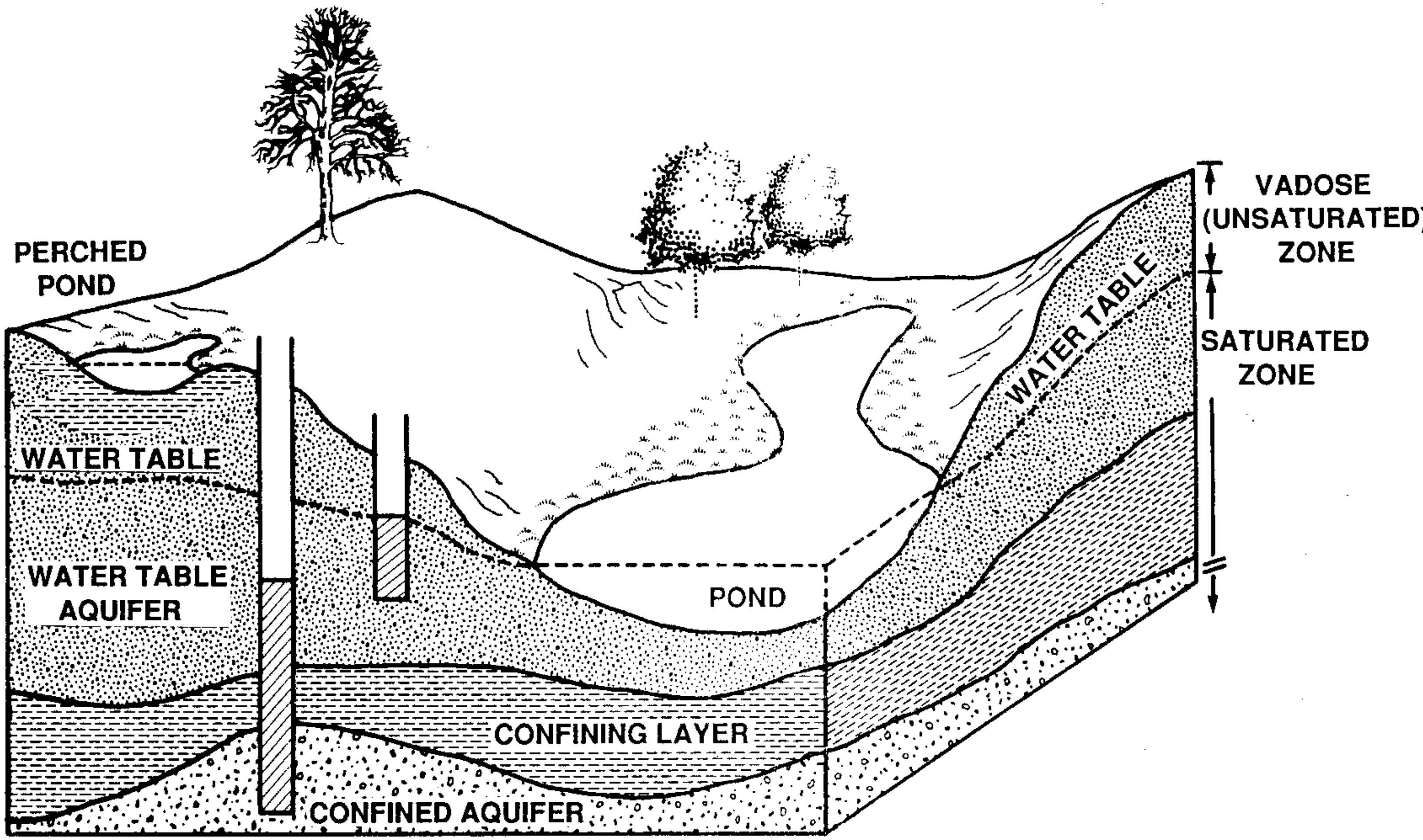


Figure II-2. Block diagram showing how the water table may be exposed at some surface waters. Perched waters do not represent the water table.

between perched conditions and water table conditions. Usually more subsurface information, such as from borings, is required.

A more general term for water table conditions is **unconfined** . A partially saturated geologic formation is called unconfined. The unconfined aquifer nearest the surface is the water table aquifer. Although not common, unconfined conditions are sometimes observed below the water table aquifer where it is underlain by a low permeability material.

DEEPER AQUIFERS

A **confining layer** is a geologic unit of relatively low permeability. An aquifer which is completely saturated and is overlain by a confining layer is called a **confined** or **artesian aquifer** (Figures II-1 and II-2). The static water level in a well casing properly sealed through a confining layer into a confined aquifer will be above the top of the aquifer, sometimes by quite a distance. The **potentiometric surface** or **head** for the confined aquifer is the surface representative of the static water level in a well cased into the aquifer.

For evaluating geologic sensitivity, a deeper aquifer is defined as one that is separated from the water table by a confining layer. A well completed in a deeper aquifer usually does not have the same static water level as an adjacent well completed in the water table. If a deeper water bearing formation exhibits a static water level elevation substantially different than that of the water table, the two ground water systems (aquifers) are probably hydrologically separated.

In some areas, such as southeastern Minnesota, deeper aquifers may exhibit unconfined conditions even though a confining layer separates them from the water table aquifer. In Figure II-3, the deeper aquifer is not completely saturated where the aquifer system is affected by discharge into a river valley. Under these conditions, the deeper aquifer becomes unconfined even though it is not connected to the water table aquifer.

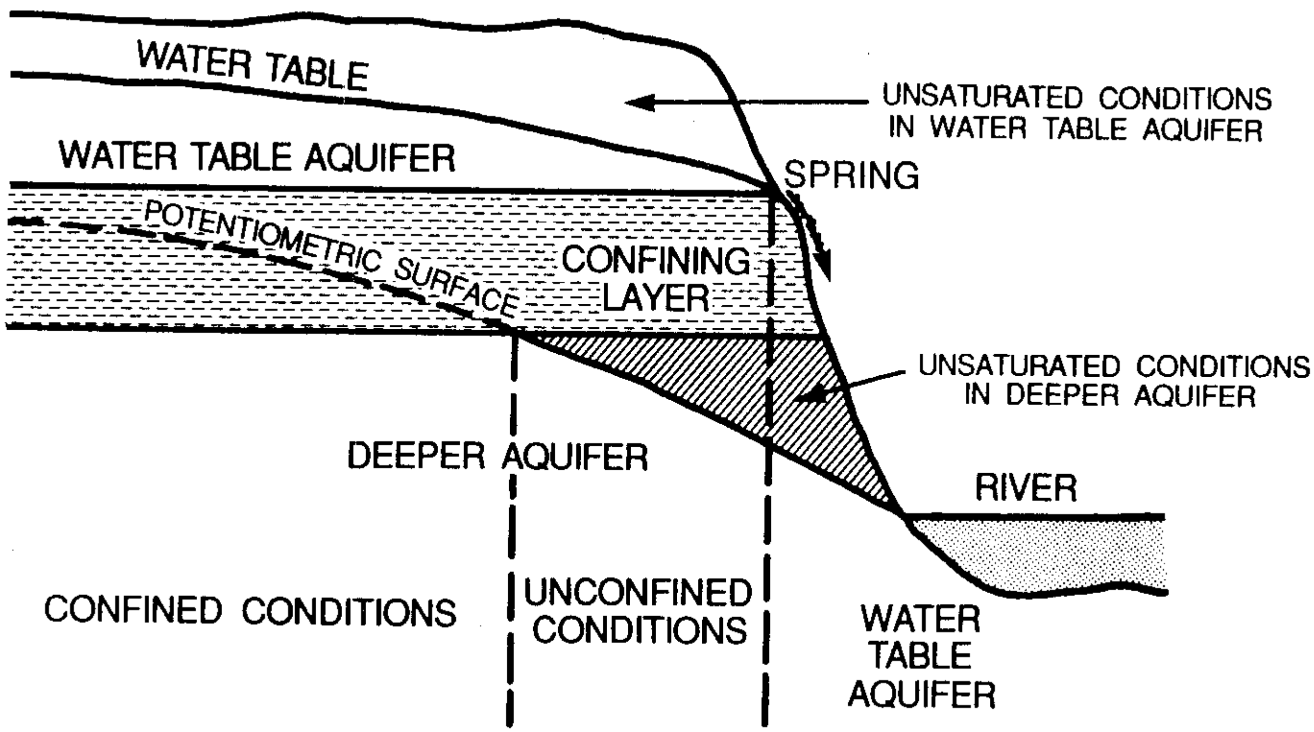


Figure II-3. In some areas (such as SE Minnesota), aquifers below a confining layer may be unconfined. For the purposes of this document, the term "water table aquifer" is used to describe the uppermost unconfined aquifer.

CHAPTER III

BACKGROUND AND APPROACH

This chapter presents the general criteria for determining geologic sensitivity in Minnesota. This chapter also introduces the method by which the general criteria can be applied. Later chapters present guidelines for applying the method.

Evaluating the sensitivity of an aquifer to contamination sometimes requires considerable effort. Many local governments may not have the resources to conduct the extensive and detailed studies required to assess an aquifer's sensitivity in all situations. The criteria and method presented in this chapter provide a way to assess the sensitivity of ground water to contamination in their jurisdiction when detailed studies are not available. For many local needs, discussed in more detail in the next chapter, using this method to apply the general criteria may be adequate.

DEFINING GEOLOGIC SENSITIVITY

The term "sensitivity" is commonly used to describe the general potential for an aquifer to be contaminated. One aquifer is said to be more sensitive than another aquifer if it has a higher potential to be contaminated. However, this definition of sensitivity is unsatisfactory because "potential" is vague and difficult, if not impossible, to measure.

Part of the difficulty is that the likelihood of contaminant release is poorly known, usually reflecting site-specific factors such as actual use, storage and handling and equipment maintenance. In addition, the physical and chemical characteristics of a contaminant, local and regional ground water flow patterns, geologic materials, land use patterns, seasonal changes, how and where the release occurs, and other factors complicate estimating the "potential" for contamination.

Instead of trying to use an unmeasurable term such as "potential" to define relative sensitivity, this report uses the concept of "time of travel", the time required for a contaminant to move vertically from the land surface to an aquifer. This interpretation is preferred as being specific and measurable.

The factors mentioned above can make it very difficult to determine the travel time for a contaminant to reach an aquifer. Therefore certain simplifying assumptions have been adopted. In particular, any factors that may change over time, such as land use and seasonal effects, are not considered. Since contaminants are so variable in their behavior, contaminants are assumed to be inert and conservative and to behave the same as water. Contaminants are assumed to be released at or near the land surface and not, for instance, from a buried tank. Ground water flow paths are assumed to be vertically downward in all cases; any lateral movement of contaminants and the rate at which they enter ground water is not considered. In addition, the method does not evaluate the effects of human related activities such as ground water withdrawals or improperly constructed, maintained or sealed wells on the movement of contaminants to or within an aquifer.

The only factor affecting sensitivity that is fundamental to contaminant movement, relatively well understood and stable over time is the geology of an area. The properties of various geologic materials are sufficiently known that reasonable estimates of contaminant time of travel from a source to an aquifer are possible. Since the time of travel estimate uses only geologic information, the evaluation is of geologic sensitivity, not some broader interpretation.

GEOLOGIC SENSITIVITY CRITERIA

In this report, geologic sensitivity is proportional to the time required for a contaminant to move vertically from the ground surface to an aquifer. Shorter travel times mean the geologic sensitivity is greater while longer travel times indicate a lower geologic sensitivity.

The general criteria for geologic sensitivity are listed in Table III-1. Figure III-1 shows Table III-1 as a graph. The five overlapping ranges of travel times have been assigned relative sensitivity ratings from Very High to Very Low. The travel time ranges overlap because of the uncertainty of travel time estimates, which can have great local variation. This definition of geologic sensitivity is based on the cumulative experience of the authors. Additional investigations such as age-dating analysis or porosity and permeability studies, as discussed in Chapter IX, can be used to confirm the ratings.

TABLE III-1. Geologic sensitivity ratings based on time of travel.

Geologic Sensitivity Rating	Estimated Travel Time
Very high	Water moving vertically will reach the aquifer within hours to months;
High	Water moving vertically will reach the aquifer within weeks to years;
Moderate	Water moving vertically will reach the aquifer in years to decades;
Low	Water moving vertically will reach the aquifer within several decades to a century;
Very low	More than a century will be required before water moving vertically will reach the aquifer. This rating should only be used in Level 3 assessments (deeper aquifers) unless age-dating or other studies confirm such conditions in water table aquifers. Special studies are discussed in Chapter IX.

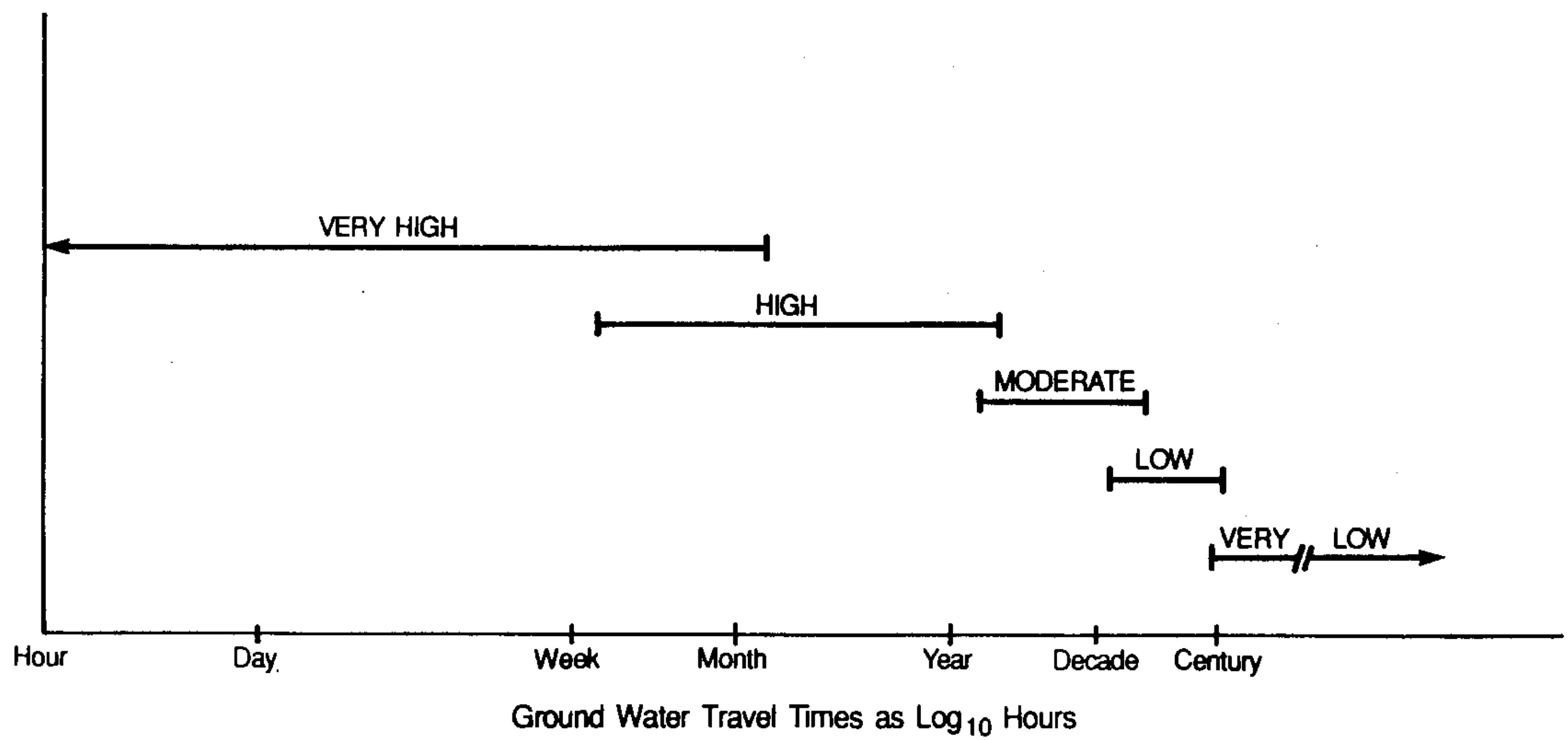


Figure III-1. Geologic sensitivity ratings and ground water travel times.

How soon a contaminant may reach an aquifer following a release is an extremely important public health issue. In some areas of Minnesota, aquifers may become contaminated almost immediately after a contaminant release. For example, sinkholes in southeast Minnesota allow contaminants to move quickly from the surface to the ground water system. In such areas there is very little time to respond and prevent aquifer contamination. In contrast, contaminants will infiltrate slowly in areas where the subsurface materials contain a lot of clay. In the first case, contaminants can move quickly and have short travel times. In the second case, contaminants move slowly and have long travel times. Based on travel times the sinkhole area is more sensitive than the clay area. Once a contaminant reaches an aquifer it may enter a water supply system, perhaps eventually enter another aquifer, or discharge to the surface water system. The experience of contamination cleanup programs shows it is more cost-effective to remove contaminants before they have a chance to enter the ground water system.

As shown in Table III-1, there is no simple measure of geologic sensitivity. Rather, there are ranges of time of travel that have been given relative sensitivity ratings. Preparation of maps showing sensitive versus non-sensitive areas is not recommended. Such maps give the unfortunate and incorrect idea that any activity may be pursued in the so-called "non-sensitive" area. No part of Minnesota is perfectly isolated from contamination, although some areas may be relatively more protected than others. Another reason to avoid preparing simple maps is the common situation where there is more than one aquifer in an area. Each aquifer needs a separate map which can be used in a coordinated aquifer protection program, perhaps requiring different protection strategies for each aquifer.

This report does not replace other criteria and methods for assessing ground water sensitivity. There are many other approaches that use different criteria and rating schemes that may be more appropriate for particular geologic and land use settings. Appendix D provides a brief description of many of the methods available to address specific types of contaminants and situations as well as other methods for evaluating ground water sensitivity.

ESTIMATING TRAVEL TIMES THROUGH VARIOUS GEOLOGIC MATERIALS

Geologic materials are defined primarily by their mineralogical and textural compositions. Textural properties, interpreted as the permeability of a material, are used by this method to estimate vertical times of travel. As discussed in Chapter II, the permeability of a material is a function of pore geometry and how well the pores are connected. Pores can be primary, such as the spaces between sand grains, and secondary, such as fractures, joints or karst features. Dense bedrock composed of interlocking crystals or cemented grains such as igneous, metamorphic and cemented sedimentary rock are evaluated in this method relative to their secondary porosities. Mineralogical composition is not used although it is a principal factor in determining the degree to which specific contaminants may react to change permeability. An example would be limestone and other carbonate rock areas that gradually dissolve in response to acidic ground water.

Geologic materials with the least vertical permeability are assumed to have the greatest ability to retard the vertical movement of contaminants, resulting in the longest travel times. Conversely, the geologic materials with the highest vertical permeability are assumed to have the least ability to retard the vertical movement of contaminants, resulting in shorter travel times. Ground water resources are at greater risk in those geologic settings which have greater vertical permeability and thus less ability to retard the movement of possible contaminants. Greater risk may be interpreted as less time to respond to a contamination problem.

METHOD FOR ASSESSING GEOLOGIC SENSITIVITY

The general criteria, presented above, can be applied using three different levels of sensitivity assessment. For convenience these options have been designated Level 1, Level 2 and Level 3. Level 1 and Level 2 are related in that both assess the geologic sensitivity of the surficial aquifer. However Level 1 is a preliminary estimate that uses only available information whereas Level 2 requires much more detailed information. The additional information collected for a Level 2 assessment allows a more reliable evaluation of an area's geologic sensitivity. The third option, or Level 3 assessment, provides a separate evaluation of each confined aquifer identified below a confining unit. Figure III-2 shows the relationship between the three assessment levels.

Completing one or more assessment options or Levels may be needed to provide information for certain tasks, such as planning or regulation. Each assessment level is discussed in more detail later in this chapter. The choice of a particular assessment level for a particular task is discussed in Chapter IV.

The general information needed to complete a geologic sensitivity assessment at each of the three Levels is shown in Table III-2. The procedures and specific information requirements for each assessment are described in detail in later chapters.

TABLE III-2. Information required to complete geologic sensitivity assessments at each of the three levels.

Information needed to evaluate	Assessment Level		
geological sensitivity	1	2	3
Soil texture/parent materials	X		
Depth to water	X	X	
Vadose zone material		X	
Deeper aquifers/confining units			X

The following brief discussion presents a general description of each level and describes the limitations and benefits of each in making decisions affecting land and water use.

Level 1 - Estimates the vertical permeability of the vadose zone based on the geologic material present at the ground surface. It has the following benefits and limitations:

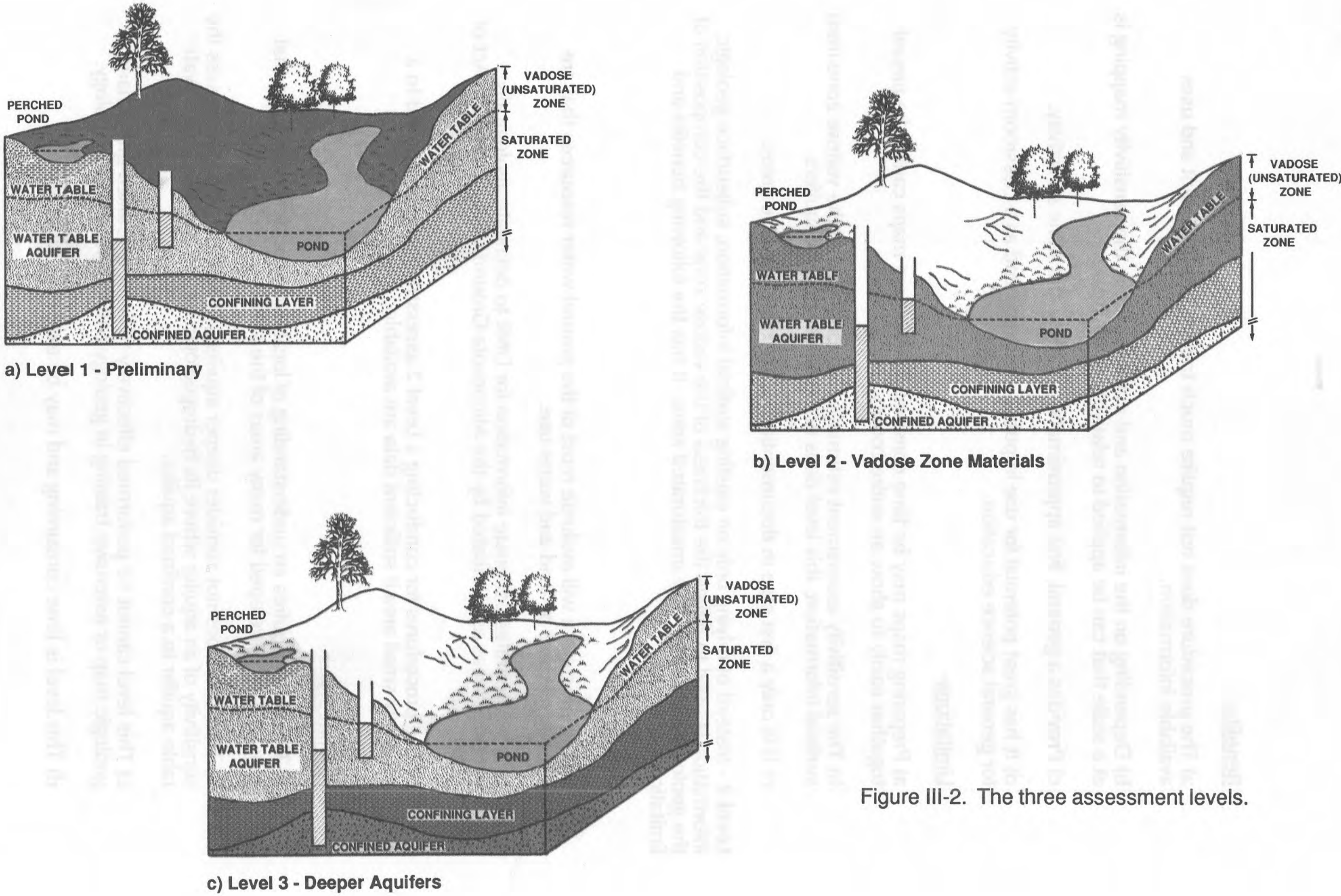


Figure III-2. The three assessment levels.

Benefits-

a) The procedure does not require much training or equipment and uses available information.

b) Depending on the information and maps available, the sensitivity mapping is at a scale that can be applied to relatively small areas.

c) Provides a general, first approximation of the water table sensitivity.

d) It has great potential for use in public education and as a classroom activity for general science education.

Limitations-

a) Preparing maps may be time consuming and some maps cannot be pieced together easily to show an entire county.

b) The sensitivity assessment estimates the conditions in the vadose zone from surficial information; this level does not consider deeper aquifers.

c) It is only a first step in documenting geologically sensitive areas.

Level 2 - Instead of relying only on existing surficial information, subsurface geologic information is used to define the thickness of the vadose zone and the composition of the geologic materials in the unsaturated zone. It has the following benefits and limitations:

Benefits-

a) The procedure will evaluate most of the ground water resources that are directly affected by land and water use.

b) It incorporates adequate information for DNR to delineate geologically sensitive areas as mandated by the Minnesota Ground Water Protection Act of 1989.

c) The procedures for conducting a Level 2 assessment can be applied to a relatively small area if sufficient data are available.

Limitations-

a) This level requires an understanding of local hydrogeologic conditions that must yet be developed for many areas of the state.

b) This level does not consider deeper aquifers. Therefore, it cannot assess the sensitivity of an aquifer where its hydrogeologic setting changes from a water table aquifer to a confined aquifer.

c) This level cannot be performed effectively without a detailed quaternary geologic map or extensive training in geology and ground water hydrology.

d) This level is time consuming and may be expensive to conduct.

Level 3 - Evaluates the geologic sensitivity of aquifers occurring below, and separate from, the water table aquifer. Deeper aquifers are evaluated by identifying the presence of confining layers. This level has the following benefits and limitations:

Benefits-

a) This procedure, when used with a Level 2 assessment, provides a complete initial assessment of the geologic sensitivity of the entire ground water system.

b) Some deeper aquifers may change from confined to unconfined conditions within an assessment area. In such cases, the unconfined portion of the deeper aquifer is assessed using the Level 2 procedure.

Limitations-

a) This level requires collection of additional subsurface geologic data in many areas of the state.

b) This level cannot be performed effectively without extensive training in geology and ground water hydrology.

c) This level is time consuming and expensive to conduct.

LIMITATIONS OF METHOD

The criteria and three-level method for mapping geologic sensitivity provides a flexible procedure suitable for general use. The resulting maps will help state or local governments to manage their land, water and other resources.

These guidelines for developing sensitivity assessments are necessarily general to make them widely useful. However, a number of issues were not addressed: 1) the physical and chemical properties of contaminants and their interactions with earth materials; 2) whether contaminants are persistent or whether they transform to other substances under particular conditions during a particular time; 3) whether contaminants are introduced at or near the surface such as pesticides, or originate below the surface, such as leaking underground storage tanks; 4) the moisture content of the vadose zone; and 5) the differences in behavior of saturated and unsaturated flow.

The general approach to these uncertainties has been to consider the "worst-reasonable" case. For example, some contaminants transform to harmless substances, others do not. The method assumes that contaminants do not undergo transformation. The reasoning is that although some contaminants may transform to harmless substances, others may not.

Level 1 and Level 2 assessments estimate time of travel in the vadose zone. However, unsaturated flow is very complex and difficult to predict. In many cases, unsaturated flow is slower than saturated flow, so estimates of time of travel based on saturated flow will be conservative for unsaturated flow - that is, contaminants in the unsaturated zone are expected to move more slowly than predicted, but not faster. However, this behavior is not always observed; under certain conditions unsaturated flow will be faster than saturated flow.

SPECIAL CASES - SURFACE APPLICATIONS

Agricultural chemicals form a special case that may require modified treatment. They share several general characteristics: they are deliberately applied at the land surface, they may transform to other substances, and they are assumed to be applied at rates that will be entirely consumed, transformed or degraded within the soil zone. The time required for degradation depends on the particular chemical and on several other factors. Transformation takes place in the soil, in contact with air, water, and soil microbia. However, transformation takes place more slowly or not at all if agricultural chemicals are leached below the root zone.

Agricultural nutrients, comprised of fertilizers, manures and other organic matter, are intended to be taken up by plants. They will be taken up by the root system rather than leaching through the soil, unless they are applied in excess of plant needs, and/or the absorption capacity of the soil, or at times when plants are not present.

Land treatment of sludges is another activity that may need an alternate method to evaluate sensitivity. Sludges from sewage treatment processes and municipal water treatment are commonly applied at the land surface. The typical concern for land treatment is the impact of non-degradable constituents in the sludge such as heavy metals.

Other methods for assessing sensitivity are presented in Appendix D. An alternate method may be more suitable for assessing sensitivity in the case of surface applications of agricultural chemicals or sludges.

LAND-USE DECISIONS

Many land-use decision makers will want these guidelines to provide simple yes-no answers. Geologic sensitivity is a complex subject, and the methods outlined in this document have many simplifying assumptions. The guidelines have not considered all of the variables that govern sensitivity, and therefore, cannot and should not be expected to provide final land-use answers. Many land-use decisions are site-specific. The guidelines are general; they will only provide site-specific evaluations in areas where a large amount of site-specific information is available.

Geologic sensitivity is one of several criteria that can be used to make land-use decisions. The relative value of proposed facilities, compatibility with existing land uses, and various mitigation measures should also be taken into account. Even if ground water protection were the main criterion for such decisions, a trade-off still may have to be made between potential ground water and surface water effects. In a common situation in Minnesota, ground water near the surface, but underlain by low permeability material may have greater effect on surface waters. In these areas precipitation will tend to run off to surface water more readily than infiltrate into the subsurface. The complex interrelationships of surface and ground water, while not addressed in this guideline, must be considered in wise land-use management.

OTHER METHODS

These guidelines represent a qualitative approach to the assessment of geologic sensitivity of ground water resources. They are designed to use data that are already available, or can be obtained reasonably, in most parts of the state.

However, they are not rigorously quantitative. The general criteria are based on time-of-travel estimates that are very broad and overlapping. This method is not intended to substitute for site-specific studies that establish more accurately the effects of factors that affect ground water sensitivity.

For example, permeability tests performed on samples recovered from boreholes may be used directly. In addition, a mathematical model of ground water flow can be developed independently of any assessment level. Time of travel estimates from a mathematical model can be compared with the general criteria in Table III-1, and a map can be prepared, if desired.

In general, a study which takes more local physical, cultural and other factors into account takes precedence over a study which considered fewer factors. And a study which uses more exact and detailed information, including field measurements, supersedes a study which uses less or only estimates of local conditions.

All needs will not be satisfied by the general criteria and/or the application method as presented. Since some assessment needs are site-specific or require assessment results this approach does not produce, such as the potential for ground water contamination from a specific contaminant, an alternate method should be used to address these needs. Examples of such needs would be landfill or hazardous waste site evaluations, disposal basin leaching and mathematical modeling. Additional information on other sensitivity assessment methods is provided in Appendix D.

GENERAL PRECAUTIONS

The quality of an assessment and the levels which can be completed are directly related to the technical capabilities of the user and the amount and quality of available hydrogeologic information. The degree of reliability achieved by anyone using this methodology depends on their level of training and on the amount of information available to determine hydrogeologic conditions. Levels 2 and 3 require experience in interpreting subsurface geologic and ground water information to produce satisfactory results. It is recommended that someone knowledgeable in geology and hydrology participate in conducting Level 2 and Level 3 assessments.

CHAPTER IV

APPLICATION OF CRITERIA

The introduction to this report discussed in general terms some of the reasons for assessing of geologic sensitivity throughout Minnesota. In this chapter the various purposes and applications for sensitivity assessment will be reviewed in more detail. This chapter also includes a discussion on matching needs with the appropriate level of assessment.

Before undertaking an assessment, the local government, state agency or other organization should carefully evaluate the purpose of the assessment and select the appropriate level. In addition, there are other models and methods for assessing geological or ground water sensitivity and one or more of these may be more appropriate to needs of the organization. Appendix D contains a list and discussion of other assessment methods.

REASONS FOR SENSITIVITY ASSESSMENTS

The most important reason for assessing geological sensitivity is to encourage and promote public and private land use decisions which will provide better long term protection of Minnesota's ground water resources. "Land use" includes those activities and uses that occur at or near the surface. The information provided by a sensitivity assessment will assist state and local governments, industries, businesses, and citizens in deciding which land uses or near-surface activities are appropriate in sensitive areas, or which should be redesigned or modified to protect ground water resources. A sensitivity assessment may also indicate that specific uses should be restricted or excluded in certain areas. A sensitivity assessment will also encourage public and private decision-makers to seek more specific information regarding the potential impacts on ground water of any proposed development or activity as part of the land use decision-making process.

There are a wide range of statewide and local activities that affect land use and ground water quality. Some of these activities affect whole communities while others affect specific sites. These activities can be grouped into four broad purposes: planning, regulation/management, program implementation, and education. Table IV-1 shows these categories and examples of specific activities. This discussion is not intended to be exhaustive but to suggest some of the major uses for a geologic assessment as proposed in this guideline. There may be other important activities involving local governments, state agencies, research institutions and other organizations concerned with ground water protection which would benefit from a sensitivity assessment. All potential uses should be considered when undertaking a geologic or ground water sensitivity assessment program.

Planning - A wide range of local and statewide planning activities affect land use in geologically sensitive areas. Under recent state legislation, county governments are now responsible for water resource planning in Greater Minnesota (Minn. Stat. 103B.301) and ground water planning in the Twin Cities Metropolitan Area (Minn. Stat. 103B.255). These activities include major land use plan components. In addition,

Table IV-1. Applications and suggested sensitivity assessment levels

	ACTIVITY		Suggested Assessment Level 1	2	3
1.	PLANNING				
	a.	Local government growth management/ comprehensive planning: for example the timing, location and density of development and land use, and the timing and level of public services.	M	P	-
	b.	Neighborhood and specific development planning and review: for example the type and density of commercial, residential and industrial uses; proposed types, locations and standards for public services.	M	P	-
	c.	General systems planning for highways, sewers, storm water management and similar public facilities.	M/P*	P	-
	d.	Designation of search areas for hazardous waste facilities, landfills, and similar facilities.	M	P	+
	e.	Facilities site identification and preliminary evaluation: for example sanitary landfills, hazardous waste facilities and wastewater treatment plants.	M*	M*	+
	f.	County-wide water resource/ground water planning: for example goals, objectives, and standards for the protection of ground water and sensitive areas.	M	P	+
	g.	Local (city and township) water management planning including the identification of regulated areas and guidance for the application of water quality protection methods and official controls.	M	P	-

M = Minimum Assessment Level
P = Preferred Assessment Level
* = Depending on specific planning needs and contaminants involved.
+ = Suggest completion of Level 3 assessment for this activity.
- = Completion of Level 3 assessment may not be needed.

Table IV-1. Applications and suggested sensitivity assessment levels (Cont'd)

ACTIVITY			Suggested Assessment Level 1	2	3
2.	REGULATION/MANAGEMENT				
	a.	Zoning and subdivision regulations: for example standards and specifications for industrial, commercial and other land use districts and new subdivisions.	M	P	-
	b.	Local conditional or special use permits reviews and approvals.	M	P	-
	c.	Building, health and sanitary codes: for example requirements for septic systems, storage tanks, and handling/use of hazardous substances.		M	+
	d.	Management and design standards: for example highway stormwater storage ponds.	M	P	-
	e.	Best management practices: for example management requirements for surface runoff and road salt application.	M	P*	-
3.	PROGRAM IMPLEMENTATION				
	Guidance for programs related to ground water protection, including but not limited to, the following: - power plant siting and pipeline routing - Environmental Assessment Worksheet (EAW)/ Environmental Impact Statement (EIS) reviews - National Pollutant Disposal Elimination System (NPDES)/State Disposal System (SDS) permits - municipal sludge disposal - clean-up of accidental spills - Superfund sites		M	M/P*	+

M = Minimum Assessment Level
P = Preferred Assessment Level
* = Depending on specific program needs and contaminants involved.
\+ = Suggest completion of Level 3 assessment for this activity.
\- = Completion of Level 3 assessment may not be needed.

Table IV-1. Applications and suggested sensitivity assessment levels (Cont'd)

	ACTIVITY	Suggested Assessment Level 1	2	:	3
3.	PROGRAM IMPLEMENTATION (Cont'd)				
	- hazardous and solid waste facilities	M	M/P*		+
	- sealing of abandoned wells on state-owned and other lands				
	- Clean Water Partnership grant program				
	- state water resources protection and management grant program				
	- well-head protection				
	- Reinvest in Minnesota (RIM) (sensitive areas)				
	- permitting gas and liquid storage				
	- ambient ground water monitoring				
4.	EDUCATION				
	Education of public and officials regarding risks of ground water contamination and need for protection.	M	P		+

M = Minimum Assessment Level
P = Preferred Assessment Level
* = Depending on specific program needs and contaminants involved.
+ = Suggest completion of Level 3 assessment for this activity.
- = Completion of Level 3 assessment may not be needed.

cities and townships in the Twin Cities Metropolitan Area must prepare local water management plans (consistent with watershed plans) which are to address land use and water quality protection (Minn. Stat. 103B.235).

Other planning activities among local governments include growth management, comprehensive plan development and neighborhood and site planning/review (planned unit development). These activities affect the type (residential, commercial or industrial) and density of land uses in sensitive areas. Local governments are also involved in public facility planning and siting, such as the extension of sanitary sewers and landfill siting.

At the state and regional level, assessment information developed according to this guideline will guide systems planning efforts for facilities such as highways and airports. The information can also be used to screen potential search areas for new waste disposal facilities and identify specific site areas for more detailed investigations.

Private business and industries can also use the information to assist locating new facilities and making other land use and development decisions.

Sound planning requires appropriate and reliable information describing the potential impacts of planning options and decisions on existing conditions. Geologic sensitivity information will broaden the environmental information base for local and state-wide planning. This will help assure that impacts on and protection of ground water resources are considered in the planning process.

Regulation/Management - Many regulatory and management activities at the local and state level that affect land use (and thus potentially affect shallow and/or deep ground water) could benefit from the information provided in a sensitivity assessment. Local governments have the most significant impact on land use in sensitive areas. Local governments are involved in community-wide zoning, subdivision regulation and environmental controls, the review and approval of conditional or special use permits and the development of building, health, and sanitary codes. Each of these activities has the potential to affect ground water quality. For example, zoning determines the type and density of land use in sensitive areas. Geologic sensitivity information will be a valuable asset when evaluating proposed rezonings and amendments to land use controls and sanitary codes to protect ground water resources. Also, geologic sensitivity information can indicate where additional management, engineering or other controls may be needed to protect water resources.

Geologic sensitivity information can support statewide regulatory and management functions by assisting the development of statewide health and sanitary codes, providing information for various statewide facility design and management standards and guidance for state-wide best management practices.

Program Implementation - There are a number of ongoing programs primarily statewide in focus, that could benefit from the information developed through sensitivity assessments. These programs directly or indirectly affect ground water protection. The assessment criteria will assist in focusing program goals, priorities, guidelines and activities to achieve protection of sensitive areas. Local communities may also have similar activities and need additional information, for example, the administration of septic system controls. Among the related programs are facility siting, Environmental Assessment Worksheet and Environmental Impact Statement preparation and review, various permitting programs, cleanup of spills and other contamination, well-head protection and other well-related programs, protection of sensitive areas through the Reinvest in Minnesota program and development of management plans for certain industrial facilities and chemicals.

Education - This is both a statewide and local concern. There is a statewide need for better information to improve public understanding of the link between land use activities and ground water quality and protection. On the local level the results of a geologic sensitivity assessment at any level may encourage individual and general public support for stronger local action to protect ground water.

MATCHING NEEDS TO APPROPRIATE ASSESSMENT LEVELS

One of the design criteria used by the project work group in the development of the proposed guidelines presented in this report was to provide as flexible a system as possible. That is the reason for the three assessment levels. Three levels allow a reasonable amount of flexibility to fit a particular situation. However, this also makes the application of the proposed guidelines somewhat more difficult because a choice is possible as to which level to complete for a particular need. To assist the user, Table IV-1 shows suggested sensitivity assessment levels for various needs or activities. The table suggests when Level 1 and Level 2 assessments would be suitable for the surficial aquifer. The table also indicates when a deeper aquifer, or Level 3 assessment, is suggested. In some instances, because of the type of land use or contaminants involved, both surficial and deeper aquifer assessments are suggested to adequately assess the impact on ground water resources.

Level 1 - Preliminary. This is a minimum level of effort suggested for all four activity categories. At a minimum, a Level 1 assessment is suggested for planning at all levels of government, including local comprehensive plan development, public facilities systems planning, county-wide water resources planning and local water management plan development. For several regulatory and management activities, a minimum of a Level 1 assessment is also suggested, such as support for zoning and subdivision regulations. A Level 1 assessment provides the minimum information necessary for identifying search areas for locating sanitary landfills, hazardous waste facilities and similar facilities. A Level 1 assessment provides the minimum level of information necessary to support education activities directed towards the public and public officials on the potential for ground water contamination.

Level 2 - Vadose Zone. Level 2 is indicated in Table IV-1 as a suggested minimum assessment level for the important task of facility site identification and preliminary evaluation for any site which may handle or potentially produce toxic or other contaminants. A Level 2 assessment is suggested as the preferred assessment level for several planning activities, including neighborhood planning where specific uses are known, identifying search areas for construction of public waste handling facilities and local water management planning. This level is also the preferred assessment level for most of the regulation and management activities listed in Table IV-1. These activities include permitting of conditional or special uses and developing requirements and standards for regulations. Level 2 is the suggested preferred assessment level for all the ground water related programs shown in Table IV-1 although there may be cases where Level 2 should be considered the minimum assessment level. The program manager will need to compare program information needs to the information required and produced by each assessment level and choose the appropriate level. The public and public officials will benefit as more information becomes available and the assessment is refined. Compared to a Level 1 assessment, a Level 2 assessment provides a higher level of confidence that the sensitivity of the surficial aquifer has been adequately evaluated for screening purposes.

Level 3 - Deeper Aquifers. As shown in Table IV-1, a Level 3 assessment is indicated for relatively few activities. However, these activities may be critical to long term protection of ground water quality. Since Level 3 assesses deeper aquifers, this level of assessment is suggested when identifying areas for facilities which may handle or produce toxic or other contaminants such as a sanitary or hazardous waste landfill. A Level 3 assessment can assist in designating potential sites for further investigation. However, the siting of hazardous and solid waste disposal facilities requires additional and more detailed evaluation of the ground water resources and potential impacts than the information provided by a Level 2 and/or Level 3 assessment. The additional information provided by a Level 3 assessment may greatly assist the implementation of related ground water programs and is therefore suggested for these activities. Protection of deeper aquifers may be of great concern to the public and public officials; the deeper aquifers assessment provided by a Level 3 analysis can be of great benefit by identifying those deeper aquifers most at risk and in need of protective measures.

> **Note:** Level 1 assessment ratings are available for all counties in Minnesota. Ratings may be downloaded from the DNR Waters web site at www.dnr.state.mn.us/waters/. For more information, contact DNR Waters at 651-296-4800.

CHAPTER V

LEVEL 1 ASSESSMENT - PRELIMINARY

INTRODUCTION

Many local and state activities can benefit from an assessment of geologic sensitivity. However, some planning is necessary before beginning the assessment process. A financial status review may indicate insufficient resources for an immediate and complete assessment for a particular area. A preliminary assessment of geologic sensitivity can provide enough information to guide decisions and planning for many activities, including the completion of a more complete sensitivity assessment.

A Level 1 assessment rates geologic sensitivity according to the geologic materials present at or near the ground surface. No new data are collected and no new geologic interpretations are necessary for a Level 1 assessment. A Level 1 assessment uses existing maps and assumes that the geologic materials at or near the ground surface, as portrayed on those maps, are representative of the entire vadose zone. In many places, this assumption is not true, but near-surface information may be all that is readily available. Figure V-1 shows that only surface or near surface conditions are directly considered by a Level 1 assessment.

A Level 1 assessment is a first approximation of the geologic sensitivity of an area. It can quickly and inexpensively provide an overview of geologic sensitivity and may be adequate for certain purposes, including regulation, as described in Chapter IV. Local

> **Level 1 Assessment - Preliminary**
>
> **General Assumptions** - Based on the estimated time a water-borne contaminant requires to move from the surface to the water table. Ratings reflect general knowledge of the permeabilities of broad groups of geologic materials and depth to the water table. Existing information, which may include geologic maps and geologic information in soil surveys, is used to estimate the geologic sensitivity of an area. Assessment ratings assume that geologic materials identified at or near the land surface represent the entire vadose zone. Assessment ratings also assume that the vadose zone is less than six feet thick unless additional information is available. The seasonal high water table as identified in a soil survey is used as an estimate of the depth to the true water table.
>
> **Benefits** - No new data or geologic interpretations are required. Only minimal training needed. May be completed relatively quickly. Expensive equipment not required. May be adequate for some purposes. Can be used to help identify if and where more detailed sensitivity studies are needed.
>
> **Limitations** - For screening and first approximation estimate only. Does not consider lateral ground water movement. Is not site specific. Does not assess variations in materials deeper in the vadose zone.

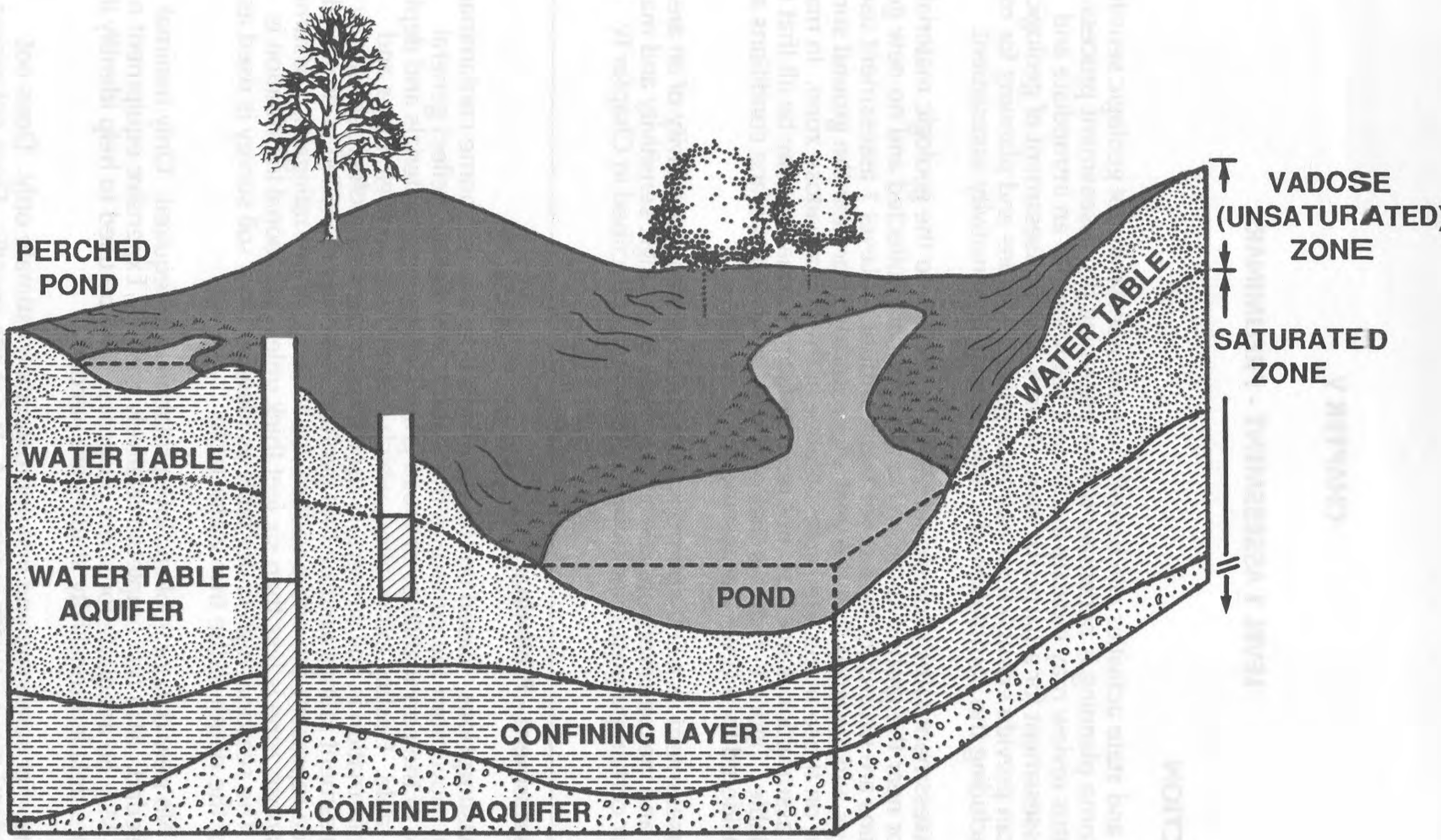


Figure V-1. A Level 1 Preliminary assessment evaluates surficial materials.

governments can prepare Level 1 sensitivity assessments with minimal training of their current staff. Much of the information required for a Level 1 assessment can be used for Level 2 and Level 3 assessments.

The intended use of any sensitivity assessment must be compatible with the data on which it is based. Contact either the Minnesota Department of Natural Resources, Division of Waters, or the Minnesota Geological Survey before beginning a preliminary assessment. Discussing the intended purpose of the assessment with these agencies will help identify useful data and resources. The U.S. Department of Agriculture, Soil Conservation Service, and University of Minnesota Extension can provide additional information about soils. If the sensitivity map will be used for a particular regulatory purpose, contact the appropriate state and federal agencies to assure that the sensitivity map will be compatible with the requirements of the regulatory program.

GENERAL RATINGS

Geologic sensitivity, as defined in Chapter III, is based on the estimated time that a water-borne contaminant requires to move from the ground surface to the water table. Travel time is related to the permeability of the materials in the vadose zone and the depth to the water table. Permeability is based on the types of geologic materials present at the ground surface and assumed to represent the entire vadose zone. Depth to the water table is considered only where consistent information is available.

The ratings given in Table V-1 should be used to interpret the sensitivity of geologic materials portrayed by suitable large-scale maps. The two most common types of maps that can be used for a Level 1 assessment are large-scale geologic maps and soil surveys. The depth to water criterion in the rating has a threshold of six feet because those data are available in soil surveys for many counties in Minnesota. The depth to water reflected in soil surveys indicates the minimum depth to saturated material during some portion of the year. In many cases this saturated zone does not reflect the water table.

Depth to the water table cannot be determined from large-scale geologic maps. Assume that the water table is within six feet of the ground surface at every point when using such maps as the primary source of geologic information. A Level 1 assessment may combine sources of information, using geologic maps to determine the geologic materials at the surface and using soil surveys to determine the depth to the water table. The oldest soil surveys do not contain depth to water information. Newer surveys contain depth to water information that may be outdated. Users of soil surveys should consult the U.S. Department of Agriculture, Soil Conservation Service, in St. Paul for the current interpretations of the various soils in the area of interest.

USING LARGE-SCALE GEOLOGIC MAPS

Large-scale geologic maps prepared for other purposes may be used for assessing geologic sensitivity. Reports prepared for aggregate investigations, mining activities, remedial investigations, graduate theses by geology students and other special reports may be useful. Consult the Minnesota Geological Survey, Minnesota Department of Natural Resources, Minnesota Department of Transportation, and local colleges and universities to identify suitable geologic maps.

TABLE V-1. General geologic sensitivity ratings for Level 1 assessments.

Geologic Material	Sensitivity Rating	
Unconsolidated Deposits		
	Depth to Water Table	
	<6 feet	>6 feet
Outwash, glacial lake sand & gravel	Very High	Very High
Terrace sand & gravel deposits	Very High	Very High
Organic material, peat	High	Moderate
Loess, glacial lake and terrace silt & fine sand	High	High
Sandy loam till, loamy sand till	High	Moderate
Alluvium, colluvium	High	Moderate
Loamy till, clay loam till, clay till	Moderate	Low
Glacial lake clay & silty clay	Moderate	Low
Bedrock or Bedrock Residuum		
Limestone, dolomite	Very High	Very High
Sandstone	Very High	High
Igneous & metamorphic rocks	High	High
Siltstone	Moderate	Moderate
Shale	Low	Low

*Note: Although loess has a relatively high water-holding capacity and does not readily transmit water, loess overlies karstic bedrock throughout a significant portion of southeast Minnesota.

Correlate the map units of a large-scale geologic map to the geologic-materials categories in Table V-1. In many cases the match will not be exact and geologic judgement will be required to properly correlate map units with the ratings table. Unless depth to the water table is known, assume that the depth is less than six feet throughout the area. The Minnesota Geological Survey should be consulted to determine the suitability of a particular geologic map and the ratings of the map units. Many geologic maps portray geologic formations that are buried by other materials. The only suitable geologic maps for an assessment of geologic sensitivity are surficial geologic maps, those maps that portray the geologic materials at the ground surface.

County geologic atlases prepared by the Minnesota Geological Survey include a plate that portrays geologic sensitivity. These plates were prepared at a scale of 1:100,000 or one inch equals approximately one and one-half miles. A map of this scale cannot show all of the detail actually present or that could be shown on a map of greater detail. Therefore, the atlas plates can be used, but only as general guides and not as a basis for decisions about specific sites.

A map must never be enlarged from its original scale. The resolution of any map is controlled by the scale at which the map will be reproduced; detail is omitted for legibility. As discussed in Appendix C, many small inclusions within larger areas are omitted on maps. Enlarging a portion of a map will give a false impression of the complexity of the area and may give a false indication of the actual sensitivity of any particular site.

USING COUNTY SOIL SURVEYS

County soil surveys are the most detailed natural resources maps that are readily available. They contain a variety of useful information. A Level 1 assessment does not evaluate directly the effect of the material in the soil profile, or pedologic soil, in determining geologic sensitivity. Rather, the soil survey is used to prepare a geologic map which is then used for the Level 1 assessment. Soil surveys are not as desirable as a source of geologic information as is a large-scale map of surficial geology. However, soil surveys are adequate and are more readily available than are suitable geologic maps.

An assessment based on a county soil survey requires a series of steps that are described below. The general procedure is to prepare a geologic map based on the parent materials and texture, or proportions of sand, silt, and clay, of the soils. Geologic map units are then given a sensitivity rating based on Table V-1. Experienced soil scientists or geomorphologists and glacial geologists who are knowledgeable about soils can draw additional inferences from a soil survey and thus prepare a more accurate geologic map than will result from the process given below.

Soil surveys have been produced in Minnesota over a period of four decades. Much has been learned about soils during this time. Although the boundaries on soil maps distinguish natural soil bodies reasonably well, the interpretation of some of those soils has changed as a result of more information and additional study. Hence, information in an older survey may not accurately reflect the current interpretations of some soils. The user is encouraged to contact the local Soil and Water Conservation District or the U.S. Department of Agriculture, Soil Conservation Service, in St. Paul for further information about the soils in any particular area.

SENSITIVITY MAP PREPARATION

Step 1 - Become familiar with the soil survey.

Soil surveys contain enough geologic information for a preliminary assessment. However, surveys have been produced over several decades and the style and information presented varies from county to county according to the date of publication.

The maps and information within the survey are based on the concept of the soil series. A soil series is the lowest, or most detailed, category in the soil classification system currently used by the U.S. Department of Agriculture. A survey will describe every identified soil series within a county. Each soil series consists of a unique sequence of layers or soil horizons that are distinguished on the basis of physical and chemical characteristics. The description of each series will include details of the soil horizons constituting that soil series. Soil mapping units are named for the dominant soil series. In some places, several soil series are significant components of a soil mapping unit. In such cases, the mapping units are called soil complexes. There may be several different soil complexes in a county, each consisting of a different mix of soils.

Review the survey and become familiar with its contents. Pay particular attention to sections that discuss parent material and geology. These sections may be entitled "Parent Material", "Geology", "Physiography, Drainage, and Relief", "Physiography", or "Factors of Soil Formation". Diagrams found in sections entitled "General Soil Map", "Soil Associations", or "Soil Series and their Relations" may also be helpful in understanding the relationship between soils and geologic materials. Some surveys will include a table that gives the parent material either for each or for selected soils. Become familiar with the way each soil series is described.

Step 2 - Identify the soil parent material for each mapping unit.

Identify the parent material of each soil mapping unit. The organization of soil surveys has changed in the past, but sections in older surveys that contain this information are "Descriptions of the Soils", "Descriptions of Soil Profiles", or "Morphology of the Soils." As examples from an older survey of Isanti County, the key words that indicate the parent material in the description of the Onamia Soil are "...water deposited sands and gravel derived from noncalcareous red glacial drift..." and "...outwash plains and terraces..." (Figure V-2). The parent material of the Greenbush Soil is "...thin...lake-washed or modified till [over] noncalcareous red glacial outwash of the Cary substage..." (Figure V-3).

In a newer survey of Hennepin County, the parent material of the Salida Series is indicated as "...alluvium over calcareous gravel and sand..." (Figure V-4). The Minnetonka Series description includes important information about the parent material in more than one paragraph (Figure V-5). The parent material is "...calcareous, clayey sediments [over] silty sediments [over] loamy till [that is a] calcareous, olive-gray silty clay loam." One of the most complex soils in this survey is the Langola Series (Figure V-6). The soil has formed in two distinct geologic layers because the top layer is relatively thin. The parent material of the upper layer is "...sandy mantle..." and the lower is "...dark reddish-brown sandy loam till..." The parent material of the soil should be described as "sandy mantle over dark reddish-brown sandy loam till".

Onamia Soil

Onamia fine sandy loam is the only soil of the Onamia series mapped in Isanti County.

Onamia fine sandy loam, 2 to 12 percent slopes (ON).—This well-drained soil has developed from water-deposited sands and gravel derived from noncalcareous red glacial drift. It occurs on undulating to gently rolling outwash plains and terraces in the northern part of the county along the Kanabec County line. It is associated with Kanabec and Milaca soils. Only a few small areas are mapped.

Profile description of virgin soil:

0 to 4 inches, dark-gray fine sandy loam; fine granular structure; slightly acid.
4 to 10 inches, grayish-brown fine sandy loam; thin platy structure; medium acid.
10 to 25 inches, reddish-brown clay loam; medium subangular blocky structure; slightly plastic when wet; medium acid.
25 inches +, reddish-brown stratified sand and gravel; many large pebbles; slightly acid.

This moderately coarse textured soil is underlain at depths of 20 to 40 inches by stratified gravel. It is similar to the Chetek loamy sands, except that the layers of gravel are at greater depths and the surface layer is not so coarse textured. Internal drainage is rapid.

This soil is cropped and managed in about the same way as the associated Milaca soils, but yields are generally lower. Because of the coarse substratum, the soil does not hold enough moisture so that hay crops and small grains will do well during dry years. In extremely dry years, crop yields are very low. This soil is in management group 8.

Figure V-2. Description of Onamia Soil, Isanti County.

Greenbush Soils

Only two soils of the Greenbush series were mapped in Isanti County.

Greenbush silt loam, 0 to 2 percent slopes (X).—This inextensive, moderately well drained soil occurs on level flats and in slight depressions in the extreme northeastern corner of Dalbo Township. It has developed on thin deposits of lake-washed or modified till that overlie noncalcareous red glacial outwash of the Cary substage. Depth to sand and gravel ranges from 20 to 36 inches.

Surface drainage is moderately slow and there is little runoff. Underdrainage is rapid because of the sandy and gravelly substratum. Because this soil is less well drained than Greenbush silt loam, 2 to 7 percent slopes, its yellowish-brown subsoil layer is somewhat more mottled.

Yields of general farm crops are good. Corn, oats, and hay are the most common crops. This soil is much less affected by drought than Greenbush silt loam, 2 to 7 percent slopes, but in extremely dry years it does not supply enough moisture for crops. This soil is in management group 8.

Greenbush silt loam, 2 to 7 percent slopes (Xu).—This inextensive, moderately well drained to well drained soil occupies smooth undulating topography in the Cary outwash region. It occurs only in Dalbo Township near the Kanabec County line. It has developed from thin deposits of lake-washed or modified till overlying red sands and gravel. Internal drainage is medium, and underdrainage is rapid.

Profile description of virgin soil:

0 to 4 inches, very dark brown, smooth, friable silt loam; fine granular structure; a few stones on surface.
4 to 14 inches, brown friable silt loam; well-developed thin platy structure; stone free.
14 to 25 inches, dark yellowish-brown silty clay loam; well-developed medium subangular blocky structure; slightly plastic when wet, hard when dry.
25 inches +, reddish-brown stratified sand and gravel; some pebbles up to 3 inches in diameter; depth to acid sand and gravel outwash ranges from 20 to 36 inches.

The crops commonly grown on Dalbo, Hayden, and Milaca soils are grown on this soil. Corn, small grains, and hay are the chief crops; hay crops are best suited. The water-holding capacity is comparable to that of the associated glacial soils. Yields are about the same as on the associated soils, except in abnormally dry years. This soil is in management group 8.

Figure V-3. Description of Greenbush Soil, Isanti County.

Salida Series

The Salida series consists of deep, excessively drained, sandy and gravelly soils that formed in 6 to 14 inches of alluvium over calcareous gravel and sand. These soils are on knolls and hills on stream terraces and outwash plains. Slopes are both simple and complex and range from 2 to 35 percent. The native vegetation was prairie grasses that are encroached upon by oaks in some places.

In a representative profile, the surface layer is black coarse sandy loam about 10 inches thick. The subsoil is very dark grayish-brown gravelly loamy sand about 4 inches thick. The underlying material is dark grayish-brown to brown gravelly loamy sand.

Salida soils have very low available moisture capacity. Permeability and internal drainage are very rapid. The water table is deep in all seasons. The root zone is shallow and is limited to the surface layer and thin subsoil. These sandy soils are low in natural fertility and organic-matter content.

Representative profile of Salida coarse sandy loam, 2 to 6 percent slopes, in a cultivated field, SE1/4 NE1/4 SE1/4 sec. 3, T. 119 N., R. 24 W.:

Ap--0 to 10 inches, black (10YR 2/1) coarse sandy loam; weak, very fine, granular structure; friable; common roots; neutral; abrupt, smooth boundary.
B--10 to 14 inches, very dark grayish-brown (10YR 3/2) gravelly loamy sand; weak, very fine, granular structure; very friable; common roots; about 15 percent gravel; neutral; clear, smooth boundary.
C1--14 to 18 inches, dark grayish-brown (10YR 4/2) gravelly loamy coarse sand; single grain; loose; few roots; about 20 percent gravel; mildly alkaline; strongly calcareous; clear, smooth boundary.
C2--18 to 60 inches, grayish-brown (10YR 5/2) and brown (10YR 4/3) gravelly loamy coarse sand; single grain; loose; about 25 percent gravel; mildly alkaline; strongly calcareous.

The solum commonly is 8 to 14 inches thick, but it is thinner in areas where the surface layer has been eroded. The Ap horizon is black or very dark brown coarse sandy loam or loamy coarse sand 7 to 10 inches thick. The B horizon is commonly discontinuous. It is 3 to 6 inches in thickness and very dark grayish brown to dark yellowish brown in color. Texture ranges from gravelly loamy sand to coarse sandy loam. Texture of the C horizon is gravelly loamy coarse sand or gravelly sand. Gravel content throughout the profile ranges from 10 to 60 percent but is commonly 20 to 40 percent. Reaction of the A and B horizons is commonly neutral but ranges from slightly acid to mildly alkaline. The A horizon is weakly calcareous in places where it is mildly alkaline. The C horizon is mildly alkaline and strongly calcareous.

Salida soils contain more gravel throughout than the associated Hubbard and Mymore soils. Salida soils are more sandy and more shallow to sand and gravel than the associated Estherville soils.

Figure V-4. Description of Salida Soil Series, Hennepin County.

Minnetonka Series

The Minnetonka series consists of deep, poorly drained soils that formed in 30 to 60 inches of calcareous, clayey sediments. In most places a 2-foot to 3-foot layer of silty sediments lies between the clayey sediments and the underlying loamy till. These soils are on broad flats and in drainageways. The native vegetation was prairie grass encroached upon by mixed hardwoods. There are a few stones and boulders, mainly near the surface. These soils occupy scattered tracts and are associated mainly with the Lester, Hayden, and Shorewood soils.

In a representative profile, the surface layer is black silty clay loam about 13 inches thick. The subsoil is mostly firm, olive-gray silty clay about 22 inches thick. The underlying material is calcareous, olive-gray silty clay loam.

Minnetonka soils have high available moisture capacity, slow internal drainage, and slow permeability. The water table is at a depth of 1 to 3 feet during wet periods. The root zone is limited by the high water table. The organic-matter content and natural fertility are high.

Representative profile of Minnetonka silty clay loam, in a cultivated field, SE1/4 NE1/4 NE1/4 sec. 33, T. 118 N., R. 23 W., Orono village:

Ap--0 to 8 inches, black (10YR 2/1) light silty clay loam; weak, very fine, subangular blocky structure; friable; many roots; slightly acid; clear, smooth boundary.

A12--8 to 13 inches, black (10YR 2/1) heavy silty clay loam; lower part of the horizon contains patches and thin seams of gray (10YR 5/1); moderate, very fine, subangular blocky structure; friable; many roots; slightly acid; clear, smooth boundary.

B1tg--13 to 18 inches, very dark gray (10YR 3/1) silty clay intermingled with olive gray (5Y 4/2); strong, very fine, subangular blocky structure; firm; few roots; few, fine, tubular pores; common, thick, black (10YR 2/1) and very dark gray (10YR 3/1) clay films on faces of peds; slightly acid; clear, smooth boundary.

B21tg--18 to 25 inches, olive-gray (5Y 4/2) silty clay; weak, fine, prismatic structure parting to strong, very fine, subangular blocky; firm; few fine roots and pores; many, thick, black (10YR 2/1) and very dark gray (10YR 3/1) clay films on faces of peds and in root channels; slightly acid; clear, smooth boundary.

B22tg--25 to 31 inches, olive-gray (5Y 5/2 and 5Y 4/2) silty clay; few, fine, distinct, olive (5Y 5/6) mottles; weak, medium, prismatic structure; firm; few fine roots; common, fine, tubular pores; many, thick, black (10YR 2/1) and very dark gray (10YR 3/1) clay films on faces of peds and in root channels; neutral; clear, smooth boundary.

B3tg--31 to 35 inches, olive-gray (5Y 5/2) silty clay loam; few, fine, distinct, olive (5Y 5/6) mottles; weak, very fine, subangular blocky structure; friable; few, fine, tubular pores; few, medium, very dark gray (10YR 3/1) and black (10YR 2/1) clay films on faces of peds and in root channels; neutral; clear, smooth boundary.

C1g--35 to 40 inches, olive-gray (5Y 5/2) silty clay loam; common, fine, prominent, olive (5Y 5/6) mottles; moderate, very fine, subangular blocky structure; friable; few, thin, black (10YR 2/1) clay films in root channels; common, fine, light-gray lime concentrations; few black concretions; mildly alkaline; strongly calcareous.

C2g--40 to 60 inches, olive-gray (5Y 5/2) silty clay loam; few thin strata of very fine sandy loam; common, fine, prominent, yellowish-brown (10YR 5/6) mottles that increase in size and abundance with increasing depth; weak, coarse, subangular blocky structure parting to weak, very fine, subangular blocky structure; friable; common, fine, light-gray lime concentrations; mildly alkaline; strongly calcareous.

A thin, distinct A2 horizon that dries to gray or grayish brown occurs in some places. The B horizon is typically olive gray but ranges from dark gray to olive and light olive brown. The zone of maximum clay content in the B2 horizon ranges from silty clay to clay. The C horizon is olive gray or light olive gray and is variable in texture. It ranges from heavy silty clay loam or silty clay to silt loam or light silty clay loam or to clay loam or loam glacial till. The glacial till occurs within a depth of 10 feet in most places. Reaction of the A horizon ranges from slightly acid to neutral, and reaction of the B horizon ranges from medium acid to neutral. Depth to lime carbonates ranges from 26 to 40 inches.

Minnetonka soils have a finer textured B horizon than the similar Cordova soils. They have a thicker, darker colored A horizon than associated Shields soils.

Figure V-5 Description of Minnetonka Soil Series in Hennepin County.

Langola Series

The Langola series consists of deep, moderately well drained and well drained soils that formed in a sandy mantle 18 to 40 inches thick and are underlain by dark reddish-brown sandy loam till. These soils are on the broad outwash plain in the northeastern part of the county. Slopes are mainly simple and range from 0 to 12 percent. The native vegetation was mixed hardwoods and tall prairie grass. Stones and boulders are scattered on and in the soil.

In a representative profile, the surface layer is very dark brown loamy sand about 8 inches thick. The subsoil is about 32 inches thick. The upper part is a mixture of very dark brown and dark yellowish-brown loamy sand. The lower part is dark yellowish-brown to brown and reddish-brown, cobbly and gravelly sandy loam. The underlying material is reddish-brown sandy loam.

Langola soils have low to moderate available moisture capacity and medium internal drainage. The sandy layers are rapidly permeable, but the underlying material is only moderately permeable. In some wet seasons the water table is at a depth of 3 to 5 feet but is usually at a depth below 5 feet in all seasons. Langola soils have a shallow to moderately deep root zone because root growth is limited to the sandy material above the cobbly layer. They have moderate organic-matter content and low natural fertility.

Representative profile of Langola loamy sand, 1 to 2 percent slopes, in a cultivated field, NE1/4 NE1/4 NW1/4 sec. 3, T. 120 N., R. 21 W.:

Ap--0 to 8 inches, very dark brown (10YR 2/2) loamy sand; weak, very fine and fine, subangular blocky structure; very friable; many roots; medium acid; clear, wavy boundary.

B1--8 to 15 inches, very dark brown (10YR 2/2), dark grayish-brown (10YR 4/2), and brown (10YR 4/3) loamy sand, very dark grayish brown (10YR 3/2) when rubbed; weak, medium and coarse, subangular blocky structure; very friable; few roots; few thin clay bridges between sand grains; medium acid; clear, smooth boundary.

B21--15 to 18 inches, dark yellowish-brown (10YR 4/4) loamy sand; weak, medium and coarse, subangular blocky structure; very friable; few roots; few, fine, tubular pores; thin, patchy, brown (10YR 4/3) and dark-brown (10YR 3/3) clay flows; slightly acid; clear, smooth boundary.

IIB22--18 to 24 inches, dark yellowish-brown (10YR 4/4) gravelly sandy loam; weak, medium, subangular blocky structure; very friable; few roots; few, very fine, tubular pores; common, thick, patchy, dark-brown (10YR 3/3) clay films on faces of peds; about 30 percent coarse fragments, mainly igneous; slightly acid; clear, wavy boundary.

IIB23--24 to 29 inches, brown (7.5YR 4/4) cobbly loamy coarse sand; weak, medium and coarse, subangular blocky structure; very friable; few roots; few, fine, tubular pores; few thin clay films on faces of peds; about 60 percent coarse fragments, mostly igneous; few black concretions; slightly acid; clear, wavy boundary.

IIB24--29 to 40 inches, reddish-brown (5YR 4/4) sandy loam; weak, coarse, subangular blocky structure; friable; few, fine, tubular pores; about 15 percent coarse fragments, mostly igneous; slightly acid; clear, smooth boundary.

IIC--40 to 60 inches, reddish-brown (5YR 4/4) sandy loam; weak, coarse, subangular blocky structure grading to platy; friable; slightly acid.

The solum ranges from 20 to 40 inches in thickness. The A horizon is 7 to 11 inches in thickness, very dark brown or black in color, and loamy fine sand or loamy sand in texture. Texture of the B1 and B21 horizons is sand, loamy sand, or loamy fine sand. The IIB22 and IIB23 horizons are commonly dark yellowish brown and brown, but they are very dark grayish brown in some places. They consist of cobbly gravelly loamy sand or sandy loam. About 30 to 70 percent of the soil by volume consists of cobblestones, and the rest of the coarse material is gravel and sand in varying sizes. The gravelly cobbly layer ranges in thickness from 4 to 24 inches but is commonly 8 to 24 inches thick. The IIB24 horizon is reddish-brown or dark-brown sandy loam or loamy sand that contains 5 to 20 percent coarse fragments. The C horizon is reddish brown, dark brown, or brown and ranges from coarse sandy loam to loamy coarse sand in texture. The C horizon contains 5 to 20 percent coarse fragments. In some places there are gray and strong-brown mottles in the lower part of the IIB horizon and in the C horizon. Depth to the top of the IIB horizon ranges from 18 to 40 inches. The solum is slightly acid to medium acid throughout.

Figure V-6. Description of Langola Soil Series in Hennepin County.

The newest surveys, such as the Dakota County survey, have sections entitled "Soil Descriptions" and "Soil Series and their Morphology". Useful information about the Mahtomedi Loamy Sand from "Soil Descriptions" is "...end moraines and pitted outwash plains...grayish brown loamy sand [over] brown and yellowish brown gravelly coarse sand and coarse sand..." (Figure V-7). "Soil Series and their Morphology" adds "...pitted outwash plains and end moraines...sandy and gravelly outwash..."

Review all pertinent sections of the survey for proper identification of the parent material for each soil mapping unit. Distinguish as many different parent materials as the soil descriptions will allow. Forty-four soils are found in the example assessment area (Figure V-8) in Greenfield, Minnesota located in northwest Hennepin County. Table V-2 lists the soils and parent materials for the example area.

Several different soil series will have the same parent material. The oldest surveys identify soil series by a capital and a small letter. In some cases, a change in the small letter will change the soil series and thus the parent material of the soil. An example from the Isanti County soil survey legend is given in Table V-3. For other surveys, the soil series is indicated by two letters; the second letter changes when the soil texture changes. A third letter indicates slope. The symbols used for any particular soil series in older surveys usually varies from county to county. The newest surveys use numbers for particular soil series map units that are unique and can be used state-wide.

TABLE V-3. Selected soil names and symbols from the Isanti County soil survey.

Soil	Symbol
Bluffton loam and silty clay loam	Bc
Hayden silt loam, 2-7 percent slopes	B
Hayden silt loam, 2-7 percent slopes, moderately eroded	Bu
Hayden silt loam, 7-12 percent slopes	Bp
Hayden silt loam, 7-12 percent slopes, moderately eroded	Bd
Hayden silt loam, 12-18 percent slopes	Br
Hayden silt loam, 12-18 percent slopes, moderately eroded	Bx
Brickton silt loam	Bk
Brickton silt loam, clayey subsoil variant	Bv

Step 3 - Identify the texture of each map unit.

Identify the texture of the lowest described horizon for each soil map unit. Table V-4 provides a list of possible textures and modifying adjectives. As examples, the texture of the lowest horizon of the Onamia Soil is "sand and gravel"; Greenbush Soil is "sand and gravel"; Salida Series is "gravelly loamy coarse sand"; Minnetonka Series is "very fine sandy loam"; Langola Series is "sandy loam"; and Mahtomedi is "gravelly coarse sand" (Figures V-2 to V-7).

Mahtomedi series

The Mahtomedi series consists of deep, excessively drained soils on pitted outwash plains and end moraines. They are rapidly permeable. These soils formed in sandy and gravelly outwash. Slopes range from 3 to 25 percent.

The Mahtomedi soils are similar to the Chetek, Emmert, Hawick, and Hubbard soils and are commonly adjacent to the Chetek and Kingsley soils. The Chetek soils have more clay in the surface and subsoil horizons, and the Emmert soils have more gravel than the Mahtomedi soils. The Hawick and Hubbard soils have a mollic epipedon. The Kingsley soils formed in sandy loam glacial till. The Mahtomedi, Chetek, and Kingsley soils are in similar positions on the landscape.

Typical pedon of Mahtomedi loamy sand, 8 to 15 percent slopes, 380 feet west and 600 feet south of the center of sec. 29, T. 27 N., R. 22 W.

A—0 to 5 inches; very dark grayish brown (10YR 3/2) loamy sand, grayish brown (10YR 4/2) dry; weak fine granular structure; very friable; 12 percent coarse fragments; slightly acid; abrupt boundary.

Bw1—5 to 27 inches; dark brown (7.5YR 4/4) gravelly coarse sand; single grain; loose; 15 percent coarse fragments; slightly acid; clear wavy boundary.

Bw2—27 to 35 inches; dark yellowish brown (10YR 4/4) coarse sand; single grain; loose; 10 percent coarse fragments; slightly acid; abrupt smooth boundary.

C1—35 to 50 inches; yellowish brown (10YR 5/4) sand; single grain; loose; less than 3 percent coarse fragments; neutral; abrupt smooth boundary.

C2—50 to 60 inches; yellowish brown (10YR 5/4) gravelly coarse sand; single grain; loose; 25 percent coarse fragments; slight effervescence; mildly alkaline.

The thickness of the solum is 20 to 40 inches. Coarse fragments in the control section average 10 to 35 percent, by volume.

The A horizon has value of 2 or 3 and chroma of 1 or 2. Texture generally is coarse sand, sand, loamy coarse sand, or loamy sand; but fine sand, loamy fine sand, coarse sandy loam, sandy loam, and fine sandy loam are within the range. Reaction ranges from slightly acid to strongly acid. Some pedons have an E horizon that has hue of 10YR, value of 4 or 5, and chroma of 1 or 2. An Ap horizon in cultivated pedons has hue of 10YR and value and chroma of 3 or 4. The B horizon has hue of 5YR, 7.5YR, or 10YR; value of 4 or 5; and chroma of 4 through 6. Texture is coarse sand, sand, gravelly coarse sand, or gravelly sand. Reaction ranges from slightly acid to strongly acid. The C horizon has hue of 5YR, 7.5YR, or 10YR; value of 5 or 6; and chroma of 3 or 4. Texture is coarse sand, sand, gravelly coarse sand, or gravelly sand.

454B—Mahtomedi loamy sand, 3 to 8 percent slopes. This undulating to rolling, excessively drained soil is on end moraines and pitted outwash plains. Individual areas are irregular in shape and range from about 3 to 50 acres.

Typically, the surface layer is very dark grayish brown loamy sand about 7 inches thick. The subsoil is dark brown and dark yellowish brown gravelly coarse sand and coarse sand about 35 inches thick. The underlying material to a depth of about 60 inches is yellowish brown stratified sand and gravelly coarse sand.

Included with this soil in mapping are a few small areas of the Kingsley soil. It formed in sandy loam glacial till. The Kingsley soil is similar in position to the Mahtomedi soil. This soil makes up about 15 percent of the map unit.

Permeability of this Mahtomedi soil is rapid. The available water capacity is low, and runoff is slow. Reaction in the subsoil ranges from slightly acid to strongly acid. Organic matter content is low. Depth to the seasonal high water table is more than 6 feet.

This soil is poorly suited to most cultivated crops because it has a low available water capacity. Droughtiness limits crop production in most years. Early maturing crops are best suited to this soil. Using minimum tillage, returning crop residue to the soil, and including forage in the rotation improve the available water capacity and reduce erosion.

This soil has fair suitability for pasture and hay. Productivity is generally low and supplemental pastures may be needed to insure adequate yields. Proper stocking, rotation grazing, fertilizing, and controlling weeds help maintain a good cover of the more desirable grasses. Where planting is necessary to improve stands, more drought-resistant plants are needed.

This soil is fairly suited to woodland. Because it is droughty, seedling mortality is severe and many trees grow poorly.

Buildings constructed on this soil should be designed to conform to the natural slope of the land. Land shaping may be necessary in some areas. This soil is suitable for road construction. This soil readily absorbs but does not adequately filter the effluent from septic tank absorption fields. The poor filtering capacity may result in the pollution of ground-water supplies, but this limitation can be reduced by installing distribution lines close to the surface. In some areas additional precautionary measures may be necessary.

This Mahtomedi soil is in capability subclass IVs.

Figure V-7. Description of Mahtomedi Soil Series, Dakota County.

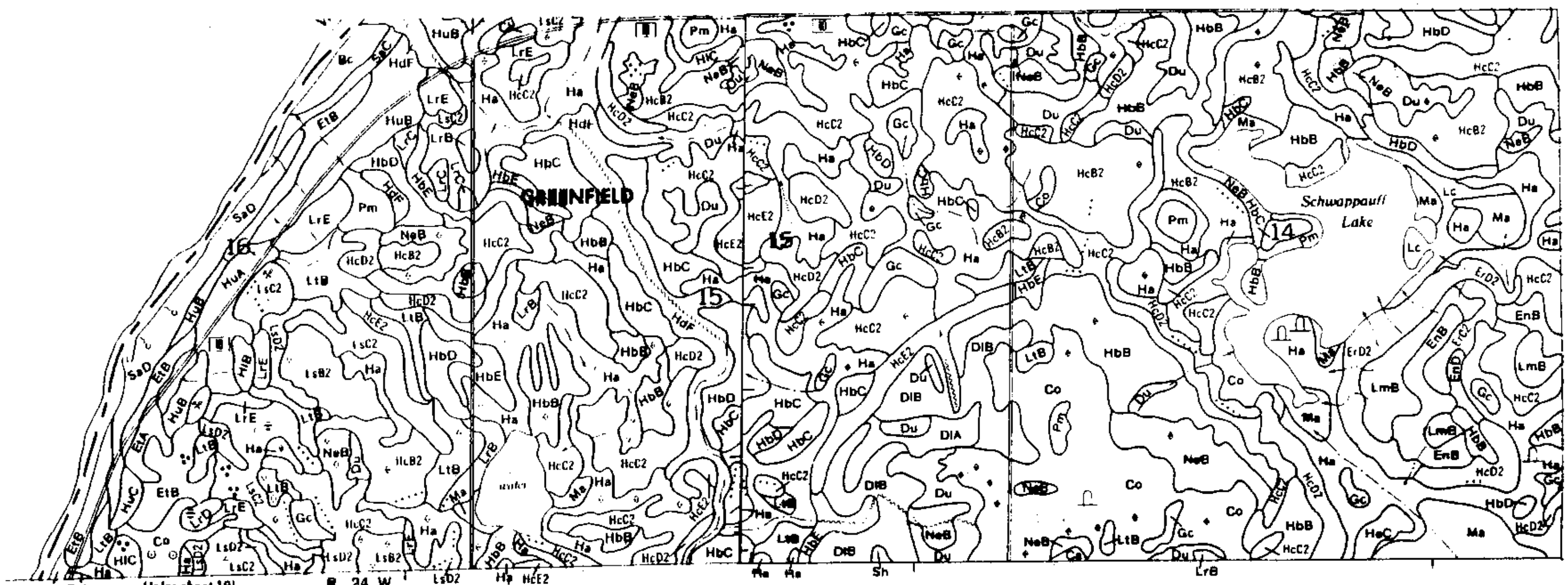


Figure V-8. Soils map for example area in Greenfield, Minnesota, northwest Hennepin County.

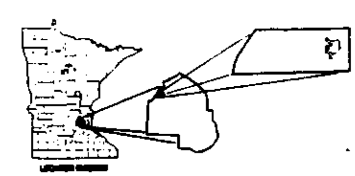


TABLE V-2. Soils and parent materials for the example area.

Symbol	Soil Name	Parent Material
Bb	Becker loam	Alluvium over sand
Bc	Biscay clay loam	Alluvium over sand & gravel
Ca	Canisteo clay loam	Calcareous loamy till
Co	Cordova silty clay loam	Loamy till
Cu	Cut and fill land	Man-made
DlB	Dalbo silt loam, 2 to 6 % slopes	Alluvium over loamy till
Du	Dundas silt loam	Calcareous loamy till
EnB	Erin loam, 2 to 6 % slopes	Calcareous shaly till
EnD	Erin Loam, 12 to 18 % slopes	Calcareous shaly till
EtA	Estherville sandy loam, 0 to 2 % slopes	Alluvium over sand & gravel
EtB	Estherville sandy loam, 2 to 6 % slopes	Alluvium over sand & gravel
Gc	Glencoe silty clay loam	Colluvium over loamy till
Ha	Hamel loam	Colluvium over loamy till
HbB	Hayden loam, 2 to 6 % slopes	Loamy till
HbC	Hayden loam, 6 to 12 % slopes	Loamy till
HbD	Hayden loam, 12 to 18 % slopes	Loamy till
HbE	Hayden loam, 18 to 24 % slopes	Loamy till
HcB2	Hayden clay loam, 2 to 6 % slopes	Loamy till
HcC2	Hayden clay loam, 6 to 12 % slopes	Loamy till
HcD2	Hayden clay loam, 12 to 18 % slopes	Loamy till
HcE2	Hayden clay loam, 18 to 24 % slopes	Loamy till
HdF	Hayden and Lester loams, 24 to 35 % slopes	Loamy till
HlB	Heyder complex, 2 to 6 % slopes	Sandy loam till
HlC	Heyder complex, 6 to 12 % slopes	Sandy loam till
HuA	Hubbard loamy sand, 0 to 2 % slopes	Outwash sand
HuB	Hubbard loamy sand, 2 to 6 % slopes	Outwash sand
HuC	Hubbard loamy sand, 6 to 12 % slopes	Outwash sand
Lc	Lake beaches, sandy	Sand over loamy till
Lm	Lerdal loam	Loamy till
LrB	Lester loam, 2 to 6 % slopes	Loamy till
LrC	Lester loam, 6 to 12 % slopes	Loamy till
LrD	Lester loam, 12 to 18 % slopes	Loamy till
LrE	Lester loam, 18 to 24 % slopes	Loamy till
LsB2	Lester clay loam, 2 to 6 % slopes	Loamy till
LsC2	Lester clay loam, 6 to 12 % slopes	Loamy till
LsD2	Lester clay loam, 12 to 18 % slopes	Clay loam till
LtB	Le Sueur loam, 2 to 6 % slopes	Loamy till
Ma	Marsh	Organic material
NeB	Nessel loam, 1 to 4 % slopes	Loamy till
Pa	Peaty muck	Organic material
Pm	Peaty muck over loam	Organic material
SaC	Salida coarse sandy loam, 6 to 12 % slopes	Alluvium over sand & gravel
SaD	Salida coarse sandy loam, 12 to 18%	Alluvium over gravel & sand
Sh	Shorewood silty clay loam	Clayey alluvium over loamy till

Table V-4. Textures of various soils, with modifiers.

Soil Type	Textures
sandy soils	sand, loamy sand
coarse loamy soils	sandy loam, fine sandy loam
medium loamy soils	very fine sandy loam, loam, silt loam, silt
fine loamy soils	clay loam, sandy clay loam, silty clay loam
clayey soils	sandy clay, silty clay, clay

Typical Adjectives that Modify Textures

gravelly	cobbly	stoney	shaly
cherty	flaggy	slaty	
coarse	fine	very fine	

Step 4 - Identify the depth to seasonal high water.

Determine the depth to seasonal high water for each soil mapping unit. Note that depth to seasonal high water indicates the depth to seasonal saturation within the pedologic soil. This is not always the same as the depth to the water table. A Level 1 assessment conservatively assumes that depth to seasonal high water is equal to depth to the water table because seasonal high water data are available. In newer surveys, this information is included in tables entitled, "Estimated soil properties significant in engineering" (e.g., Hennepin County), "Water features" (e.g. Dakota County), "Soil and water features" (e.g. Washington and Ramsey counties), and "Engineering description of the soils and their estimated properties significant to engineering" (e.g. Wright County). Information from these tables may not be identical to data from the U.S. Soil Conservation Service state-wide data base. Information in older surveys has been recently reviewed and updated. Users are encouraged to contact their Soil and Water Conservation District or the U.S. Soil Conservation Service St. Paul office for updated information.

Step 5 - Summarize mapping unit information in a table.

Develop a table that groups every soil mapping unit in the survey according to parent material. Include the texture of the lowest horizon described for each soil series, depth to seasonal high water, and the preliminary sensitivity rating for each parent material based on the general ratings (Table V-1). Have the table reviewed by the Minnesota Geological Survey before proceeding further. A table for the example assessment area is given in Table V-5. Table V-5 contains depth to water information both from a soil survey and from updated information supplied by U.S. Department of Agriculture, Soil Conservation Service. Note that the sensitivity rating is different for a significant number of soils because the depth to seasonal saturation has been reinterpreted. The example assessment for Hennepin County in this document is based on the updated information.

TABLE V-5. Parent material, texture, and sensitivity ratings for the example area.

Symbol	Soil Name	Parent Material	Texture	Hennepin Co. Soil Survey		SCS Soil Database	
				Water Table*	Rating	Water Table*	Rating
Bb	Becker loam	Alluvium over sand	Fine sand	3	VH	4-6	VH
Bc	Biscay clay loam	Alluvium over sand & gravel	Coarse sand	2	VH	1-3	VH
Ca	Canisteo clay loam	Calcareous loamy till	Loam	1	M	-	M
Co	Cordova silty clay loam	Loamy till	Loam	1	M	1-3	M
Cu	Cut and fill land	Man-made	N/A	N/A	N/A	N/A	N/A
DlB	Dalbo silt loam	Alluvium over loamy till	Loam	3	M	2-5	M
Du	Dundas silt loam	Calcareous loamy till	Loam	2	M	-	M
EnB	Erin loam	Calcareous shaly till	Loam	5	M	>6	L
EnD	Erin Loam	Calcareous shaly till	Loam	5	M	>6	L
EtA	Estherville sandy loam	Alluvium over sand & gravel	Gravelly coarse sand	5	VH	>6	VH
EtB	Estherville sandy loam	Alluvium over sand & gravel	Gravelly coarse sand	5	VH	>6	VH
Gc	Glencoe silty clay loam	Colluvium over loamy till	Loam	0	M	-1	M
Ha	Hamel loam	Colluvium over loamy till	Loam	1-2	M	1-3	M
HbB	Hayden loam	Loamy till	Loam	5	M	>6	L
HbC	Hayden loam	Loamy till	Loam	5	M	>6	L
HbD	Hayden loam	Loamy till	Loam	5	M	>6	L
HbE	Hayden loam	Loamy till	Loam	5	M	>6	L
HcB2	Hayden clay loam	Loamy till	Loam	5	M	>6	L
HcC2	Hayden clay loam	Loamy till	Loam	5	M	>6	L
HcD2	Hayden clay loam	Loamy till	Loam	5	M	>6	L
HcE2	Hayden clay loam	Loamy till	Loam	5	M	>6	L
HdF	Hayden and Lester loams	Loamy till	Loam	5	M	>6	L
HlB	Heyder complex	Sandy loam till	Sandy loam	10	M	>6	M
HlC	Heyder complex	Sandy loam till	Sandy loam	10	M	>6	M
HuA	Hubbard loamy sand	Outwash sand	Coarse sand	5	VH	>6	VH
HuB	Hubbard loamy sand	Outwash sand	Coarse sand	5	VH	>6	VH
HuC	Hubbard loamy sand	Outwash sand	Coarse sand	5	VH	>6	VH
Lc	Lake beaches, sandy	Sand over loamy till	Loam	1-2	M	-	M
Lm	Lerdal loam	Loamy till	Loam	3	M	1-3	M
LrB	Lester loam	Loamy till	Loam	5	M	>6	L
LrC	Lester loam	Loamy till	Loam	5	M	>6	L
LrD	Lester loam	Loamy till	Loam	5	M	>6	L
LrE	Lester loam	Loamy till	Loam	5	M	>6	L
LsB2	Lester clay loam	Loamy till	Loam	5	M	>6	L
LsC2	Lester clay loam	Loamy till	Loam	5	M	>6	L
LsD2	Lester clay loam	Loamy till	Loam	5	M	>6	L
LtB	Le Sueur loam	Loam till	Heavy loam	3	M	2-4	M
Ma	Marsh	Organic material	N/A	0	VH	0	VH
NeB	Nessel loam	Loamy till	Loam	3	M	3-5	M
Pa	Peaty muck	Organic material	N/A	0	VH	0	VH
Pm	Peaty muck over loam	Organic material	N/A	0	VH	0	VH
SaC	Salida coarse sandy loam	Alluvium over gravel & sand	Gravelly loamy coarse sand	10	VH	>6	VH
SaD	Salida coarse sandy loam	Alluvium over gravel & sand	Gravelly loamy coarse sand	10	VH	>6	VH
Sh	Shorewood silty clay loam	Clayey alluvium over loamy till	Clay loam	3	M	3-5	M

* Water Table - Depth (ft) to seasonal high water table.

Step 6 - Prepare the parent-materials geologic map and the sensitivity map.

Using the table developed in Step 5, create a parent-materials map by grouping the soil mapping units according to parent material. This is done by ignoring or erasing the boundaries between soil mapping units that have the same parent materials. No "new" boundaries are drawn. Figure V-9 shows the parent-materials map of the example area that was created by hand-coloring the soil map units. A parent-materials geologic map is a valuable document to geologists for any future work and can be used directly for assessments of a higher level.

Using the general ratings, create a sensitivity map by grouping the parent-materials map units according to the ratings developed for Table V-5. This is done by ignoring or erasing the boundaries between parent-materials map units that have the same sensitivity rating. No "new" boundaries are drawn. Figure V-10 shows the preliminary sensitivity assessment for the example area. Remember to label the map as a preliminary assessment to avoid confusion with maps prepared at other assessment levels.

USING THE MINNESOTA SOIL ATLAS

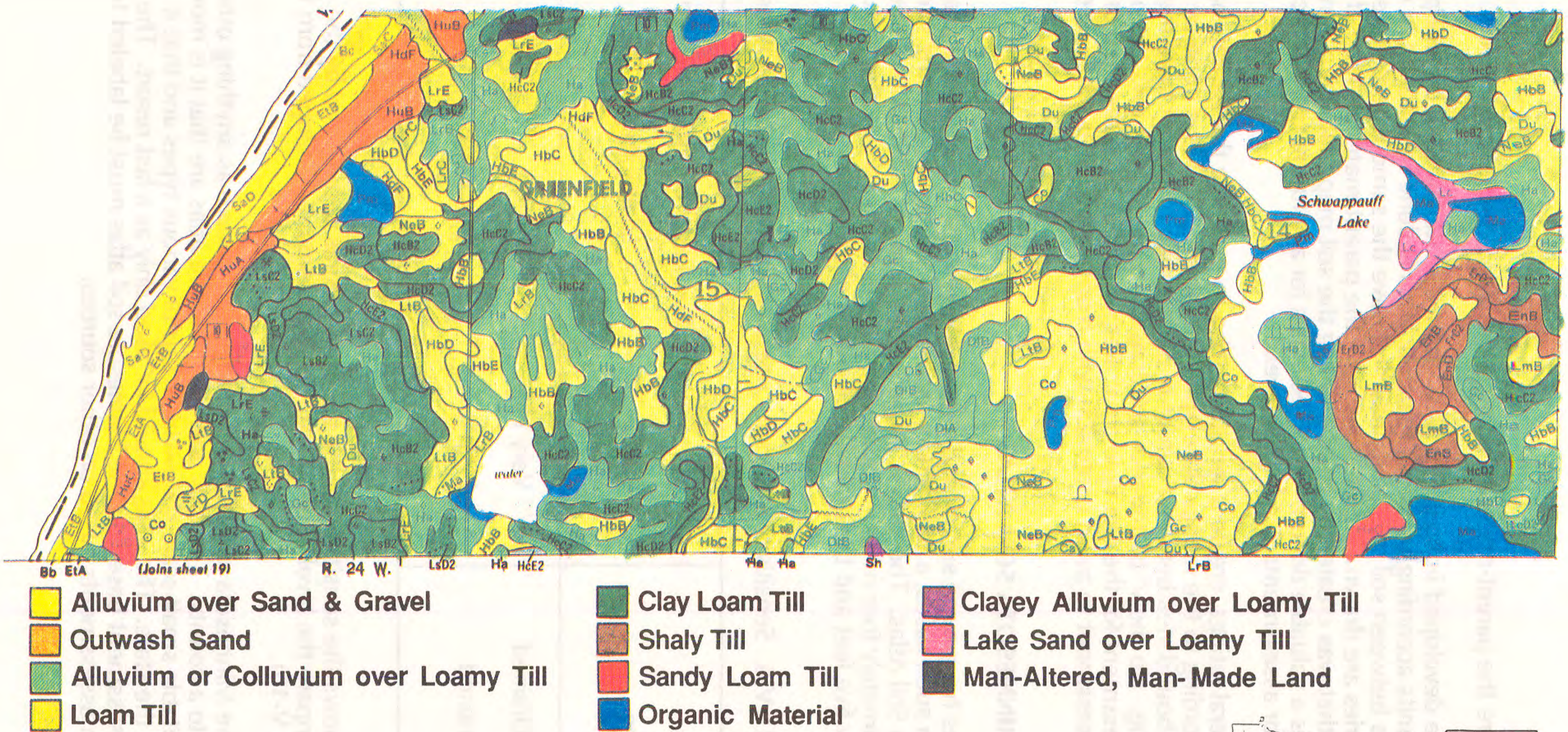
Not all counties have a soil survey and large-scale geologic maps are not available for most areas. In such cases, a preliminary assessment can be made using sheets from the Minnesota Soil Atlas. The atlas is prepared at a scale of 1:250,000 or one inch equals approximately four miles. Prepare the sensitivity map using the texture of the material below five feet and the drainage as indicated in Table V-6.

TABLE V-6. Sensitivity ratings for use with the Minnesota Soil Atlas.

	Soil Texture Below Five Feet		
Drainage	Sandy	Loamy/Silty	Clayey
Poorly Drained	Very High	High	Moderate
Well Drained	High	Moderate	Low

Figure V-11 shows the sensitivity of the example area as determined by the Minnesota soil atlas. Compare the level of detail with the assessment developed from the soil survey (Figure V-10).

The scale of the Minnesota soil atlas is far too small to serve as anything other than a general guide to a county. The only advantages of the atlas are that it is more detailed than the unsuitable small-scale state-wide maps of various types and that it is available for all areas of the state. The atlas should be used only as a last resort. The preliminary assessment based on the Minnesota soil atlas must be labeled to avoid confusion with assessments based on other sources.



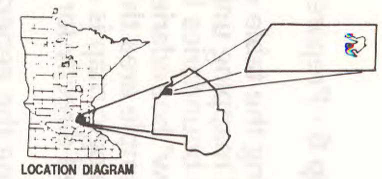
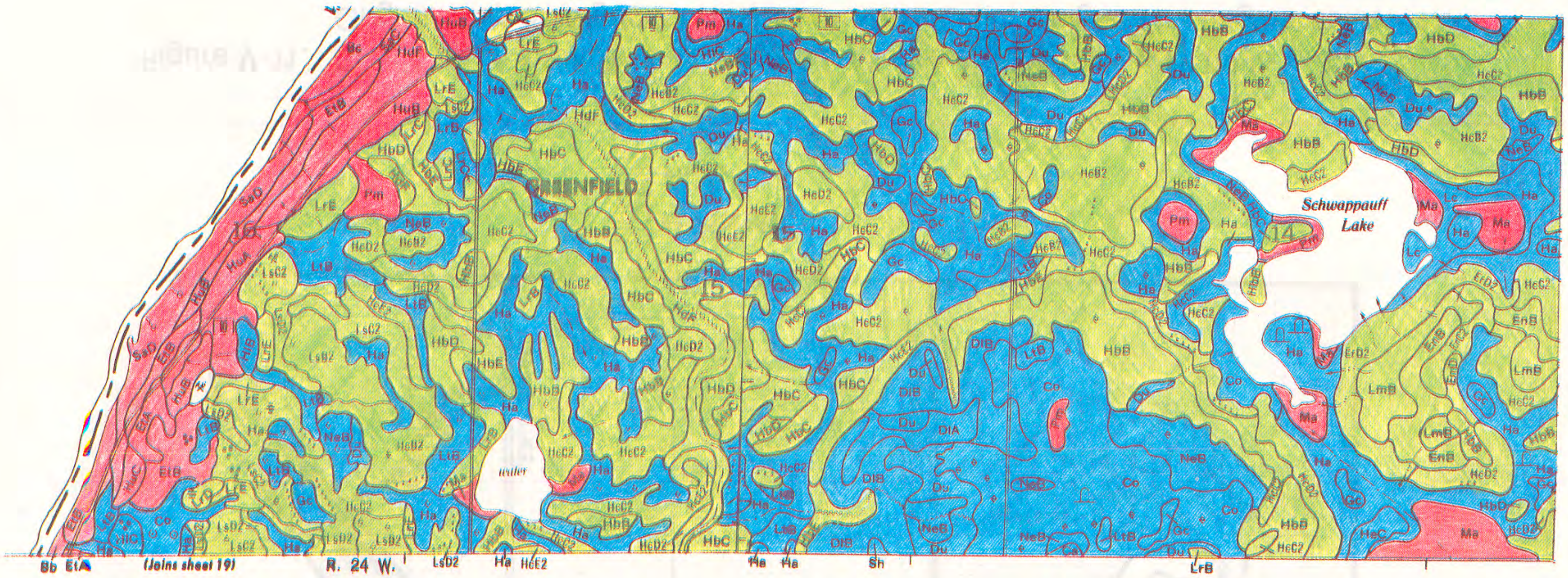
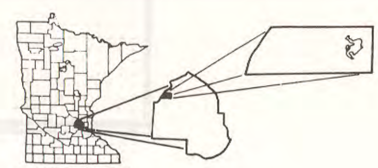


Figure V-9. Level 1 parent materials geologic map for example area in Greenfield, Minnesota, northwest Hennepin County.



Very High
High
Moderate
Low

Figure V-10. Level 1- Preliminary geologic sensitivity map for example area in Greenfield, Minnesota, northwest Hennepin County.



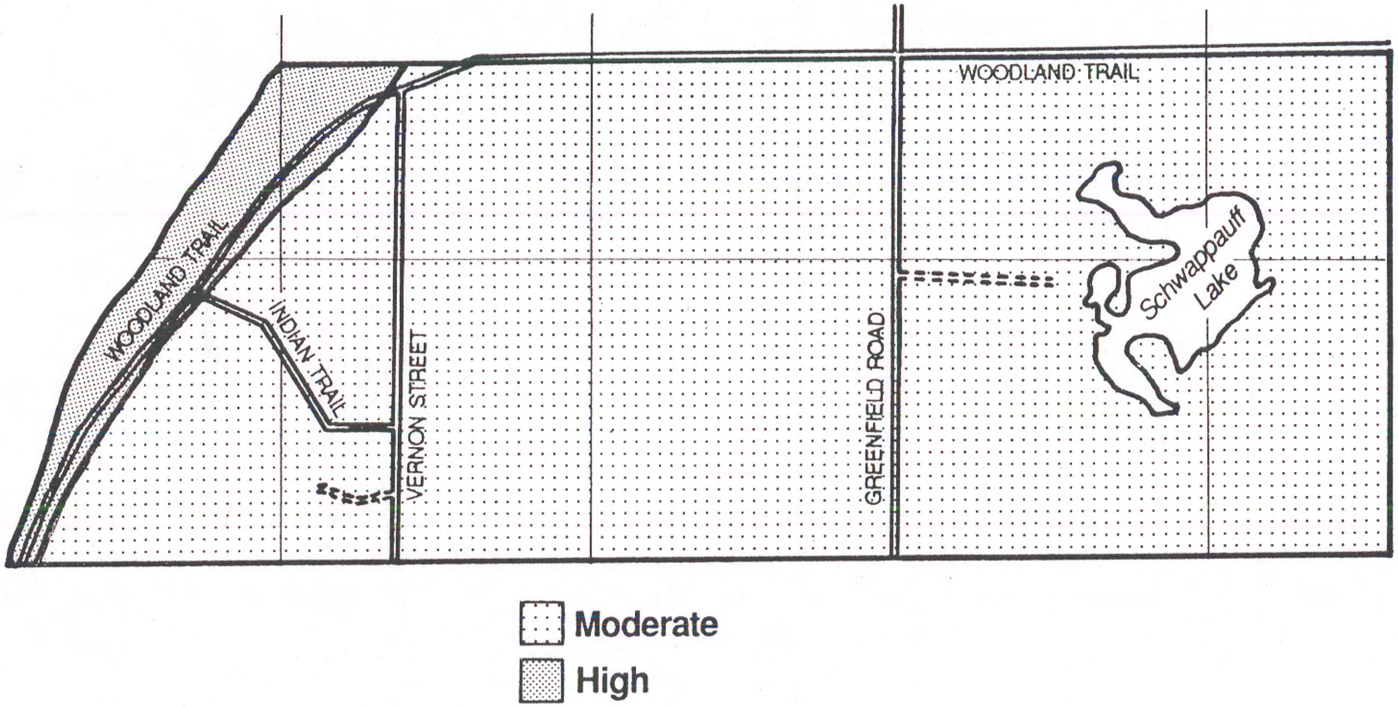
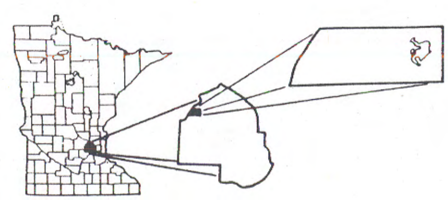


Figure V-11. Sensitivity of example area using the Minnesota Soil Atlas and Table V-6. Original map enlarged for illustration: see location diagram for original scale.



METHODS OF MAP PREPARATION

The simplest method of preparing a sensitivity map is to make photocopies of the original geologic map or to remove the map sheets from a soil survey and color them by hand. This method is the fastest and cheapest way to obtain a manually-prepared sensitivity map. The principal drawbacks to this method are that the map sheets cannot be easily pieced together to show an entire county, the manuscript cannot be readily duplicated, and that the map cannot be directly overlain on other maps.

Another way to manually prepare sensitivity maps is by using transparent overlay sheets. The appropriate geologic, parent-materials, and sensitivity unit boundaries can be traced on an overlay sheet placed over the source map. This method creates an easily reproducible manuscript. Information from adjoining maps can be joined on the overlay sheet. The overlay sheet may also include base map information such as road networks, section lines and property parcel lines. In some cases, differences in scale and map projection can be accommodated. Under no circumstances is it permissible to enlarge the scale of an existing geologic or soils map! See Appendix C for more information.

Computer mapping is another way to prepare sensitivity maps. The computer can create a Level 1 sensitivity map very quickly if it has the appropriate mapping unit boundaries and information. The initial steps in this method may be very time consuming if no suitable data are in the computer system. However, the necessary information can be used for a variety of purposes beyond sensitivity mapping if the project is carefully planned. The most powerful and useful computer systems will overlay or merge the sensitivity information with all other geographic information about an area.

Please note that computers are machines and machines do not care! A computer will prepare a map based on inaccurate or inappropriate information if the user desires. Also note that analysis and interpretation of computer output may be required to prepare and use computer-based maps. Computers cannot make interpretations; they can only make simple and absolute decisions based on the data provided to them. The user must be able to evaluate the answers and recognize answers that are incorrect or inappropriate.

In the near future, Soil and Water Conservation Districts, located in every county, will have information in their Field Office Technical Guide that will contain the information gathered in Steps 1 to 4, described above. This information may be obtained for all soil mapping units in the state from the U.S. Department of Agriculture, Soil Conservation Service, in St. Paul. An ASCII file created by downloading this data base can be incorporated into a variety of geographical information systems. Details of this process will vary from system to system.

Counties that have their soil surveys automated in the Soil Survey Information System (SSIS) may be able, in the future, to use SSIS to directly prepare both a parent-materials geologic map and a preliminary assessment of geologic sensitivity. One drawback to SSIS is that it operates on a single section (one square mile) of land at a time. A complete map of an area would require a mosaic of individual section plots. Extra care must be taken to match map edges and soil boundaries. However, updates to the SSIS program are planned to geographically reference and automatically mosaic sections. In addition, the updated program will allow a user to compare several assessment methods at the same time, as well as export the file for use by general mapping software.

LIMITATIONS AND BENEFITS

A preliminary assessment is based on geologic conditions at the land surface. Many factors or conditions that affect geologic sensitivity and that lie below the surface cannot be identified with the information used for a Level 1 assessment. Hence, the reliability of a preliminary assessment depends directly on the assumption that the material at the surface is representative of the entire vadose zone. The vadose zone is always assumed to be thin unless additional, reliable data on depth to the water table are available. Information about pedologic soils that indicates whether the depth to seasonal high water is greater than or less than six feet is used for assessments based on soil surveys. This makes the imperfect assumption that saturated soil conditions reflect a high water table.

A Level 1 assessment is most accurate in areas where the water table is shallow. A thicker vadose zone is more likely to include buried geologic layers that are significantly different from the material at the ground surface.

A preliminary assessment does not require extensive training or expensive equipment. It has great potential for raising awareness of ground water sensitivity among the public and government officials and can be used as valuable classroom material in general earth science education.

A preliminary assessment will not necessarily predict actual ground water quality. The assessment addresses only the vertical movement of contaminants to the water table and does not indicate the lateral movement that will often occur. Some contaminants may be introduced to the ground water from within or below the vadose zone. Also, some ground water may be uncontaminated because no contaminant has been introduced rather than because the area has a low sensitivity rating.

The user must also remember that the assessment is based on the landscape that existed when the information source was prepared. Construction of landfills, large buildings, industrial plants, subdivisions, and shopping centers commonly cuts or fills enough material to make the original mapping irrelevant for assessment purposes because so much of the natural geologic material has been altered. Areas altered by man cannot be assessed with the methods described in this chapter.

There is no substitute for a site-specific assessment for projects that may affect ground water quality. A site-specific assessment will not modify the sensitivity ratings listed above; it refines knowledge about the intricacies of the geologic setting at the site and allows a more accurate and detailed delineation of the site sensitivity. It is vitally important that a site-specific assessment extend beyond the boundaries of an individual project to place it within the context of the surrounding area. The appropriate distance beyond a project to include in an assessment will vary with each project.

A preliminary assessment is only a first step in documenting sensitive geologic areas and is extremely limited in its ability to show that particular land uses may or could cause or result in ground water contamination. However, local governments are encouraged to prepare a preliminary assessment with their own resources. This will reduce the cost of a subsequent Level 2 or Level 3 assessment and will give local staff a familiarity with geologic conditions within the county that they otherwise would not have.

CHAPTER VI

LEVEL 2 ASSESSMENT - VADOSE ZONE MATERIALS

INTRODUCTION

The vadose zone is the unsaturated material above the water table (Figure VI-1) and includes all unsaturated materials from the surface to the water table whether unconsolidated or consolidated. In Minnesota the vadose zone thickness may range from zero where the water table is at the surface to over a hundred feet. The vadose zone is typically not a single homogeneous unit but may be many distinct geologic materials. The vadose zone may be composed of unconsolidated materials such as clay, sand or gravel or consolidated materials such as sandstone or limestone bedrock, or both.

A Level 2 assessment of geologic sensitivity, as defined in Chapter III, is an estimate of the vertical downward travel time of contaminants from the surface to the water table. This travel time depends on both the rate of downward movement and the thickness of the vadose zone. The vertical permeability of the vadose zone material is an important factor controlling the rate of downward migration.

Vadose zone permeability is influenced by several factors. One factor is the texture (grain size distribution) of the material. For example, sands and gravels are more permeable than mixtures of sand, silt and clay. Another important factor is the presence of fractures, joints and solution features in underlying bedrock. Fractures, joints and solution features act as conduits through which water, along with any contaminants it may carry, migrates very quickly.

Level 2 Assessment - Vadose Zone Materials

General Assumptions - The ratings tables are based on general knowledge of the saturated permeabilities of broad groups of geologic materials. Saturated permeabilities are used as a conservative estimate of difficult-to-evaluate unsaturated permeability. A person experienced in subsurface geologic mapping will be capable of completing this assessment level, including necessary steps which are not detailed in this document. This assessment level assumes that all contaminants are conservative, that is, contaminants have characteristics similar or identical to water, and are introduced at the surface.

Benefits - A Level 2 assessment is a more complete evaluation of the sensitivity of the water table aquifer in the mapped area than a Level 1 assessment. A Level 2 assessment can be applied to a relatively small area.

Limitations - This assessment process requires a person to be familiar with the geology of the area of concern and possess a thorough knowledge of geologic principles and processes. A Level 2 assessment can be very time consuming and expensive if existing subsurface data are inadequate. It does not evaluate complex vadose zone processes and therefore should not be used for contaminant or site specific applications, although it may be useful as a screening tool where data are available. It does not evaluate deeper aquifers.

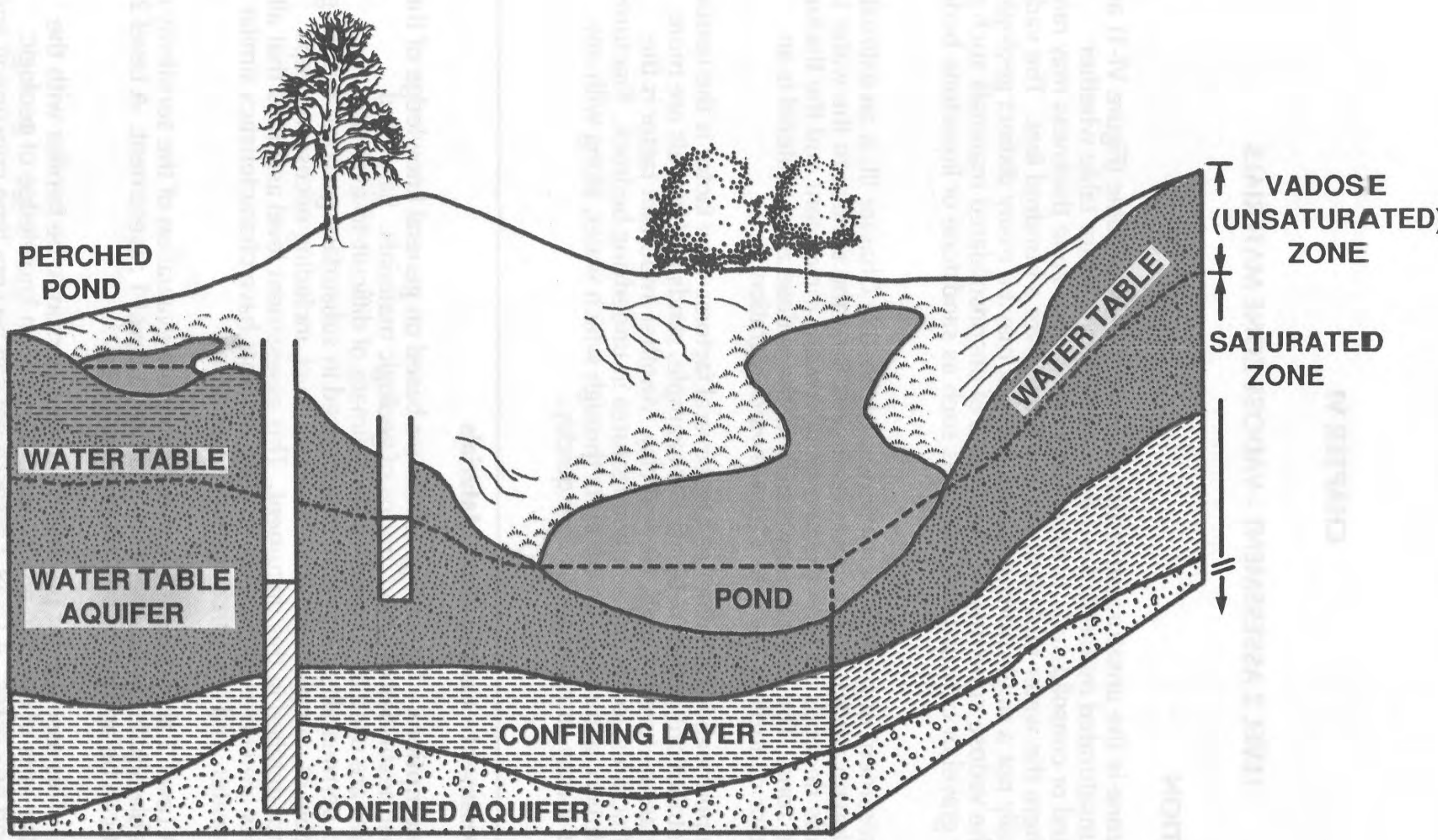


Figure VI-1. A Level 2 geologic sensitivity assessment evaluates vadose zone materials to estimate the sensitivity of the water table aquifer.

The procedures described in this chapter combine information about vadose zone material and depth to the water table to estimate the vertical time of travel. The general geologic sensitivity criteria presented in Chapter III are then used to determine the sensitivity ratings.

A Level 2 assessment can be completed by using either of two related procedures: the Point Method and the Area Method. The Point Method uses subsurface information at specific locations (from driller's, engineering or geologic logs) to interpret and assign a geologic sensitivity rating. This procedure is generally most useful in settings where data are sparse and evaluation of specific points is desired. Larger areas such as townships or counties with adequate subsurface data coverage may apply the Area Method. The Area Method requires a detailed surficial geologic map or its equivalent of the area to be assessed. A geologist constructs a surficial geologic map by using all available surface and subsurface data, including soil parent materials information, local geomorphic expression and an extensive field investigation along with knowledge of the geologic processes that have affected the area over time. The geologic map produced is the result of combining many different information sources and is an interpretation of those sources. Because geologic interpretation is required for both assessment methods, a Level 2 assessment should be attempted only by a person experienced in geological investigations.

A Level 2 assessment is a more realistic predictor of the sensitivity of the water table aquifer to surface contamination than a Level 1 assessment because it considers the variability of geologic materials from near the surface all the way down to the water table. However, a Level 2 assessment requires knowledge of the water table depth and the characteristics of the vadose zone materials in the area to be assessed. The information from a Level 1 assessment is not sufficient in most locations because a Level 1 assessment only considers the materials at or near the land surface Where the water table is located in the deeper subsurface additional effort may be necessary determine its depth. Considerable effort is usually required to characterize the materials in the vadose zone.

This assessment level does not take into account the complex processes and properties of unsaturated materials such as the behavior of infiltrating water, evaporation, vegetation, preexisting moisture conditions, etc. These factors are very difficult to evaluate and are beyond the scope of this assessment system. To allow some estimate of travel time, saturated conditions under a nominal vertical head are assumed. Although the assumption of saturated conditions in the vadose zone may result in some inaccuracies in estimating travel times, for many situations assuming saturated conditions will probably give a more conservative, or shorter, estimate of the travel time. For site specific applications, a sensitivity assessment model which evaluates the complex behavior of the vadose zone should be considered. Other assessment models are discussed in Appendix D.

Subsurface information needed for a Level 2 assessment includes data found in well records, exploration and engineering test borings, borehole geophysical records and samples of geologic materials from the vadose zone. The types of subsurface data mentioned always require interpretation; therefore, as stated previously, the vadose zone assessment should be conducted by a person experienced in geological investigations. If there are any questions concerning the interpretation or validity of specific data, the Minnesota Geological Survey staff, a professional consultant or other knowledgeable person should be consulted.

GENERAL PROCEDURE - POINT METHOD

A Level 2 assessment of geological sensitivity using point source data (i.e., driller's, engineering and geological logs) should be considered preliminary in most areas. In many areas water well driller logs are the only source of subsurface information. Some of these logs may not provide sufficient information to support consistent interpretations of subsurface conditions. In addition, lack of consistency among drillers, lack of training, and different aquifer targets generates conflicting data. The uncertainty introduced into the assessment process by using this information should not be ignored. An intensive investigation of the area of concern, producing a detailed surficial geologic map is recommended for a Level 2 assessment (see Area Method, page 57). The following steps describe the process when conducting a Point Method Level 2 assessment.

Step 1 - Collect all available hydrogeological information

The first step is to collect all available studies and information for the area of concern from published and unpublished sources. Refer to Appendix B for information on where to obtain subsurface geologic information.

Step 2 - Organize data

After obtaining the information, organize the subsurface data points using a worksheet such as shown in Figures VI-2 and VI-3. Figure VI-2 is a completed worksheet based on an engineering log. Figure VI-3 shows a completed worksheet based on a water well record (driller's log). At a minimum, a worksheet should contain: the source of information, data identification number (unique well number for wells or a test boring), location information, elevation, depth of well/boring, static water level and a geologic log containing depth intervals and lithology. The location information should include county, township, range, and section to the quarter-quarter-quarter-quarter (2.5 acres). The total thickness of the vadose zone will be calculated by knowing the depth to the water table. If the depth to water is not recorded on a well/boring log it should not be estimated and that log should be used only for stratigraphic information. In addition, the worksheet should include an inventory of any low or moderate permeability units and a description of the material at the water table. Low and moderate permeability units and water table materials are discussed in more detail in Steps 5 and 6.

Step 3 - Determine vadose zone thickness at data point location

In many cases, the depth to water or static water level is the vadose zone thickness for each subsurface data point. If the position of the water table is given as a local or National Geodetic Vertical Datum (NGVD) elevation, subtract the water table elevation from the elevation given for the surface at that point. Care must be taken to avoid using static water levels which represent perched conditions, a deeper aquifer or different levels within a single aquifer. The static water levels recorded on water well records are usually measured after completion of well construction and represent the water level of the aquifer in which the casing ends. That water level may be the same as the water table, or it may represent a separate aquifer. If a deep open hole exists beneath the cased portion of the hole, the measured static water may not be representative of the aquifer in which the casing ends. Also, if significant thicknesses of confining materials occur between the land surface and the bottom of the casing the aquifer is probably confined and the static water level can not be used to determine the vadose zone thickness.

FIGURE VI-2. Data worksheet with example of engineering boring log.

ID # 242282 LOCATION 119-24-15, DBBB

SOURCE MGS TOTAL DEPTH 217′

ELEVATION 982′ STATIC WATER LEVEL 42′

__ Driller's Log X Engineering boring log __ Geologic log

Depth	Thickness	Material Description
0-2′	2′	No sample
2-4′	2′	Sandy lean clay
4-7′	3′	Lean clay
7-34′	27′	Clayey sand w/a little gravel
34-57′	23′	Silty sand
57-67′	10′	Sand w/ silt and gravel
67-118′	51′	Sandy lean clay w/a little gravel
118-173′	55′	Sand w/ silt and a little gravel
173-208′	35′	Silty sand
208-218′	10′	Sand w/ silt and gravel

Vadose zone thickness: 42′

Presence of low permeability units: moderate permeability unit >20′ thick

Material at water table/rating category: sandy till/3

Vadose zone rating: moderate

Note: Static water level was measured when the total depth of the boring was 51 feet and the casing depth was 49 feet.

After determining the vadose zone thickness, record this information on the data worksheet. In Figures VI-2 and VI-3 the static water level shown on the logs is the vadose zone thickness. This number, 42′ and 50′, respectively, is recorded on the lower part of the worksheet.

Step 4 - Determine terminology used for subsurface data points

Material descriptions on subsurface logs can be vague and confusing. Different terms are sometimes used to describe identical geologic materials. For these reasons the user must become familiar with the sources of information and the terms used for various materials.

FIGURE VI-3. Data worksheet with example of driller's log.

ID # 162847

LOCATION 119-24-15, BBACBD

SOURCE MGS

TOTAL DEPTH 169'

ELEVATION 959'

STATIC WATER LEVEL 50'

CASING DEPTH 155'

X Driller's Log ___ Engineering boring log ___ Geologic log

Depth	Thickness	Material Description
0-6'	6'	No Record
6-18'	12'	Clay
18-40'	22'	Clay
40-55	15'	Sand
55-120'	65'	No Record
120-169'	49'	Sandstone

Vadose zone thickness: 50'

Presence of low permeability unit: low permeability unit greater than 10' thick

Material at water table/rating category: glacial gravel/3

Vadose zone rating: low

Water well drillers typically use general descriptive terms such as sand, clay, gravel and rock. Engineering boring logs usually contain standardized terms such as lean clay, sandy silt and clayey sand that relate to engineering properties. Geologic logs include such terms as alluvium, till and outwash that describe a material's physical properties as well as its geologic history.

Table VI-1 shows the three terminologies side-by-side. Column one lists engineering terms that will commonly be seen on engineering boring logs. Geologic terms from geologic boring logs are listed in column two. Examples of terms used by water well drillers are shown in column three. The terms are arranged in groups of roughly similar permeability (rating category) and divided into unconsolidated and consolidated materials.

Step 5 - Determine presence of low or moderate permeability units

In this step the vadose zone data is examined to determine the presence of low or moderate permeability units. The material in the top ten feet of the vadose zone is

TABLE VI-1. Materials at the Water Table by Rating Category

Engineering Terminology (ASTM Unified)	Geologic Terminology	Examples of Driller's Terminology	Rating Category* [Go to Table VI-2, page 55]
	UNCONSOLIDATED MATERIALS		
Clayey gravel (GC), silty gravel(GM), poorly graded gravel(GP), well graded gravel(GW), poorly graded sand(SP), well graded sand(SW)	Outwash, glacial lake sand and gravel, terrace deposits, organic material, peat, loess**, glacial lake silt and fine sand	Any combination of sand and gravel that does not include the term clay	2
Silty sand (SM), Clayey sand (SC)	Sandy loam till, loamy sand till, alluvium, colluvium	Clay sand, sandy clay, hard pan, gravelly clay, clay and rock, any other description modified by clay	3
Fat clay (CH), lean clay (CL)	Glacial lake clays, loamy till clay loam till, clay till	Clay	4
	CONSOLIDATED MATERIALS		
Limestone, dolomite	Karstic limestone limestone, dolomite	Limestone, limerock Shakopee, Prairie du Chien, etc., rock	1
Sandstone, igneous or metamorphic rocks*	Sandstone, igneous or metamorphic rocks	Sandstone, sandrock 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

*Ratings must be modified as appropriate according to the actual permeability that results from both the primary and secondary porosity present in each material.
**Although loess has a relatively high water-holding capacity and does not readily transmit water, loess overlies karstic bedrock throughout a significant part of southeast Minnesota.

not evaluated. Infiltrating water can enter the ground water via direct pathways opened by animal burrows, root casts, or fractures and joints caused by frost action or desiccation. These complexities make estimating vertical flow in the top ten feet of the vadose zone very difficult.

For the purposes of this document the presence of low or moderate permeability units in the vadose zone can be assigned to one of four categories:

- at least one low permeability unit a minimum of 10 feet thick;

- an aggregate of low permeability units greater than or equal to 10 feet thick with no single unit greater than 10 feet thick;

- a single moderate permeability unit a minimum of 20 feet thick.

- no low permeability units greater than 10 feet thick or moderate permeability units greater than 20 feet thick;

Water well records (Figure VI-3) are the most common form of subsurface data that are available for many parts of Minnesota. Unfortunately, most water well records lack somewhat in detail compared to other information sources such as engineering boring logs. When assessing water well records (also commonly called driller's logs) for the presence of low permeability units, the only terms acceptable for low permeability units are "clay" and "shale". The terms "clay" or "shale" may not be modified by any other term; sandy clay, clay and gravel or shaly limestone do not qualify as low permeability units when the point data source is a water well record (driller's log). If a low permeability unit (unqualified clay) is not listed on the log, no low permeability unit is assumed to be present in the vadose zone. If a material is described as "clay" modified by terms such as sandy or gravelly (e.g., sandy clay but not clay with sand) then the material may qualify as a moderate permeability unit if it is greater than 20' feet thick. Also, if bedrock described as "shale" is modified by terms such as limy or sandy (limy shale, sandy shale) then the material may qualify as a moderate permeability unit if greater than 20 feet thick.

Engineering boring logs may contain different terminology depending on the classification system used. Classification systems encountered may include the American Association of State Highway Officials (AASHO) Soil Classification and the American Society for Testing and Materials (ASTM) Unified Soils Classification System. The descriptions used may differ slightly from these standard classification systems. Terms which would qualify a low permeability unit include fat clay (CH) and lean clay (CL) using the ASTM Unified system and shale. Moderate permeability units include silty sand (SM) and clayey sand (SC) and siltstone.

Subsurface material terms used on geologic logs tell geologists something about the geologic history of the material. For example, outwash, loess and till are deposits associated with glaciers. Geologic log terms indicating low permeability units include till or till modified by clay, loam or both or glacial lake clays. Geologic log terms indicating moderate permeability units include any till modified by sand, all alluvium and all colluvium.

In general, low permeability units are indicated by materials identified as clayey till, lake clay, loamy to clayey till and shale (rating category "4" in Table VI-1). Typical materials that qualify as moderate permeability units are those listed as rating category "3" in Table VI-1.

If the descriptions of subsurface data are unclear or questionable, refer to the original data source for clarification. For example, if the data source is an engineering log, the firm which conducted the work should be contacted.

Follow Figure VI-4 to determine the permeability unit category for each data point. Record this information on the worksheet. For example, when the worksheet information in Figure VI-2 is applied to Figure VI-4 it is found that:

- vadose zone thickness = 42 feet;

- there is no <u>single</u> low permeability unit greater than 10 feet thick;

- since there are no low permeability units in the vadose zone, the aggregate thickness of low permeability units is zero;

- measuring from 10 feet below the surface to the water table, the vadose zone includes one moderate permeability unit (the unit described as clayey sand with a little gravel) about 24 feet thick.

Step 6 - Determine the material at the water table

The material at the water table is used to modify the sensitivity rating of the overlying vadose zone materials. The rating is an estimate of the ease with which contaminants may enter the water table system. On each worksheet, record the category of the material at the water table using Table VI-1. If no static water level is given or if it has been determined to represent a perched or deeper aquifer, the material at the water table cannot be identified and the subsurface data point cannot be used in the assessment. In Figure VI-2 the material at the water table is silty sand. Since Figure VI-2 is an engineering boring, the first column in Table VI-1 was used to find its rating category. Silty sand is listed in rating category 3. Gravel material occurs at the water table in Figure VI-3 (driller's log). Using the driller's terminology in the third column of Table VI-1, gravel was found in rating category 2.

Step 7 - Apply information from Steps 5 and 6 to rate each point

The Level 2 geologic sensitivity assessment at each data point is determined by using the information from Steps 5 and 6. Step 5 evaluated whether a low or moderate permeability unit occurred in the vadose zone. Step 6 rated the material at the water table. Table VI-2 is used to find the sensitivity rating for each subsurface data point. The vadose zone of the boring in Figure VI-2 has a moderate permeability unit greater than 20 feet. At the water table this boring has material rated 3. According to the Table VI-2 the Level 2 geologic sensitivity rating for this point is "Moderate". In a similar manner, the boring in Figure VI-3 has material at the water table rated as 2, and a low permeability unit is present in the vadose zone. According to Table VI-2 the Level 2 geologic sensitivity for this point is "Low".

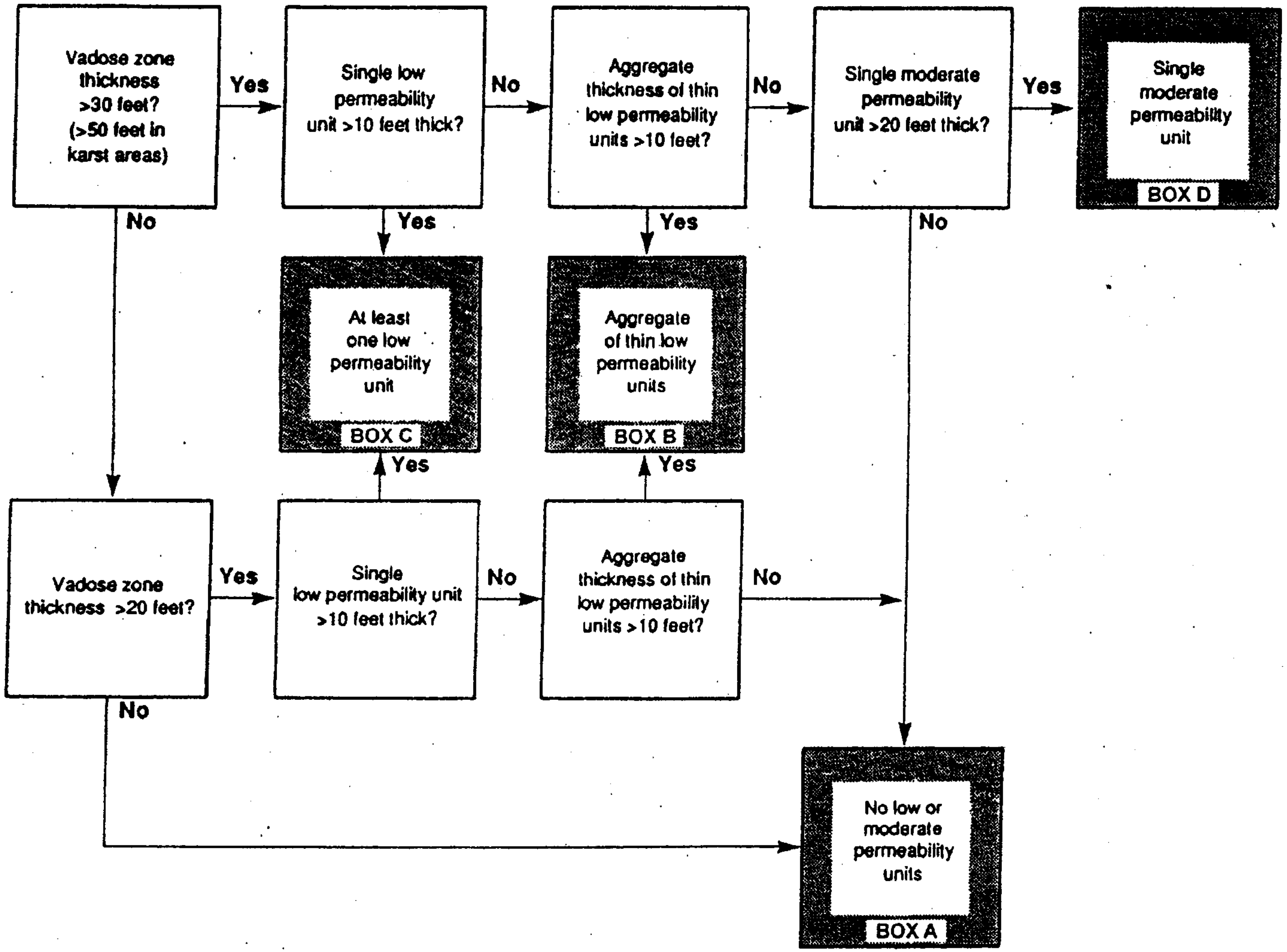


Figure VI-4. Flow chart to identify low and moderate permeability units in the vadose zone. See Table VI-2 on page 55.

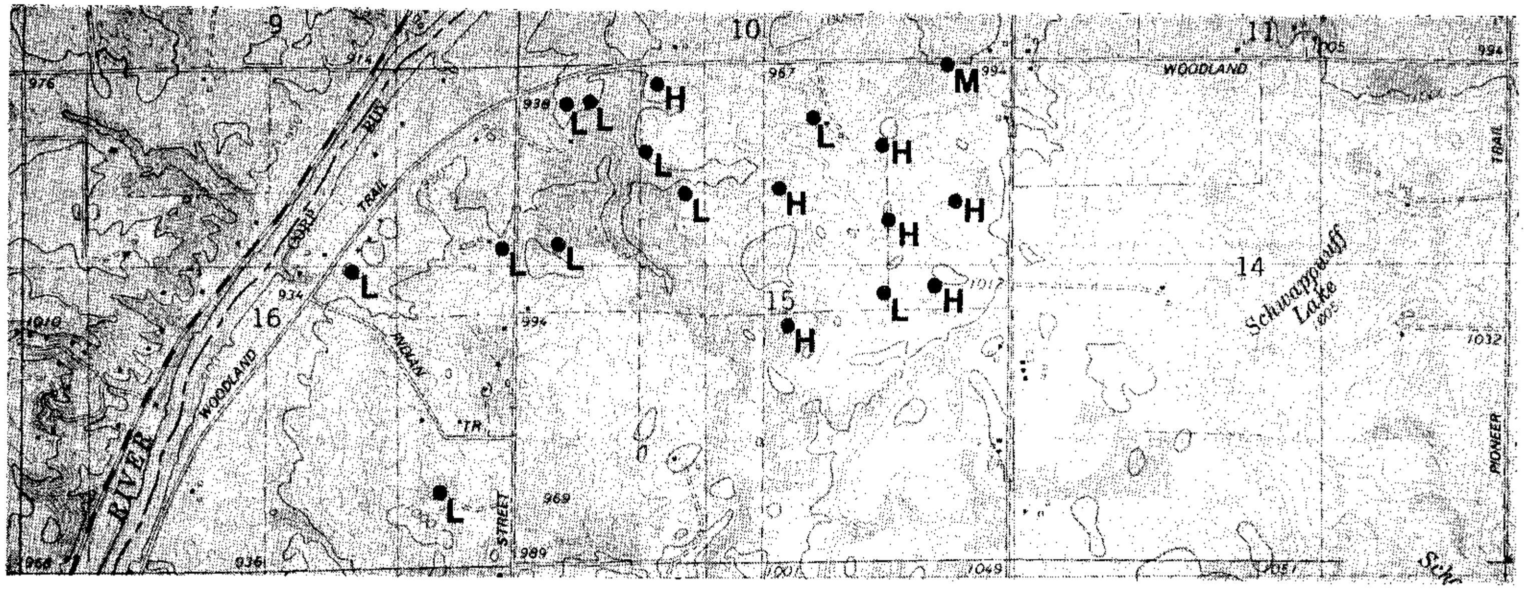
TABLE VI-2. Level 2 sensitivity rating table.

STEP 5, p. 50-53 LOW AND MODERATE PERMEABILITY UNITS IN THE VADOSE ZONE (from Figure VI-4)	STEP 6, p. 53 Water Table Material Rating (from Table VI-1)								
	Carbonate rock; Karst conditions 1			Sand/gravel, sandstone 2		Sandy till, sandy shale 3		Clay, shale 4	
	Total vadose zone thickness (feet)								
	<20	20-50	>50	<20	>20	<20	>20	<20	>20
No low or moderate permeability units **[BOX A]**	VH	VH	H	VH	H	M	M	L	L
Aggregate of thin low permeability units >10 feet thick **[BOX B]**	--	H	M	--	M	--	M	--	L
At least one low permeability unit >10 feet thick **[BOX C]**	--	M	L	--	L	--	L	--	L
	<30	30-50	>50	<30	>30	<30	>30	<30	>30
Single moderate permeability unit >20 feet thick **[BOX D]**	--	H	M	--	M	--	M	--	L

NOTE: VH = Very High; H = High; M = Moderate; L = Low; -- = No low or moderate permeability units as defined can be present; go to "No low or moderate permeability units" row.

Step 8 - Plot data points and rating on map.

Using a suitable base map, preferably a 7.5 minute quadrangle, plot the subsurface data locations and label them with the Level 2 geologic sensitivity ratings determined in Step 7. Figure VI-5 shows the Level 2 Point Method plot for the example area in Greenfield, Minnesota. Note that much of the example area has no point ratings indicated. This is one of the disadvantages of using point data to assess sensitivity. Unless the sensitivity ratings for points are consistent over a large area it is not recommended that point data be extrapolated to fill in areas lacking subsurface data. In these cases it is best to obtain additional data so a more accurate characterization of the sensitivity can be made.



H = High **M = Moderate** **L = Low**

Figure VI-5. Point Method Level 2 geologic sensitivity assessment for the example area in Greenfield, Minnesota, northwest Hennepin County. Note that rated points are not available for much of the example area. Density of rated points is not sufficient to allow extrapolation to rate areas.

GENERAL PROCEDURES - AREA METHOD

A Level 2 assessment using the Area Method requires two essential maps for the area to be assessed: geological and depth to water table.

Step 1 - Construct or obtain surficial geological map

Conducting a complete geological investigation of an area is the technical foundation of a Level 2 geological sensitivity assessment. Geological mapping requires advanced interpretive skills and a great deal of background knowledge and utilizes many different sources of information. Geological mapping should only be attempted by individuals with experience in conducting such investigations.

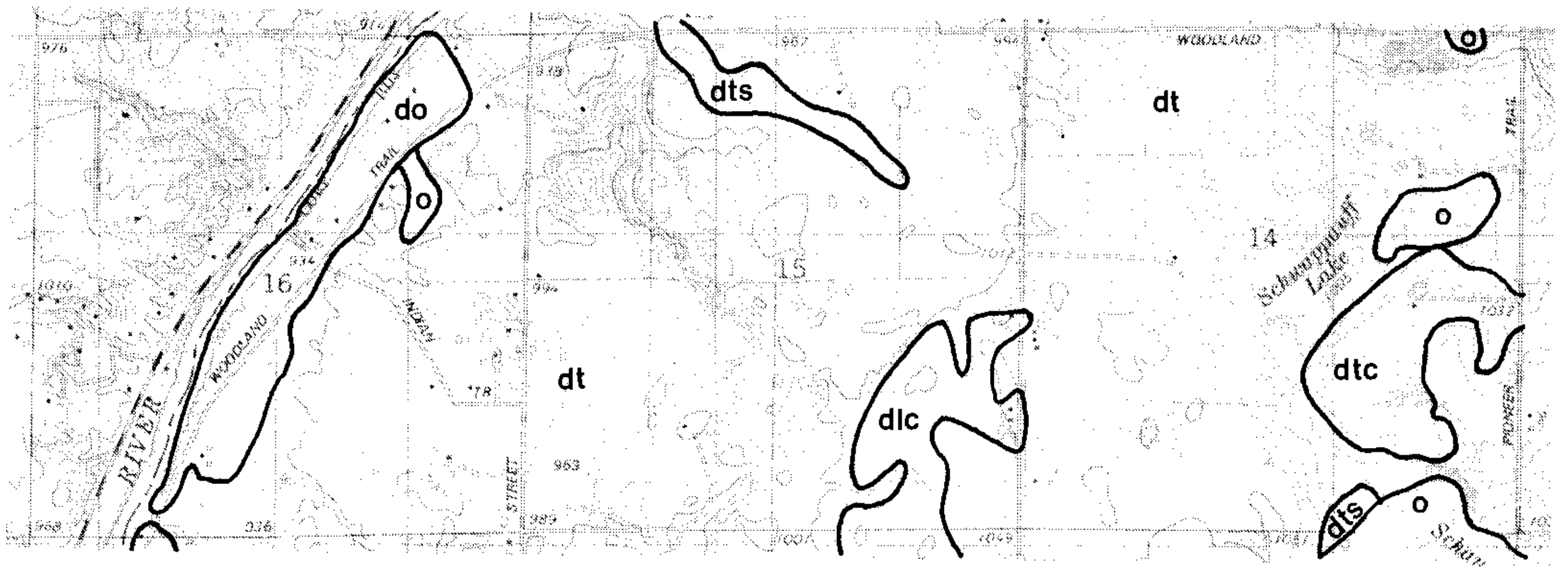
Surficial geological maps are available for some parts of Minnesota, however they may not be of adequate detail for a particular assessment project. Where surficial geological maps are not available it will be necessary to construct a map to use the Area Method. The most accurate method of mapping surficial geologic features is based on soil parent materials, local geomorphology, available subsurface data and extensive field work. It is recommended this step be completed by a geologist with considerable knowledge of near-surface geologic materials and the geologic history of the area being mapped. A geologist, (with the assistance of the staff at the Minnesota Geological Survey), will be able to delineate map units based on geologic interpretation and provide an accurate map. Figure VI-6 is a surficial geologic map for the example area prepared by the staff of the Minnesota Geological Survey.

Step 2 - Construct or obtain a depth to water table map

While accurate maps of the depth to water table may be available for some areas, most likely a map will need to be prepared. A depth to water table map requires sufficient information to be able to predict the depth of the water table throughout the area to be mapped. Figure VI-7 is a simplified depth to water table map for the example area. The figure only shows where the depth to the water table is less than or greater than 20 feet. The Level 2 rating table (Table VI-2) does not require more definition than this for most locations. In the karst areas of Minnesota (rating Category 1 in Table VI-2), however, the depth to water map should show areas of less than 50 feet and greater than 50 feet. A geological professional should be consulted to prepare a water table depth map for the assessment area.

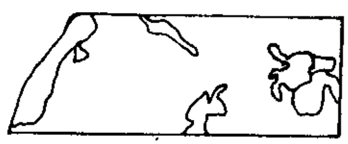
Step 3 - Determine presence and lateral extent of mapped units

Before the surficial geologic map can be rated the areal extent and thickness of mapped units must be documented. In some areas of the state, mapped surficial deposits may be a very thin veneer over more laterally persistent units. In the example area in Figure VI-6, the units marked **dlc** and **o** are known to be relatively thin deposits over glacial till. Very thin surficial deposits may not always be important, however because of the shallow depth to the water table where these units occur these units will be considered in the Level 2 rating. In situations where the depth to the water table is considerably more than 20 feet, thin surficial units should not be considered in most cases as representative of the vadose zone. This type of information is not readily inferred from typical surficial geologic maps; a geologist knowledgeable in the area of concern should interpret the surficial geologic maps before the area is rated.

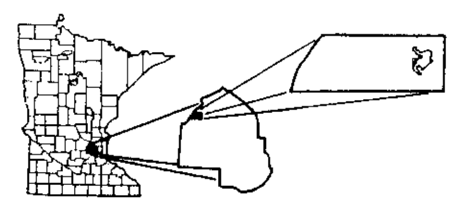


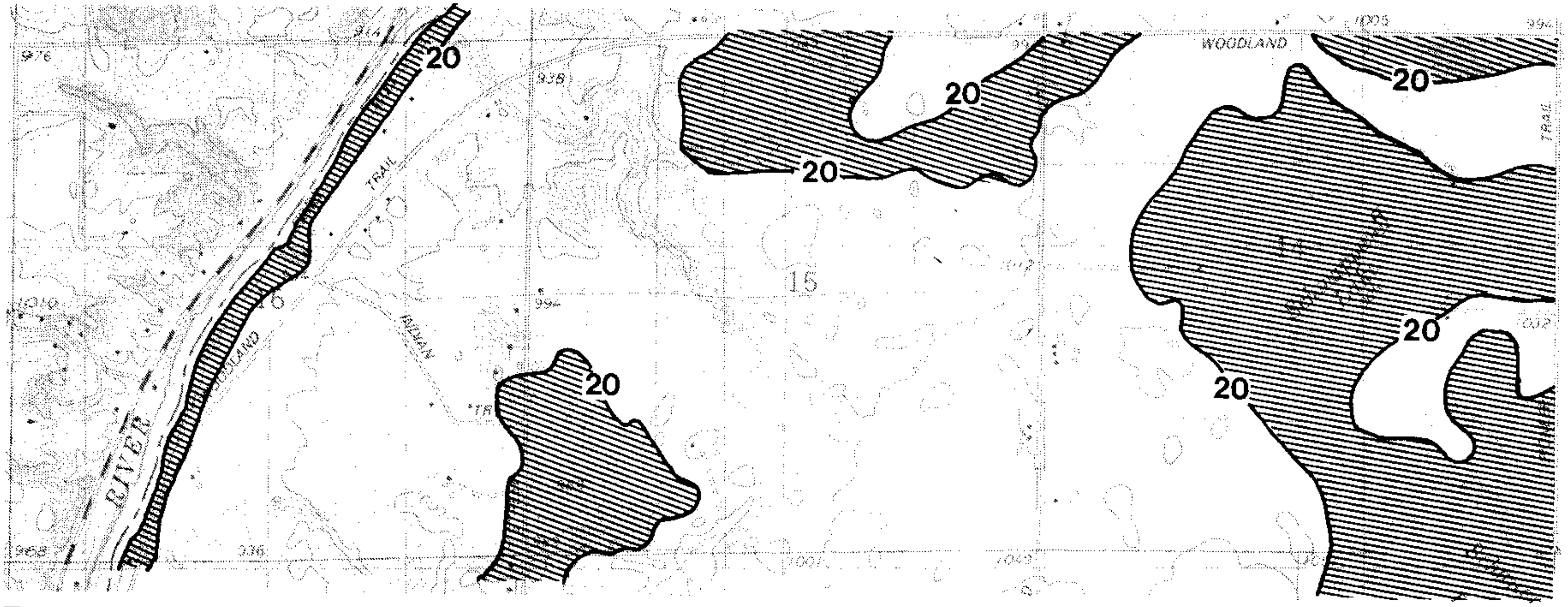
do=outwash, dlc=lake clays, dt=till, dts=sandy till, dtc=clayey till, o=organic

Figure VI-6. Surficial geologic map of sections 14-16, Greenfield Township, Hennepin County, Minnesota. Original map enlarged for illustration.



Original Map Scale





EXPLANATION

DEPTH TO WATER

- (hatched box) Less than 20 feet
- (empty box) Greater than 20 feet

Figure VI-7. Depth to the water table in the example area.

Step 4 - Construct sensitivity map

The last step is to rate the geologic units and construct the sensitivity map. The depth to the water table map (Figure VI-7) is overlaid on the surficial geologic map. Table VI-2 is used after working through Table VI-1 (water table materials category) and Figure VI-4 (presence of materials with low or moderate permeability). The map is constructed by combining units with identical sensitivity. Figure VI-8 is the Level 2 geologic sensitivity map for the example area using the Area Method. The final map should be marked as Level 2 to avoid confusion with a Level 1 assessment map.

The Level 2 assessment for the example area (Figure VI-8) looks quite different compared to the Level 1 assessment for the same area (Figure V-10). Most of the area is now rated "Low" instead of mixed "Low" and "Moderate". This means surface contamination is expected to take longer to infiltrate the surficial materials and enter the water table aquifer. The area along the Crow River rated "Very High" in Level 1 is now rated mostly "High" with the exception of a narrow band of "Very High" next to the river where the water table is shallow. The thin sandy surficial materials around the edges of Schwappauff Lake and the pond were dropped from the rating since they were determined to be not representative of the underlying till.

BENEFITS AND LIMITATIONS

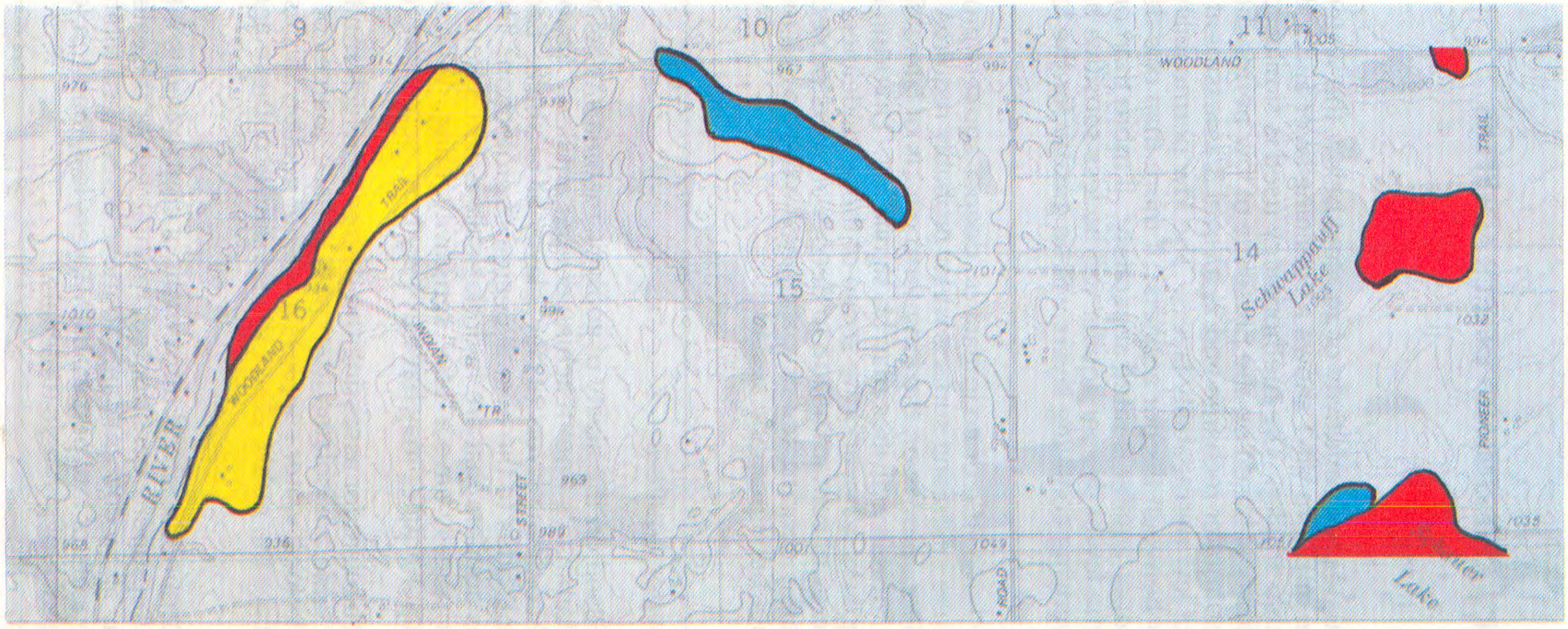
Compared to a Level 1 assessment, a Level 2 assessment is a more complete and realistic evaluation of the sensitivity of the water table aquifer in the mapped area. The assessment considers both the rate at which a contaminant may move vertically downward as well as the distance to the water table aquifer.

The assessment allows evaluation of both points and areas. Assessment of points allows initial screening when subsurface mapping is not available. This may assist prioritizing future mapping and other ground water protection efforts. When data density is sufficient a Level 2 assessment using point information can be applied to relatively small areas.

A Level 2 assessment of areas requires technical capability in geology and ground water hydrology and detailed understanding of local geologic and hydrogeologic settings. If an area Level 2 assessment is desired, but existing subsurface data are inadequate, developing the data base for the assessment can be very time consuming and expensive.

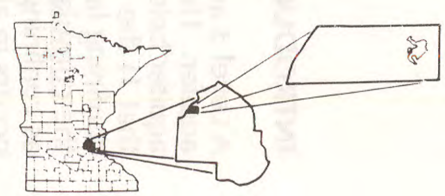
The complex processes and properties of the vadose zone are not addressed in a Level 2 assessment. Given these complexities, the rating table, Table VI-2, uses an estimate of the average vertical time of travel of a conservative contaminant under saturated, not unsaturated, conditions. In many situations, this assumption should give a more conservative estimate of the time of travel.

Deeper aquifers that may exist below the water table are not considered. The Level 3 assessment presented in Chapter VII explains how deeper aquifers may be evaluated.



Very High
High
Moderate
Low

Figure VI-8. Area Method Level 2 geologic sensitivity assessment for the example area in Greenfield, Minnesota, northwest Hennepin County. Compare to the Point Method Level 2 assessment in Figure VI-5. Map base enlarged for illustration.



CHAPTER VII

LEVEL 3 ASSESSMENT - DEEPER AQUIFERS

INTRODUCTION

A Level 3 assessment evaluates the sensitivity of aquifers below the water table aquifer. The block diagram in Figure VII-1 shows a confining layer and a deeper aquifer below the water table aquifer. The methodology used is similar to Level 2 in that 1) the degree of sensitivity is based on the presence of low permeability or confining layers that reduce aquifer recharge and 2) a Level 3 assessment evaluates the <u>cumulative</u> thickness of low permeability layers. The low permeability layers act as confining units above or between deeper aquifers. If more than one deeper aquifer occurs in an area, each deeper aquifer is rated separately. If more than one deeper aquifer occurs in an area, the lower deeper aquifer will be less sensitive because the cumulative thickness of overlying confining layers will be greater for the lower deeper aquifer.

Human activities will likely have little or no impact on deeper aquifers protected by thick confining layers because infiltrating surface water probably requires a relatively long time to reach the aquifer. However, the long-term effects of lateral flow from recharge areas affected by human activities may be significant. Unfortunately, analysis of lateral flow in deeper aquifers is beyond the scope of these guidelines. Experience indicates the principal sources of contamination to deeper aquifers protected by thick confining layers are improperly constructed or maintained wells and abandoned wells or test holes which have not been properly sealed.

Level 3 Assessment - Deeper Aquifers

General Assumptions - Based on the ability of geologic materials to retard or prevent water-borne contaminants from reaching deeper aquifers. Ratings reflect the thickness of potential confining layers of clay, clayey till or shale. Each ten foot thickness of these materials adds to the overall degree of protection. This level defines deeper aquifers as aquifers that are hydrologically isolated from the water table aquifer and so automatically have a "Low" sensitivity rating. With additional geologic protection, a deeper aquifer may have a "Very Low" sensitivity rating.

Benefits - Provides a mechanism for assessing the degree to which multiple aquifers below the water table are isolated from near surface sources of contamination. Where the local water supply is a deeper aquifer, this assessment level can be used to educate the public about the sensitivity of these aquifers to potential contamination.

Limitations - Does not account for lateral movement of contaminants into a deeper aquifer nor the effects of improperly constructed, maintained, or unsealed abandoned wells that may allow contaminants to move across a confining layer. Does not consider the benefits of low permeability layers less than ten feet thick or local changes in the sequence of geologic materials.

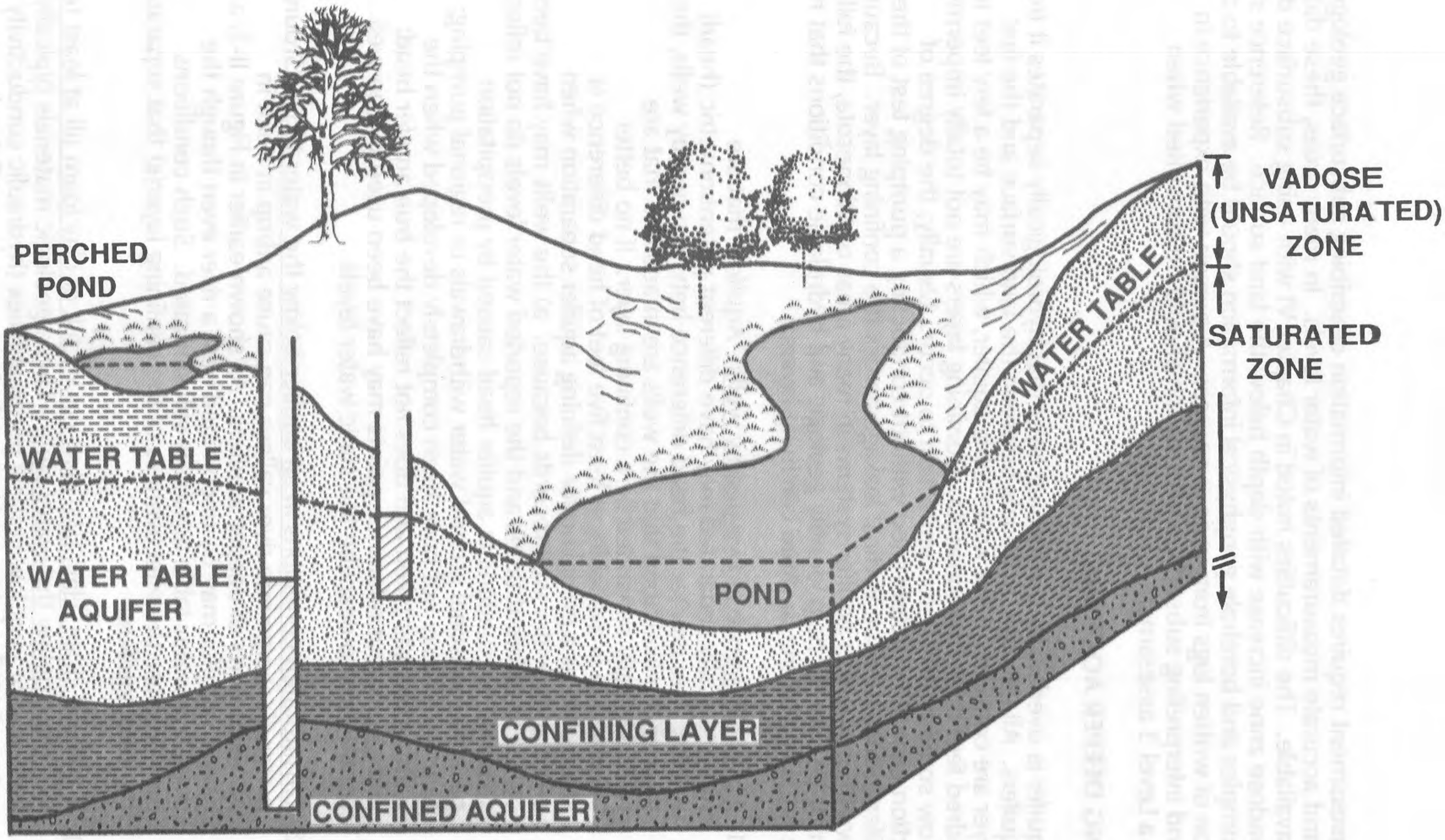


Figure VII-1. Deeper aquifers are below the water table aquifer and beneath a confining unit. A Level 3 assessment of a deeper aquifer rates the protection provided by overlying confining units.

A Level 3 assessment requires detailed information describing subsurface geologic conditions and accurate measurements of water levels. In many areas, these data are not readily available. The difficulties noted in Chapter VI with using subsurface data to define the vadose zone increase with depth below the land surface. Reference sets of formation samples and borehole geophysical information should be available to assist interpretation of written logs from various sources. A person with experience in collecting and interpreting subsurface information should be consulted when conducting a Level 3 assessment.

IDENTIFYING DEEPER AQUIFERS

A deeper aquifer is overlain by a confining layer that hydrologically separates it from overlying aquifers. All geologic materials between the land surface and the first confining layer are considered the water table aquifer, which may be a few feet to several hundred feet thick in Minnesota. Confining layers are not totally impermeable and may allow some aquifer interconnection to occur. Usually, the degree of interconnection cannot be determined without conducting a pumping test of the deeper aquifer to measure the vertical leakage across the confining layer. Because little is known about deeper aquifer systems in many areas of Minnesota, the following guidelines may be used to help identify geologic and hydrologic conditions that may indicate the presence of one or more confining layers:

1. Head Difference in two nearby wells - Aquifers that are hydrologically separated may have different potentiometric (head) values. The greater the head difference between nearby wells, the greater the likelihood that the wells are in aquifers that are hydrologically separated by a confining layer. If no better information is available, at least five feet of head difference is suggested as a guideline for defining aquifer separation when comparing water well records because: a) the wells may have been drilled at different times and the reported water levels do not reflect seasonal fluctuations in aquifer head caused by precipitation patterns, seasonal ground water withdrawals or regional pumping; b) the well may not have been completely developed when the water level was taken and does not reflect the true aquifer head; and c) different reference points may have been used by the well contractors to describe the static water levels.

2. Unsaturated conditions in an aquifer below the water table- Ground water discharge into river valleys can cause a drop in head in adjacent parts of deeper aquifers. As shown earlier in Figure II-3, a deeper aquifer may be unconfined near a river even though the overlying water table aquifer is still saturated. Such conditions demonstrate the effectiveness of the confining layer(s) that separate the two aquifers.

3. A layer of shale, clay, lake clay, clayey till, or clay loam till at least ten feet thick below the water table - These geologic materials typically have low or very low vertical permeabilities (hydraulic conductivity value of 10^{-3} cm/sec or less) and often serve as confining layers. However, the presence of a low or very low permeability layer does not guarantee the layer is a reliable confining unit. Pumping tests, geologic mapping, permeability measurements, tracer studies, or other hydrologic investigations should be conducted to confirm the

effectiveness of a low or very low permeability layer to separate aquifers. A ten foot thickness is a guideline and reflects the thickness intervals generally used to describe geologic materials in well records. Also, samples of drilling cuttings are often collected at ten foot intervals which limits the accuracy of material descriptions.

4. Differences in ground water chemistry between aquifers - Chapter IX describes additional studies that use chemical parameters to confirm the presence of a confining layer. Chemical studies may also identify multiple routes used by infiltrating surface water to recharge a deeper aquifer. It is recommended that geological mapping and hydraulic head differences between aquifers (items a-c, above) be used as the principal means for delineating the distribution of deeper aquifers. Differences in water chemistry should be used only to support these other methods. An additional parameter, while not strictly chemical, is the temperature of the water in the aquifer. Thermal profiles may assist defining separate aquifers. There is currently insufficient ground water chemistry data for most parts of Minnesota to be used as the only means for documenting the occurrence and distribution of deeper aquifers.

All of the methods just described should be used to determine the presence and distribution of confining layers and deeper aquifers. However, this may be impractical because of the time and costs associated with collecting these data. Method number one above is best if only head difference data are available. It is recommended that the third method to identify confining layers be given highest priority because it uses geologic criteria to define potential confining layers. The first and fourth methods rely on measurements that may be affected by well construction practices while the second is generally limited in application to relatively small geographical areas. A Level 3 assessment should begin by using subsurface geologic information to identify confining layers (method number 3, above). The other methods listed should be viewed as supportive.

GENERAL APPROACH

Deeper aquifers are defined in this document by the existence of one or more ten foot thick intervals of confining material below the water table aquifer. Note that this definition is used as a guideline: detailed studies may show that in some cases a thickness of less than ten feet may also function as an effective confining layer. The geologic materials that are used to identify a confining layer are shown in Figure VII-2 and are the same lithologies used in a Level 2 assessment to define confining layers in the vadose zone. Only these lithologies should be considered as confining unless hydrologic studies demonstrate that other materials such as sandy till or clay mixed with granular materials are shown to hydrologically separate aquifers. If the materials being considered as a confining layer are not identified as, or equivalent, to any of the materials shown in Figure VII-2, then only layers described as "clay" qualify as a confining material. Mixtures of clay and other materials such as "silty clay" or "sandy clay" from engineering boring logs would not be considered as confining unless the engineering terminology is translated into geological terminology. Refer to Chapter VI for further discussion on use of material description terms from various sources.

All of the geologic materials shown in Figure VII-2 are assumed to exhibit the same vertical permeability. This assumption may be acceptable for assessing county-wide geological sensitivity of deeper aquifers. However, more rigorous evaluations of

FIGURE VII-2. Confining materials for Level 3 assessment.

Geologic Materials Defined as Confining Materials
<u>Unconsolidated Deposits</u>
Lake Clay Clayey Till Clay Loam Till
<u>Bedrock</u>
Shale
<u>"Generic" Terminology Used in Water Well Records</u>
"Clay"

localized variations of the vertical permeabilities of these materials should be conducted when making site-specific assessments.

QUANTIFYING THE EFFECTS OF CONFINING LAYERS

The sensitivity of a deeper aquifer is assumed in this document to be a function of how well it is protected by overlying confining layers. Protection to a deeper aquifer can be given by: 1) the presence of a single, very thick confining layer, or 2) the cumulative effects of multiple, possibly thinner, confining layers. A Level 3 assessment assumes that the greater the thickness of confining material, the better the deeper aquifer is protected. In addition, the sensitivity ratings assume the net effect of several distinct and laterally continuous layers provide the same level of protection as a single layer of comparable thickness.

All deeper aquifers are, by definition, overlain by a confining layer and therefore have at least a "Low" sensitivity rating. This means that deeper aquifers can only be rated "Low" or "Very Low". If a confining unit does not exist beneath the vadose zone (water table aquifer), the entire saturated thickness is rated the same as the Level 2 assessment no matter how thick it is. For example, in some parts of Minnesota there may be one hundred feet of glacial deposits above dense metamorphic basement rock. Suppose these deposits do not contain any materials that would qualify as a confining unit, that is, they are composed of materials rated "Moderate", "High" or "Very High". In this case, the 100' thickness of glacial deposits and the underlying metamorphic rock would be rated the same as the Level 2 assessment and no Level 3 rating would be given.

Confining layers below the water table are not as prone to the development of macropores as those in the vadose zone and may exhibit even lower vertical permeabilities. The isolating effects of one or more confining layers may result in very slow recharge rates (a century or longer) for a deeper aquifer. Ground water residency studies (Alexander and Alexander, 1989) demonstrate that the "age" of the ground water in some Minnesota aquifers is centuries to tens of thousands of years old.

These aquifers are very well isolated from modern surface infiltration and according to these guidelines have a very low sensitivity rating.

It is beyond the scope of this project to determine the exact thickness of a single confining layer or the additive amount of several confining layers that will result in a "Low" or "Very Low" sensitivity rating for a deeper aquifer. As stated in Chapter III, Table III-1, a "Low" sensitivity rating implies that several decades to a century will pass before an aquifer is recharged with modern surface water. A "Very Low" sensitivity rating implies more than a century will pass before modern surface water reaches the deeper aquifer. A Level 2 assessment requires the presence of at least 10 feet of unweathered confining material to give the vadose zone a "Low" sensitivity rating. If 10 feet is viewed as the minimum thickness for water to infiltrate over several decades (i.e., about 20 years), then 50 feet would require about a century and 50 feet would be the minimum thickness of a low permeability unit to qualify a "Very Low" rating for a deeper aquifer. This 50 foot guideline for a "Very Low" rating should be considered a rough estimate. However, it is consistent with the time ranges used in this document to define sensitivity ratings.

In these guidelines a "Very Low" rating can be achieved either with a minimum of a single 50 foot layer or by adding the combined thicknesses of five "Low" layers that are a minimum of ten feet thick each. These calculations are shown in Figure VII-3. The total thickness of each qualifying layer is divided by ten and rounded down to the next lowest whole number to calculate a comparative score for each confining layer. Note that "L" scores are not obtained by adding the total thickness of all qualifying layers and then dividing by ten. Calculating an "L" score in this way may result in a higher score but may also give an overly optimistic assessment of natural deeper aquifer protection. At this time, until the methodology is thoroughly evaluated for technical soundness, the rating procedures, which give a conservative rating, should be used as stated. "L" scores should only be used as a guide for assessing the vulnerability of deeper aquifers.

"L" scores can used to compare the protection of deeper aquifers. A deeper aquifer rated "Low" with a score of L-4 has a higher degree of protection than a deeper aquifer also rated "Low" with a score of L-1. A combined score of L-5 is the minimum score for a "Very Low" sensitivity rating. The larger the "L" score the more likely the "Very Low" rating will be accurate. For example, a sequence of clayey till units separated by sand layers having a cumulative score of L-12 would probably be more effective protection to the underlying deeper aquifer than a single clayey till unit with a score of L-5.

EVALUATING THE EXAMPLE AREA

There are two components to evaluating the geologic sensitivity of a deeper aquifer: 1) site specific subsurface data that defines aquifer separation and 2) geologic mapping that defines the spatial distribution of confining layers. Subsurface data from geologic, engineering and driller's logs define site specific aquifer conditions that geologic maps cannot portray. However, site specific data cannot readily show the correlation and interpretation of geologic conditions of geologic mapping. Therefore, both components are required to conduct a Level 3 assessment of deeper aquifers. The uses of each component are demonstrated using the example area.

FIGURE VII-3. Procedure for calculating "L" scores for deeper aquifers.

Step 1. $\frac{\text{Thickness of each confining layer}}{10}$ = approximate "L" value.

Step 2. Round approximate "L" value down to next whole number to get the confining layer "L" score.

Step 3. Add the "L" scores of each confining layer to get total score for aquifer. If the score is L-5 or greater, the sensitivity rating is "Very Low".

Example 1 - A single confining layer 69 feet thick.

Step 1. $\frac{\text{69 feet}}{10}$ = L-6.9

Step 2. L - 6.9 rounded down = L-6

Step 3. Deeper aquifer is rated "Very Low" because confining layer score is greater than L-5.

Example 2 - Three confining layers 15, 11 and 23 feet thick.

Step 1. $\frac{\text{15 feet}}{10}$ = L-1.5 $\frac{\text{11 feet}}{10}$ = L-1.1 $\frac{\text{23 feet}}{10}$ = L-2.3

Step 2. L-1.5 rounded down = L-1
L-1.1 rounded down = L-1
L-2.3 rounded down = L-2

Step 3. Adding layer "L" scores gives a total score of L-4. The deeper aquifer is rated "Low" because the total confining layer score is less than L-5.

Site Specific Subsurface Data Component - Using Point Source Data

Unless detailed subsurface geologic mapping is available for the assessment area, a Level 3 assessment is limited to evaluating data for specific points based on subsurface information from various types of drilling records. Subsurface information sources such as well logs can be used to identify the presence, thickness, composition, and distribution of confining layers.

The process of analyzing subsurface geologic data is time consuming and must be coordinated with the Minnesota Geological Survey, the Minnesota Department of Natural Resources, and the Minnesota Land Management Information Center in order to avoid duplication of effort and to ensure quality control for these efforts. The data must be arranged into a geographically based filing system and geologically interpreted prior to use.

The two geologic logs shown in Figure VII-4 are from nearby wells in the example area. Notice the difference in how subsurface geologic materials are described. The geologic log of the test hole was prepared using engineering terms whereas the water well log was prepared by a water well contractor. Both logs are accurate relative to the needs of the individuals who prepared them but both must be geologically interpreted to be useful in a Level 3 assessment. Well 1 was used in Figure VI-2 (p. 49) to rate the sensitivity of the vadose zone materials. Well 1 will now be used to evaluate the presence of a deeper aquifer and its geologic sensitivity.

Test hole record - In the engineering test hole in Figure VII-4, the water table occurs at a depth of 42 feet (elevation 942 feet) in a silty sand that is interpreted to be sandy till. This sandy till (34 to 57 feet below the land surface) overlies a layer of "sand with silt and gravel" (57 to 67 feet). For purposes of this assessment, both layers are considered part of the water table aquifer because neither meet the definition of a confining (low permeability) layer (See Figure VII-2). However, the 51 feet of "sandy lean clay with a little gravel" (67 to 118 feet) is interpreted to be a loamy till and qualifies as a confining layer. The other layers below this loamy till are considered a separate aquifer and have a "Very Low" sensitivity rating. This rating was determined by dividing the 51 foot thickness of the loamy till by ten and rounding down to the next whole number, giving a score of L-5. As stated above, confining units with a score of L-5 or greater allow the deeper aquifer below to be rated "Very Low". Thus, the information presented in the record of the test hole shows that at least one deeper aquifer exists and that it is probably isolated from the water table aquifer.

Water well record - The water well record in Figure VII-4 does not provide as detailed a description of subsurface geologic materials as the record of the engineering test hole. Nevertheless, its geologic information is still useful and it also provides information not supplied by the other record. The 918 foot static water level elevation reported in the water well is significantly lower than the 942 foot static water level elevation of the water table reported in the test hole. This indicates that the well pumps from a deeper aquifer that is not directly connected to the water table. Figure VII-5 shows a profile across the example area using water level elevations from test holes, wells, and exposures of the water table. The upper line in the figure shows the water table from Schwappauff Lake to the river. The lower line shows the potentiometric head of the deeper aquifer and was drawn using mostly water well data. Notice the water level elevation differences between the deeper aquifer and the water table throughout most of the example area. It is only near the river where the two appear to have similar values and may be interconnected. The data available are insufficient to determine if the river causes the deeper aquifer to discharge into it, if the river is recharging the deeper aquifer, or if there is no hydrologic connection between the two. More detailed studies such as monitoring the water levels in both aquifers to observe seasonal changes are needed to confirm their hydrologic connection.

The well record does not provide any information about the depth to the water table. This can be estimated using the map of the water table shown in Figure VII-6. The land surface elevation at the well site is about 1045 feet and the water table elevation shown in Figure VII-6 is about 975 feet. Therefore, the depth to the water table is approximately 70 feet (1045 minus 975). Comparing this depth to the geologic log of the well indicates that the water table occurs in a "clay" layer present from 45 to 205 feet below the land surface. The lithologic descriptions from the engineering test hole show that the "clay" interval described by the well contractor is probably not all clay but rather a mixture of several layers of differing composition. However, it is not

FIGURE VII-4. Examples of engineering test hole and water well record logs.

WELL 1 - Engineering test hole

ID#: 242282
Elevation: 982′
Static Water Level: 42′*

Location: 119-24-15
Total Depth: 217′
Static Water Elevation: 942

Depth	Thickness	Material Description	Interpretation
0-2′	2′	No sample	
2-4′	2′	Sandy lean clay	
4-7′	3′	Lean clay	
7-34′	27′	Clayey sand w/a little gravel	
34-57′	23′	Silty sand	
57-67′	10′	Sand w/ silt and gravel	
67-118′	51′	Sandy lean clay w/a little gravel	Confining Layer
118-173′	55′	Sand w/ silt and a little gravel	Deeper Aquifer
173-208′	35′	Silty sand	Deeper Aquifer
208-218′	10′	Sand w/ silt and gravel	Deeper Aquifer

*Static water level was measured when the total depth of the boring was 51 feet and the casing depth was 49 feet.

WELL 2 - Water Well Record

ID#: 437510
Elevation: 1048′
Static Water Level: 130′*

Location: 119-24-14
Total Depth: 245′
Static Water Elevation: 918′

Depth	Thickness	Material Description	Interpretation
0-30′	30′	Clay	
30-45′	15′	Gravel	
45-205′	160′	Clay	Confining Layer
205-245′	40′	Gravel	Deeper Aquifer

*Static water level was measured after the well was constructed.

possible to substitute the engineering log lithologies for those of the well log because of the possibility of lateral variation in composition between the two holes. Therefore, the sensitivity rating of the deeper aquifer at the water well site will be calculated as follows: 1) ignoring the top ten feet (similar to a Level 2 assessment), the surficial clay unit is 20 feet thick and has a score of L-2, 2) The 160 foot thick clay confining layer from 45 to 205 feet below the surface has a score of L-16, 3) adding the two scores gives a cumulative score of L-18 for the clay units above the deeper gravel aquifer. This deeper gravel aquifer is rated "Very Low" since the cumulative score of L-18 is certainly greater than the required minimum of L-5 for a "Very Low" rating.

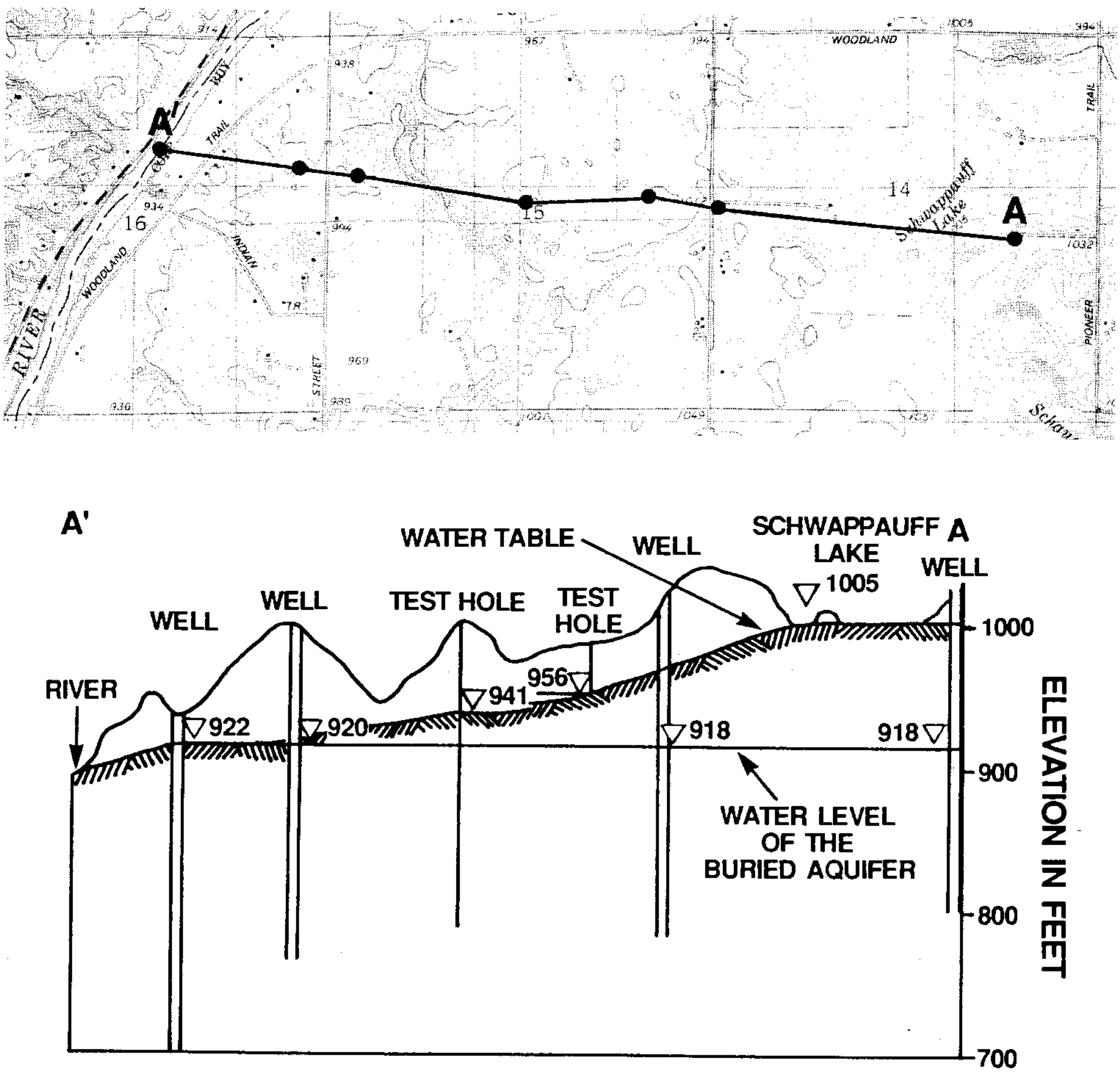


Figure VII-5. Comparison between Water Level Elevations of the Water Table and a Deeper Aquifer in the example area.

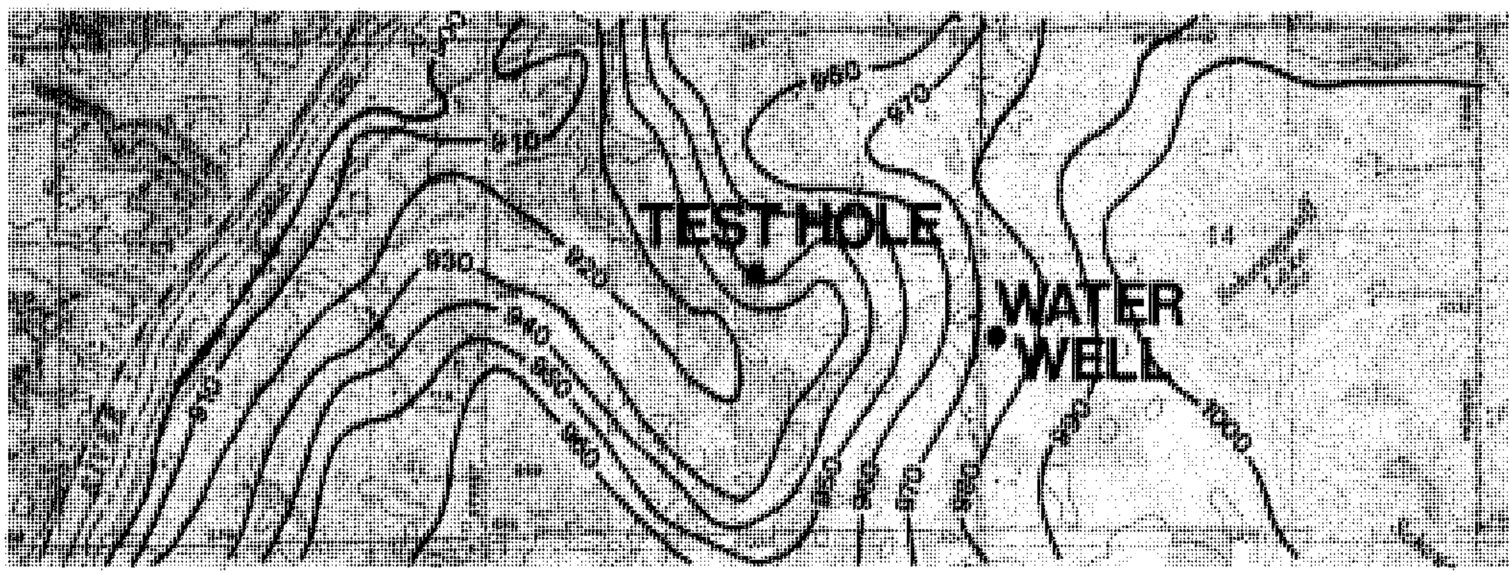
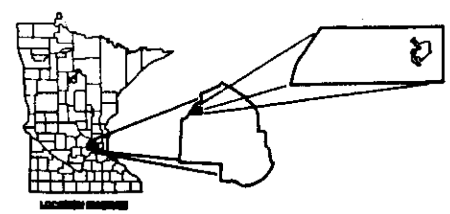


Figure VII-6. Elevation of water table in surficial aquifer of example area. Locations of test hole and water well in Figure VII-2 are shown for reference.



Using the well record to rate the sensitivity of the deeper aquifer produces the same "Very Low" rating as using data from the engineering test hole. However, the very general description of subsurface geologic materials used by the well log results in a much lower rating of L-18 compared to L-5 for the test hole. This demonstrates the need to collect subsurface geologic samples from the drilling of water wells or other boreholes in order to more accurately interpret water well contractor logs. Otherwise, using well records to assess sensitivity of deeper aquifers may result in inaccurate results, particularly in a overly optimistic impression of aquifer protection.

In summary, the principal uses of subsurface data for conducting Level 3 assessments are to determine if aquifer separation occurs and to document site specific conditions. Simply plotting "L" values on a map such as Figure VII-7 does not provide enough information to place boundaries between areas of different Level 3 sensitivities. Geologic mapping is needed to do this because it provides the three dimensional framework of consistent geologic interpretation and correlation between data points. Point source subsurface data are too variable in quality and too limited in distribution to replace geologic mapping.

Geologic Mapping Component - Using Area Data

The most accurate way to conduct a Level 3 assessment throughout an area such as a county is to use geologic maps and data presented in ground water studies. Geologic mapping in particular, provides detailed information on the occurrence, distribution and thickness of confining layers. Usually data from several types of maps such as the surficial geology and bedrock geology must be combined to adequately evaluate deeper aquifers. The county geologic atlas program of the Minnesota Geological Survey (MGS) is a good example of the mapping scale and accuracy of geologic investigations required to adequately assess deeper hydrogeologic conditions throughout a county. A geologic atlas of Hennepin County has been prepared by MGS and will be used to assess the sensitivity of deeper aquifers in the example area.

The benefit of using county-wide mapping is that it includes a much broader interpretation of ground water conditions and can sort out very localized conditions from those that are more widespread. The relationship of the water table to the deeper aquifer along the Crow River in the example area is a good illustration of this. Figure VII-5 shows that a deeper aquifer is present within the glacial deposits below the water table. However, there is insufficient information to determine if this aquifer extends downward to include any bedrock formations or if other aquifers exist beneath it. The glacial hydrogeologic map in the Hennepin County Geologic Atlas shows that hydrologic separation of the water table and the deeper glacial aquifer is present throughout most of the example area except for an area along the river (Figure VII-8). Along the river the water table aquifer and the deeper glacial aquifer are considered interconnected although additional studies should be conducted to confirm this and to more accurately define this area.

The glacial hydrogeologic map of the example area (Figure VII-8) shows the part of the example area where a confining layer separates the deeper aquifer from the water table aquifer. In this area the deeper aquifer can be given at least a "Low" rating because it is confined. However, a "Very Low" rating can be assigned where the confining layer has at least a L-5 score. The surficial geologic map in the Hennepin County Geologic Atlas describes the clay loam till confining layer as being at least 50 feet thick. The discussion of subsurface glacial stratigraphy accompanying the surficial geologic map in the atlas indicates that older, clay-rich till units exist in nearby areas

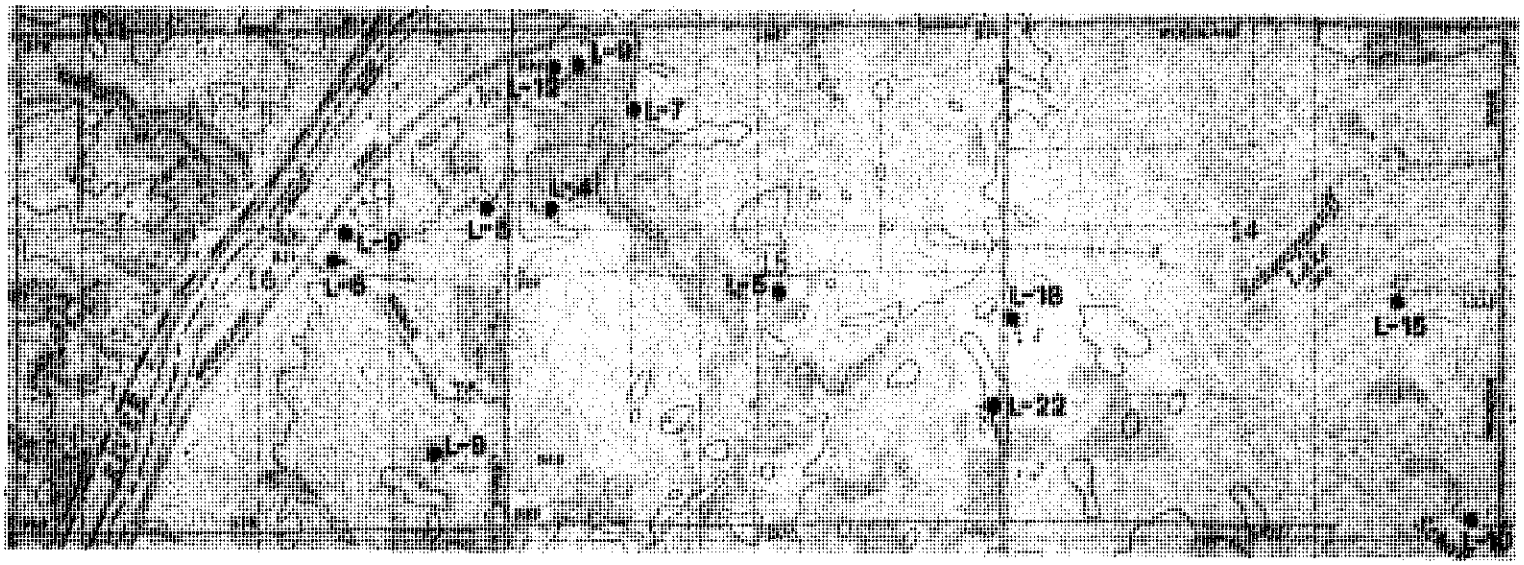
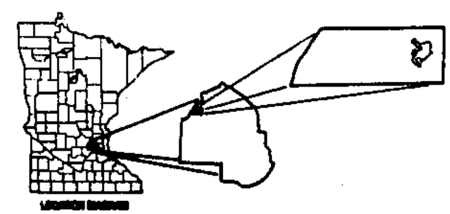


Figure VII-7. "L" values for first confined aquifer in example area.



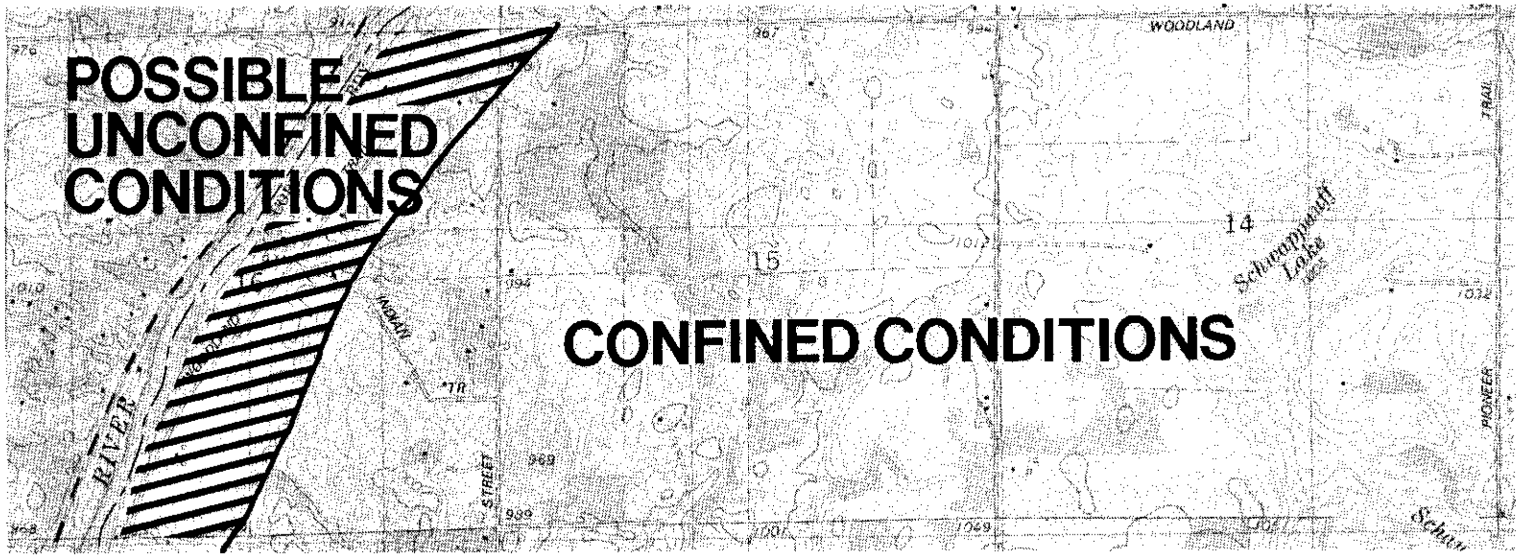
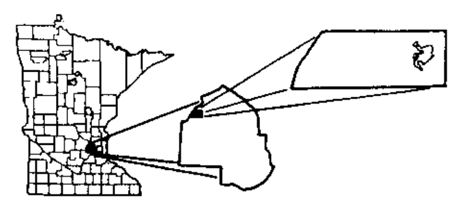
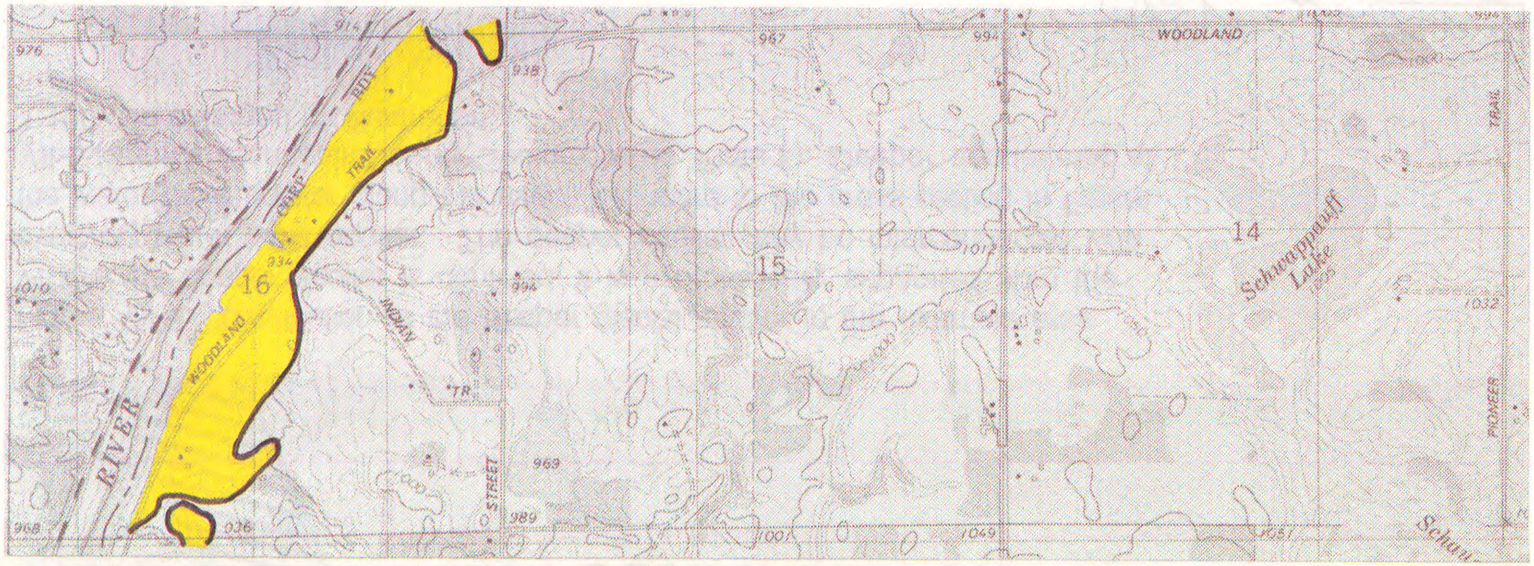


Figure VII-8. Distribution of the deeper glacial aquifer in the example area. Where the deeper aquifer is confined, it is hydrologically separated from the overlying water table aquifer. The deeper aquifer may be interconnected with the water table aquifer along the river. Compare to the cross-section in Figure VII-5 (Source: Hennepin County Geologic Atlas, Plate 5). Deeper aquifer map at 1:100,000 enlarged for illustration.

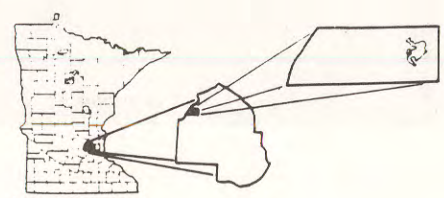




EXPLANATION

- **High** (Level 2 rating)
- **Very Low**

Figure VII-9. Level 3 Sensitivity Assessment for the first deeper aquifer below the water table aquifer.



and are shown on a cross section. The point source subsurface data also indicates their presence. Calculating confining layer scores using the available subsurface data gives confining layer scores that exceed L-5 for all but one site in the northwest quarter of section 15 (Figure VII-7). This site had a score of L-4 but nearby scores are higher. The L-4 score may reflect very site specific conditions or a poor quality well record. The site with the score of L-4 is not considered representative of the example area. With this one exception, a Level 3 sensitivity rating of "Very Low" can be assigned to the deeper glacial aquifer except along the river. Along the river the confining layer present in the rest of the area cannot be confirmed. As a result, the Level 2 sensitivity rating of "High" is used.

The Level 3 sensitivity assessment of the deeper glacial aquifer directly below the water table is shown in Figure VII-9. The deeper glacial aquifer is considered to have a "Very Low" sensitivity rating throughout most of the example area with the exception of the area along the river which is given a "High" sensitivity rating.

The Level 3 assessment of the example area shows the importance of detailed geologic mapping in an assessment area. It also shows the importance of using point source subsurface data to check and supplement area information.

BENEFITS AND LIMITATIONS

A Level 3 assessment can help identify the degree of natural protection afforded to deeper aquifers. This will aid local and State efforts to protect deeper aquifers such as directing State cost sharing for proper sealing of abandoned wells to aquifer settings with low and very low sensitivity ratings. A Level 3 assessment also has a great educational benefit to local residents who are concerned that a deeper aquifer may be contaminated by the siting of a new landfill. Furthermore, a Level 3 assessment can assist State wellhead protection efforts for public supply wells by identifying aquifers least sensitive to contamination. Wells that draw from these aquifers would not require nearly the level of protection from contamination sources as those that draw from sensitive aquifers. Aquifer sensitivity can be used to determine priorities for implementing State wellhead protection efforts.

The accuracy of a Level 3 assessment depends of the quality of the subsurface data and the expertise used to define subsurface hydrogeological conditions. Mapping the geologic sensitivity of deeper aquifers in many areas is not realistic because of the general lack of high quality subsurface data. Water well records provide a general understanding of deeper aquifer conditions but cannot provide the detailed understanding of subsurface geologic conditions that geologic test drilling, geologic mapping, and aquifer testing provide. These studies are needed to prepare accurate sensitivity maps but are time consuming and expensive to conduct.

CHAPTER VIII

SAMPLE AREA - HENNEPIN COUNTY

The previous three chapters described in detail the information required and the procedures used to complete a geologic sensitivity assessment at each of the three assessment levels. This chapter summarizes the assessment process at each level as illustrated by the example area from Hennepin County and compares the results from level to level.

Assessment of geological sensitivity is generally not done in a vacuum; there is usually a purpose for the work involved. Chapter IV discusses the various applications of the three geologic sensitivity assessment levels. Program managers should carefully identify the purpose for which the assessment is needed, the information required, the information available and the time and resources restraints before proceeding. All three assessment levels were completed in the example area, however only one level may be needed in a particular situation.

None of the assessment levels is intended to evaluate the behavior of specific contaminants. If movement of contaminants is a concern, an alternate assessment method should be considered. Appendix D summarizes information for many other empirical assessment methods. In some situations a mathematical model of ground water flow and contaminant transport may be required. Discussion of these models is beyond the scope of this document; an introduction to mathematical models of ground water and contaminant transport can be found in any good hydrogeology text.

ASSESSMENT OF THE WATER TABLE AQUIFER

Level 1 and Level 2 assessments are intended to estimate the geologic sensitivity of the first, or water table, aquifer within a particular area. A Level 1 assessment is a preliminary estimate of the geologic sensitivity using readily available information. A Level 1 assessment assumes the geologic materials identified at the surface is representative of the entire vadose zone. This simplification means a Level 1 assessment is limited in its ability to accurately describe the geologic sensitivity of the water table aquifer.

A Level 2 assessment collects detailed information describing the geologic materials present in the vadose zone. A Level 2 assessment is a better estimate than a Level 1 assessment of the sensitivity of the water table aquifer from contaminants originating at the surface. In contrast to a Level 1 assessment which uses limited surficial information, a Level 2 assessment evaluates the effect of the geologic materials in the entire unsaturated zone upon the time of travel of infiltrating water.

Level 1 - In the Level 1 assessment of the example area from northwest Hennepin County, information from the Hennepin County soil survey was used to prepare a preliminary estimate of geologic sensitivity. Descriptions of each soil map unit found in the example area were examined to determine the parent material, texture and seasonal high water table. Preparation of the Level 1 assessment was simplified by the availability of parent material, texture and water table information from a Soil Conservation Service data base. The rating chart in Figure V-1 was then applied to determine the sensitivity category of each map unit. A Level 1 Sensitivity Map,

Figure V-10 was then prepared. Figure VIII-1(a) is simplified from Figure V-10 by combining a large number of small, irregular areas of "Moderate" and "Low" into a single contiguous unit.

The Level 1 Sensitivity Map for the example area shows three levels of sensitivity. Most of the example area is rated mixed "Moderate" and "Low" sensitivity. About ten per cent of the example area is rated "Very High". No part of the example area is given a "High" or "Very Low" sensitivity rating. A Level 1 assessment is intended to be a conservative estimate of sensitivity, acknowledging the unknowns beneath the surface.

Level 2 - To conduct a Level 2 assessment, the type and distribution of geologic material between the surface and the water table aquifer is evaluated for its effect on the rate of infiltration through the vadose, or unsaturated, zone. A Level 2 assessment can be done two different ways depending on whether a detailed surficial geologic map is available. If a surficial geologic map is not available, subsurface logs can be used to determine the sensitivity rating of individual points. The result of a Level 2 Point Method assessment is shown in Figure VI-5. A Level 2 assessment of the example area using the Point Method is unsatisfactory because subsurface logs are not available for much of the area. Another limitation is that the density of subsurface logs is too low to allow rating of areas; the assessment is restricted to point ratings. When a detailed surficial geologic map is available, the map units can be interpreted and areas can be rated. The Level 2 assessment of the example area required careful interpretation of available vadose zone information whether from logs or from geologic maps. Geologic descriptions and interpretations and preliminary sensitivity ratings were reviewed by the Minnesota Geologic Survey.

Figure VIII-1(b) is the Level 2 (Area Method) assessment for the example area. Comparing the Level 1 and Level 2 assessment maps shows major changes. The geologic sensitivity for most of the area has changed from mixed "Moderate" and "Low" to mostly "Low". The change results from 1) Level 1 criteria being more conservative than Level 2 criteria and 2) different interpretation of representative surficial materials when materials throughout the vadose zone are considered. Note that many of the small "Very High" sensitivity areas around Schwappauff Lake and the pond to the southwest disappear in the Level 2 assessment. These were thin surficial deposits overlying more extensive units. These areas were rated according to the more representative underlying materials. Another change was the enlargement of the "Moderate" area in north-central part of the example area. The surficial geologic map identified sandy till there instead of the till present elsewhere. Sandy till has greater permeability than till so a "Moderate" rating was assigned to this area.

ASSESSMENT OF DEEPER AQUIFERS

The Level 3 assessment is designed to look "beneath" the water table aquifer. A Level 3 assessment identifies the presence of confining layers and evaluates the degree of protection such layers provide. A Level 3 assessment is indicated when a decision needs to be made that may affect deeper aquifers.

Completion of either a Level 1 or Level 2 assessment is not necessary in order to conduct a Level 3 assessment. However, some of the same information collected to complete a water table aquifer assessment, such as well logs, may be used to assess deeper aquifers.

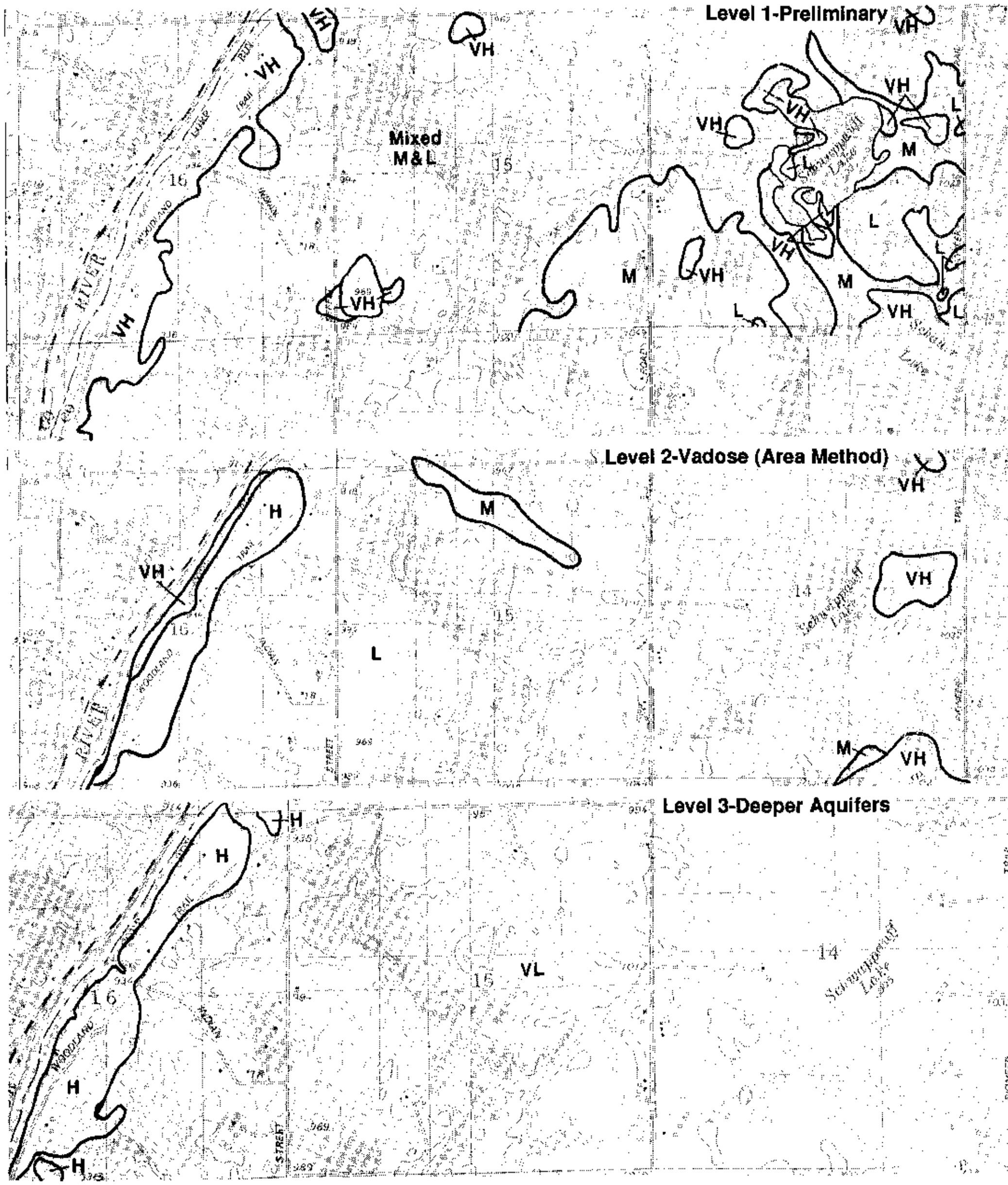


Figure VIII-1. Comparison of geologic sensitivity assessments for example area.

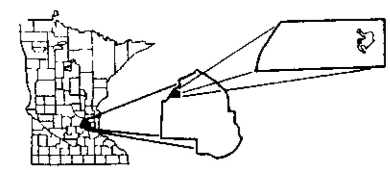
a) Level 1-Preliminary. The preliminary geologic sensitivity assessment of the example area based on available information rates most of the area as mixed "Moderate" and "Low". There is a strip of "Very High" sensitivity along the Crow River. Smaller areas of "Very High" sensitivity can be seen on the edges of Schwappauff Lake and the small pond in the southwest corner of Section 15. According to Figure V-9, the soil parent materials map, most of the soils in the example area formed in glacial till. The soils along the Crow River formed in sands and gravels. The very small "Very High" areas on the edges of surface waters represent surficial organic material or sandy deposits. A Level 1-Preliminary geologic sensitivity assessment is the minimum assessment level recommended for activities listed in Table IV-1.

b) Level 2-Vadose Zone. Using a surficial geologic map for the example area (Figure VI-6), a Level 2 (Area Method) geologic sensitivity assessment shows a major change from the Level 1 Preliminary assessment. Most of the example area is now rated "Low". The strip along the Crow River rated "Very High" in Level 1 is now rated "High" except for a thin strip next to the river where the water table is shallow. The "Very High" areas on the edges of Schwappauff Lake and Schauer Lake represent organic deposits in a marsh. A more representative evaluation of the geologic sensitivity in the example area, a Level 2 geologic sensitivity assessment is the recommended preferred assessment for most activities listed in Table IV-1.

c) Level 3-Deeper Aquifers. A Level 3 assessment evaluates the vulnerability of aquifers below the water table aquifer. By definition, a deeper aquifer must be protected by a laterally persistent confining layer. If the confining layer is thick enough, the area may be rated even lower. In the example area, a thick clay unit protects the underlying sand/gravel aquifer allowing a "Very Low" rating. Along the Crow River, the lower sand/gravel aquifer may not be confined; since a deeper aquifer may not exist, the Level 2 assessment is applied. A Level 3 assessment is recommended for relatively few activities listed in Table IV-1; a Level 3 assessment is indicated when toxic substances, deep excavation and well protection is under consideration.

Explanation

VH=Very High
H=High
M=Moderate
L=Low
VL=Very Low



Level 3 - Assessment of deeper aquifer in the example area from northwest Hennepin County required collection and detailed review of all data which describe deeper subsurface conditions. Data such as well records and drill logs were examined to determine the presence of a confining layer beneath the water table aquifer. The surficial geology and surficial hydrogeology as mapped by the Hennepin County Geologic Atlas was also studied. Analysis of this information revealed a thick confining layer of till and a deeper sand and gravel aquifer underlying the till beneath most of the example area except for a strip along the Crow River. In this area, the confining till layer could not be confirmed. As shown in Figure VIII-1(c) the thick confining layer permits a Level 3 sensitivity rating of "Very Low" for the first deep aquifer below the water table aquifer. Along the river, where a confining layer above the deeper aquifer was not confirmed, a Level 3 assessment was not possible. Instead, the Level 2 rating of "High" for the water table aquifer was transferred to the Level 3 map and assigned to the deeper glacial materials.

SUMMARY

The geologic sensitivity assessment conducted in the example area in Hennepin County shows the area does not have a single geologic sensitivity. The example area was rated mixed "Moderate" and "Low" when a Level 1 assessment is conducted. A Level 2 assessment rated the area mostly "Low". Beneath the water table aquifer is a deeper sand and gravel aquifer protected by a confining till unit. A Level 3 assessment rates the vulnerability of the deeper aquifer in this area as "Very Low".

Referring back to Chapter III in which the definition of geologic sensitivity was introduced in Table III-1, the estimated travel times of contaminants vary from location to location and from aquifer to aquifer within the example area. Depending on the location, contaminants are estimated to reach the water table either very quickly, perhaps in a few hours, or after several decades. The protection provided by a confining to a lower aquifer extends the estimated time of travel of a contaminant to over a century. The actual times of travel are not yet known, but could be determined using various hydrogeological tools, such as age dating, as described Chapter IX.

The multiple assessment levels were designed to provide a degree of flexibility when conducting geologic sensitivity assessments. However, some confusion may be possible if the results of assessments are misunderstood or applied inappropriately. Users of assessment results must verify which level of assessment has been prepared. Suggested uses and recommended assessment levels for various activities were discussed in Chapter IV.

CHAPTER IX

ADDITIONAL STUDIES

INTRODUCTION

The ground water sensitivity guidelines in this report are based on general considerations of how water travels through soil and geologic materials. They have not yet been rigorously tested in actual practice. The ratings are in any case relative; they are based on estimated travel time of a contaminant that behaves like water from the surface to an aquifer of concern, either the water table aquifer or a deeper aquifer. Areas rated High and Very High are estimated to have rapid infiltration from the surface to the water table, on the order of a few hours to a few years. In areas rated Low, on the other hand, the infiltration should take decades at least, perhaps centuries. Implicit in this rating system is the idea that water-borne pollutants will eventually reach the ground water.

This is not to say that all areas are equal, even in the long run. An area of Low sensitivity which is subjected to a local, one-time impact such as an oil spill will probably transmit very little contaminated water, if the normal recharge through the area is unpolluted. In fact, even if the water recharging an area of Low sensitivity is consistently polluted, the polluted recharge waters will constitute only a small proportion of the total recharge to an aquifer. Therefore, if the areas of higher sensitivity (i.e., higher recharge) are kept clean, the aquifer will remain fairly clean.

TESTING THE AQUIFER

It is difficult to directly test the validity of the ratings presented here. It is easier to test their validity indirectly, by testing water samples from aquifers. Several tests can be grouped under two main categories: 1) residence time and 2) water quality. Studies of residence time can determine when the water entered the ground. Water quality tests can determine whether, and how much, the water has actually been polluted.

Radioactive isotopes can be used to study residence time. Tritium is a radioactive isotope of hydrogen which decays naturally to deuterium, a nonradioactive isotope of hydrogen. The half-life of tritium is 12.5 years. Tritium was very rare in the environment until the era of atmospheric testing of nuclear weapons; its concentration in the atmosphere jumped sharply in 1953 and peaked in the 1960's. Water which entered the ground prior to the atomic era contains little or no tritium. Water which contains some tritium thus includes at least a portion which entered the ground during the last 35 years, roughly. This is the same period in which Minnesota ground water has been affected by chemical fertilizers, pesticides, pipeline spills, and sanitary landfills. Water which contains no tritium is thus less likely to contain pollutants, with the exception of some sources of pollutants that have existed for a much longer time, such as septic tank effluent and animal manure.

Radiocarbon dating is also used to determine residence time of ground water. Carbon-14 is a radioactive isotope of carbon, produced in the upper atmosphere. Like tritium, it has no source underground. It enters the ground via dissolved carbon dioxide, and gradually decays once out of contact with the atmosphere. The practical limit of dating is about 40,000 years, much older than is the case with tritium. So radiocarbon can distinguish between water that is really old, e.g., 10,000 years, and water which is only marginally old, such as 150 years. Water which entered the ground prior to the advent of European settlement, about 150 years ago, is very unlikely to be polluted. However, water with a nominal age of 150 years may be a mixture of older and younger water, and thus could contain a polluted component. An age date is only approximate, and the age of water pumped from an aquifer may change over time, as younger (or older) water is drawn in from other areas. Figure IX-1 shows the time range for tritium and carbon-14 studies relative to the time ranges for the sensitivity ratings.

Radioactive isotope tests of ground water are rather expensive, about $150 for tritium and about $200 for radiocarbon. Radiocarbon samples are also labor-intensive, because the carbon must be precipitated from a large volume of water which has been kept out of contact with the atmosphere. Radioactive isotope tests are more suited to general studies of an area or an aquifer than to studies of individual water supplies. Waters determined to be "young" are not necessarily contaminated. However, young waters are at higher risk of contamination than older water.

Water quality tests can show the presence of specific pollutants, and their concentrations. Water quality analyses vary considerably, depending on the goal of the analysis program. Bacteria and nitrate tests are commonly done by county and state health departments. These tests are fairly routine and cheap, and give a direct rating of health risk from drinking the water. Fecal coliform bacteria indicate pollution by human waste or animal manure. This test indicates a route from waste source to water supply, with little or no filtration through soil. This sort of contamination is common to sensitive aquifers, such as in karst areas, where water can pass from the surface to the water table through sinkholes and solution enlarged joints. But coliform bacteria can also enter aquifers through improperly constructed wells.

Much more common than bacterial contamination is a high level of dissolved nitrates. Nitrates are derived from septic tanks, feedlots, sewage lagoons, etc., and from fertilizer in excess of plant needs. Unlike bacteria, nitrates cannot be filtered out by passage through soil, nor can they be rendered harmless by boiling. "Natural" ground water normally contains less than 1 part per million of nitrate-nitrogen; drinking water standards require less than 10 parts per million. Ground water with detectable nitrates is common in parts of southeastern Minnesota and is sporadically present in other parts of the state, especially in unconfined sand-plain aquifers such as those north of the Twin Cities metropolitan area.

Water may also be tested for specific chemicals such as atrazine (a herbicide), or any chemical whose presence may be suspected in a given area. Herbicides, insecticides, solvents and petroleum-derived chemicals are derived from human activity at or near the land surface. Sulfate and chloride ions may be dissolved from minerals in the ground. However, in areas where natural chloride levels are low, elevated chloride may be an indicator of surface pollution such as road salt and water softener effluent.

Figure IX-2 shows the relationship between water quality and relative sensitivity of two aquifers in southeastern Minnesota. The Galena limestone forms the upper aquifer; it is protected from surface contamination only by thin glacial deposits. Once contaminants enter the rock, they spread rapidly through a system of solution-enlarged joints. Thus, the sensitivity of the Galena in this area is rated High. Water from the well shown is young, and high in nitrates.

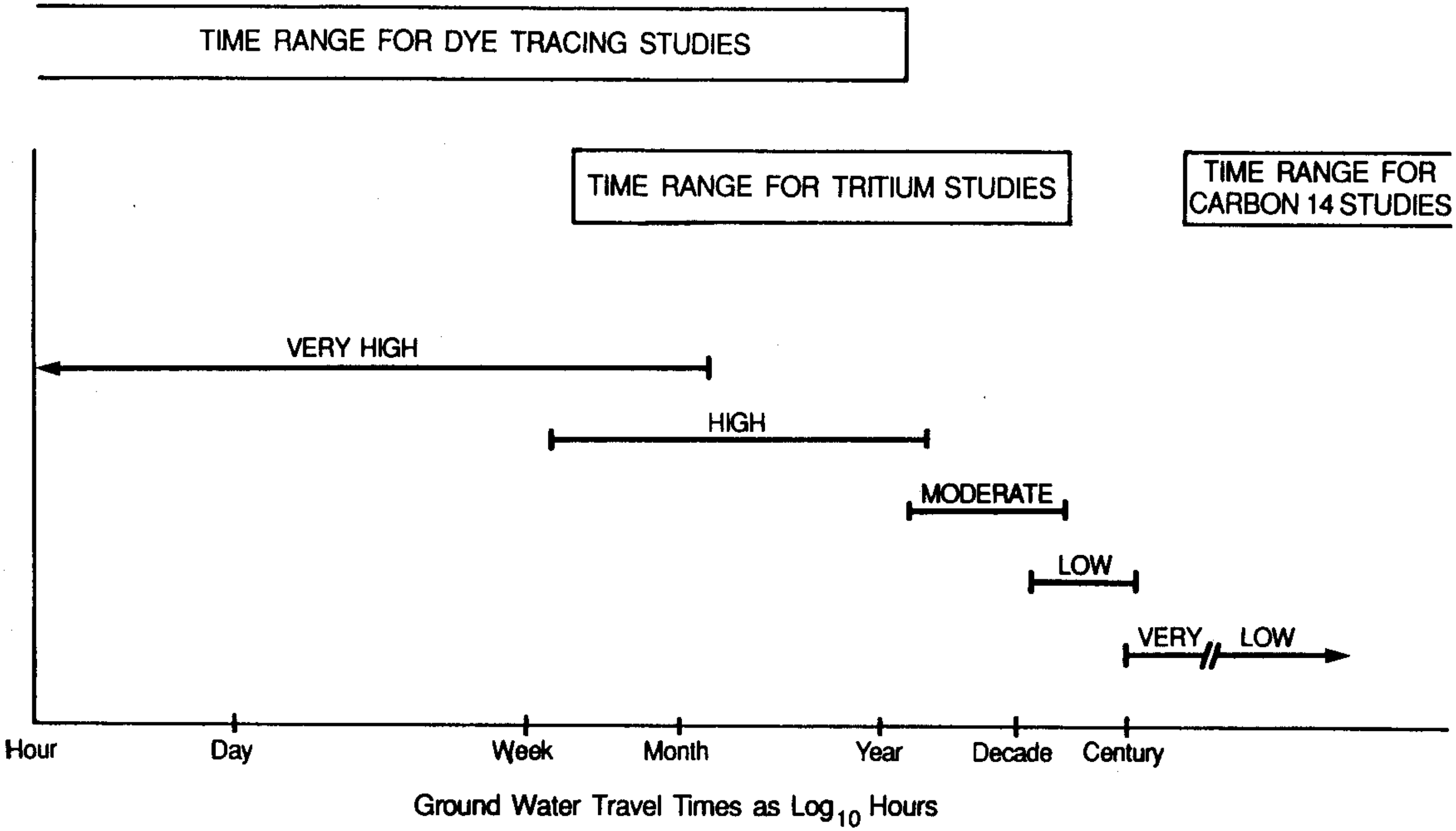
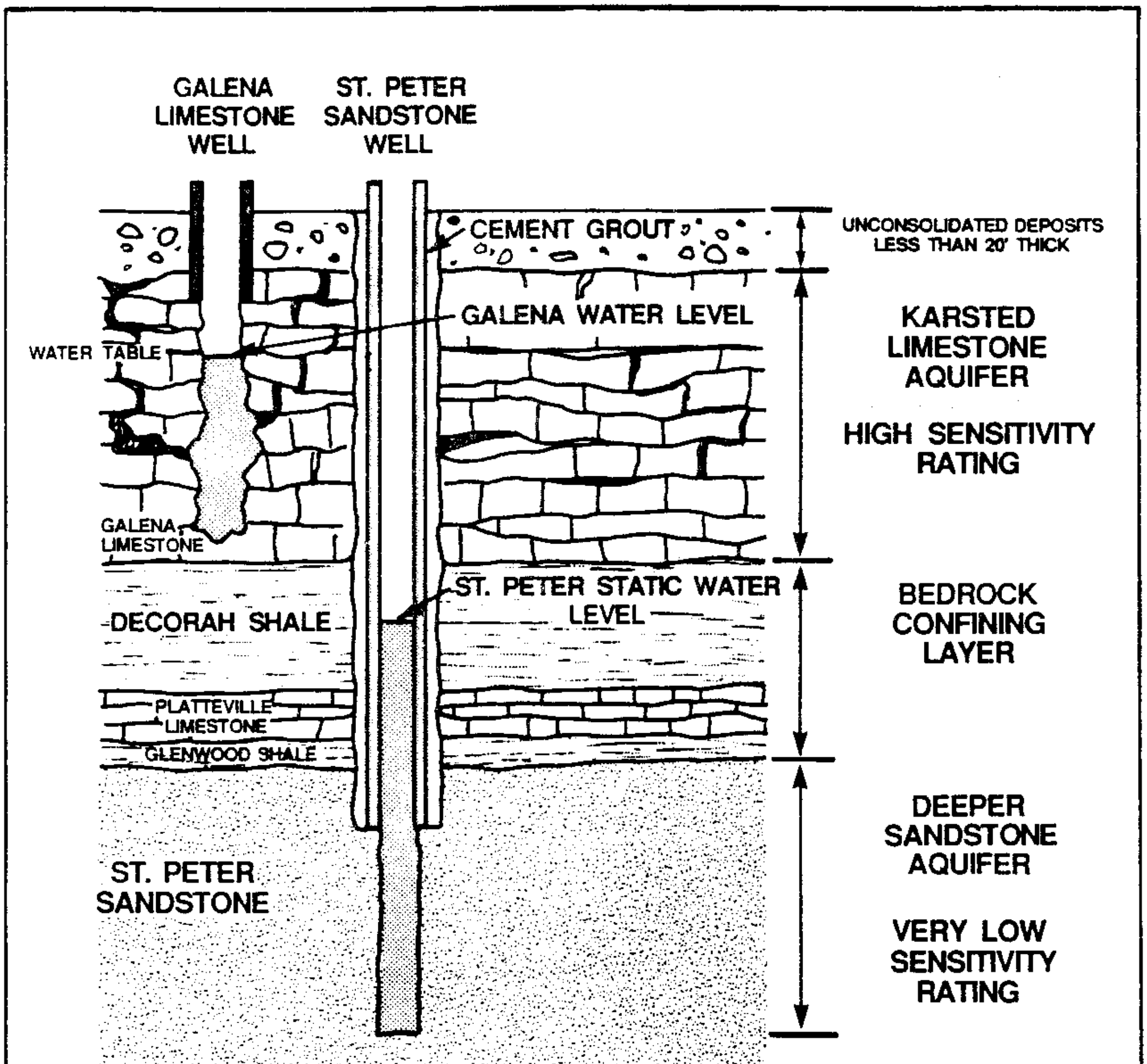


Figure IX-I. Geologic Sensitivity ratings and ground water travel times. Upper bars show time ranges for dye tracing, tritium and C14 studies.



	GALENA WELL	ST. PETER WELL
AQUIFER SETTING	WATER TABLE	BURIED ARTESIAN
NITRATE LEVEL	>10ppm	<1ppm
TRITIUM "AGE"	<30 YEARS	OLD
CARBON 14 "AGE"	YOUNG	ABOUT 2000 YEARS
SENSITIVITY RATING	HIGH	VERY LOW

Figure IX-2. Differences in Aquifer Sensitivity and Water Chemistry in Southwestern Olmsted County, Minnesota.

A nearby well is cased and grouted into the St. Peter sandstone. Water from the Galena cannot enter this well. The two aquifers are separated by a confining layer comprised of two shales and a limestone, totalling 70 feet in thickness. The effectiveness of the confining layer can be shown by the large head difference between the two aquifers of almost 100 feet. The sensitivity of the St. Peter aquifer in this area is rated Very Low. Water tests support this rating: nitrates are undetectable, and the nominal radiocarbon age is 2000 years.

The situation pictured is straightforward. But lateral flow in aquifers may introduce complications where the water quality in a well may not match the rated sensitivity of the aquifer in that area. For example, pollutants could enter the St. Peter through a sand-filled bedrock valley which cuts through the confining layer, or through a multi-aquifer well. For this reason, any map based on these guidelines must be considered tentative, not definitive.

TESTING THE SENSITIVITY RATINGS

How may these various water tests be used to test and refine the sensitivity guidelines? In some cases, the correlation is simple, as shown in Figure IX-2. Surface aquifers in areas rated High and Very High are predicted to have water which contains tritium, at least in the upper part of the aquifer. Nitrates are likely to be high if the surface is used for farming or suburban housing with septic tanks but not if the surface is mostly forested. Coliform bacteria in the water would confirm a rating of Very High, at least if the well sampled is properly constructed, but lack of coliform bacteria does not confirm a lower rating because a source may not be present. Other chemicals are expected to be found in the water, in some relationship to the chemicals locally in use.

Confirming a High rating is fairly straightforward, because most of the water in the surface aquifer percolated down from the land above it. Confirming a Low or Moderate rating is more difficult, because the ground water in such areas is likely to have infiltrated from another area and moved laterally below the surface. Some knowledge of ground water flow is necessary in order to evaluate this. It does not automatically follow that ground water in an area rated Low is old, or that it contains no nitrates. If it <u>is</u> old, it will tend to confirm the rating, but a finding of young polluted water does not disprove a Low rating. The ratings apply to the surface, not to the aquifer. That is, they rate the time for surface contaminants at a given point to reach the aquifer in question, not the residence time of water in the aquifer at that point.

The best way to resolve these complications and uncertainties is to plot the results of a large number of water quality samples on a sensitivity map. The data points should be color-coded into water-table aquifer and confined-aquifer groups, where information is available. Confined-aquifer data should not be used to test the sensitivity of the water table. A perfect correlation should not be expected, but the general trend of water quality should follow the general trend of sensitivity mapping. Major discrepancies should be investigated to determine the cause. Possible reasons for low nitrates in an area mapped high include: lack of sources at the surface, unrecognized confining zones, or nitrates may simply have not yet migrated from the water table to the well screen. High nitrates in areas mapped low may have infiltrated through unmapped inclusions of high sensitivity or improperly constructed wells, or may have flowed laterally from areas of higher sensitivity. Major unresolved discrepancies indicate that something is wrong with the sensitivity map. There may be too little data to properly map the area, or the data may be poor-quality and/or improperly interpreted or the underlying guidelines may be faulty.

Deeper aquifers may be tested in the same manner as the water table aquifer. The sensitivity map must be specially constructed for the deeper aquifer because the map constructed for the water table does not take into account additional protection between the water table and the deeper aquifer. Only samples drawn from the aquifer should be used to test the sensitivity map.

A point to remember when checking the ratings against water quality data is that areas rated High or Very High will have a disproportionate influence on the "average" pollution sensitivity of an area. If other ratings remain almost the same, the doubling of the area of High from 10% to 20% will almost double the real aggregate sensitivity of the whole area. On the other hand, the doubling of the area of Low under the same conditions will have little effect. Similarly, an area which is rated 50% High and 50% Low will have a much higher real sensitivity than an area rated moderate throughout. Another factor to keep in mind is that people are more likely to have their water tested if they suspect it may be contaminated than if they feel it is good. This may bias the nitrate data towards higher sensitivity wells. Thus, in a given area, water samples may show higher nitrate values than would be shown in a strictly random sample.

Computer models of ground water flow have been constructed by the U.S. Geological Survey for parts of Minnesota. They may assist interpretation of the water-quality data and residence time studies and compare those data to the sensitivity maps. Computer models require large amounts of high-quality data in order to work well. Where data do not exist, approximations must be made. One of the greatest limitations of ground water flow models is the data, not the model itself. And the same is true of these guidelines.

There is a considerable amount of ongoing research, in Minnesota and elsewhere, on the movement of various chemicals through the soil and into the ground water, such as the movement of nitrogen fertilizers and pesticides in different soils and geologic settings. The results of these studies should help test the guidelines, but these studies are of specific contaminants, while the guidelines were deliberately written to not be contaminant-specific.

It is clear that sensitivity assessments cannot be exhaustively tested and confirmed in all particulars. But it is feasible to check on the general reliability and comparability of the ratings scheme. Tritium and radiocarbon can sometimes be used to estimate residence time of the water. Tests for nitrate and other contaminants can be used to estimate the actual extent of pollution.

APPENDIX A

GLOSSARY

GLOSSARY

ALLUVIUM - material deposited by streams and rivers.

AQUIFER - geologic material capable of yielding a useable quantity of water to a well.

ARTESIAN AQUIFER - see CONFINED AQUIFER

ARTESIAN PRESSURE - the pressure exerted by water in a confined aquifer that will raise the water level in a well above the top of the aquifer.

BEDROCK - solid rock. See also CONSOLIDATED DEPOSITS.

BMP - Best Management Practice

COLLUVIUM - loose deposits at the foot of slopes and cliffs.

CONFINED AQUIFER - an aquifer which is completely saturated, is overlain by a confining layer and is under artesian pressure.

CONFINING LAYER - a geologic unit of low permeability.

CONSOLIDATED DEPOSITS - firm and coherent earth materials; cemented sediments.

DNR - Minnesota Department of Natural Resources

DRAWDOWN - the lowering of ground water level (head) caused by pumping a well.

DRIFT (glacial) - any rock debris, such as boulders, till, gravel, sand or clay, transported and deposited by ice or meltwater.

EAW - Environmental Assessment Worksheet

EIS - Environmental Impact Statement

FLUVIAL - produced by river action.

GROUND WATER - water in the saturated zone.

HEAD - height of water in a well above a specific measuring point. - see also POTENTIOMETRIC SURFACE

LCMR - Legislative Commission on Minnesota Resources

LOESS - silt-sized material deposited by the wind.

MGS - Minnesota Geological Survey

NPDES - National Pollutant Discharge Elimination System

OUTWASH - stratified sandy sediment deposited by glacial meltwater streams.

PEDOLOGIC SOIL - the material making up the soil profile, from the land surface to a depth of about six feet.

PIEZOMETER - an observation well.

PIEZOMETRIC SURFACE - the surface to which water from a given aquifer will rise in a well. - see also POTENTIOMETRIC SURFACE

PERCHED WATER - ground water that is not part of a water table aquifer because unsaturated materials occur beneath it. Generally isolated areas above a continuous water table.

PERMEABILITY - a measure of the relative ease with which water can move through a geologic material.

POROSITY - the percentage of void space in a geologic material.

POTENTIOMETRIC SURFACE - the surface representative of the static water level in a well cased into a single aquifer.

RIM - Reinvest in Minnesota

SATURATED ZONE - the portion of the subsurface in which all voids and cracks in geologic materials are completely filled with water.

SDS - State Disposal System

SOIL - earth material modified by natural physical, chemical and biological agents and capable of supporting the growth of plants.

SOIL HORIZON - a layer of soil material that is different from other layers by characteristic properties such as structure, color or texture.

STATIC WATER LEVEL - the level to which water will rise in an unpumped well that is open to a single aquifer.

TILL - unsorted sediment deposited by a glacier. - see also DRIFT

UNCONFINED AQUIFER - an aquifer in which the upper portion is unsaturated or which is saturated but under less than artesian pressure.

UNSATURATED ZONE - zone above the water table where voids and cracks are not completely filled with water.

UNCONSOLIDATED DEPOSITS - loose material overlying bedrock. Includes soil, glacial deposits, stream sediments, windblown deposits, weathered bedrock, and organic deposits.

USGS - United States Geological Survey

VADOSE ZONE - see UNSATURATED ZONE.

WATER TABLE - the surface separating the unsaturated and saturated zones.

WATER TABLE AQUIFER - the uppermost aquifer which has a water table; more generally, an unconfined aquifer..

APPENDIX B

SOURCES OF SUBSURFACE GEOLOGIC INFORMATION

SOURCES OF SUBSURFACE GEOLOGIC INFORMATION

Subsurface geologic information is the basis for assessing the susceptibility of ground water to contamination. There are various types of information describing subsurface conditions, ranging from detailed maps and reports to uninterpreted records of water wells and borings.

PUBLISHED REPORTS AND MAPS

The state is covered in varying degrees of detail by published reports and maps, depending on the level of detail and coverage of the various investigative and mapping efforts. The degree to which these reports are useful depends on the scale and detail of the questions being asked of them. Soil atlases and county soil surveys cover the entire state, but are concerned with only the upper 5-6 feet of the earth's surface. Geologic and hydrogeologic maps of Minnesota at various scales are available from the Minnesota Geological Survey (MGS). Hydrologic Atlases published by the U.S. Geological Survey (USGS) provide statewide coverage and are useful for establishing the general hydrogeologic setting for the area to be assessed. Other sources include MGS county atlases and USGS reports including Water Resources Investigations, Water Supply Papers, and Open-File Reports. Additional information can be found in studies conducted by state agencies, colleges and universities, and consulting firms. The coverage across the state is by these reports is uneven.

The "Minnesota Ground Water Bibliography" published by the Department of Natural Resources(DNR) in 1989 is a useful guide to published reports and maps. The Minnesota Geological Survey "List of Publications in Print" is also useful.

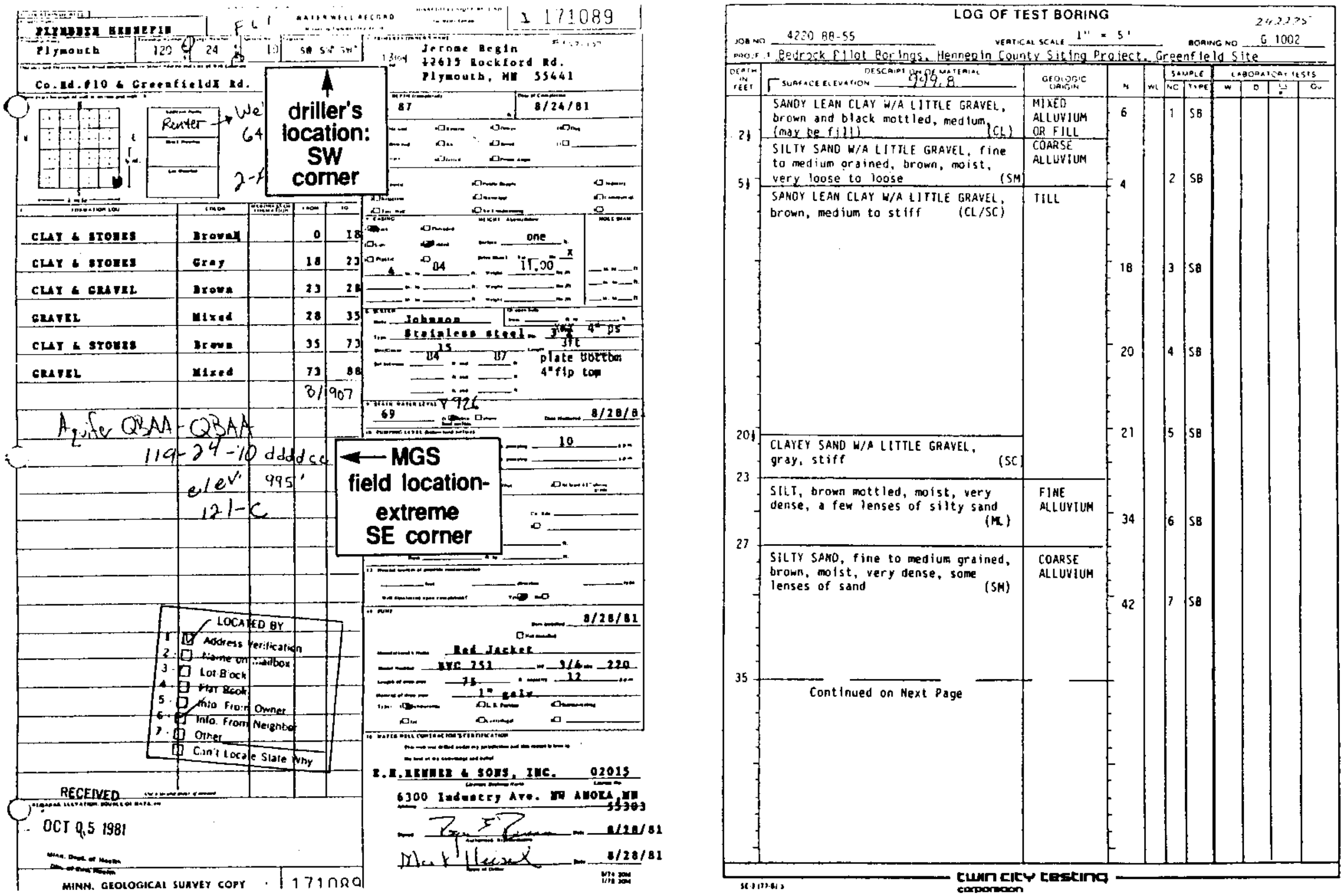
WELL RECORDS AND BORING LOGS

Records from water wells and test borings are the most important and basic source of subsurface geologic information for the state.

Water well records - Since 1975 water well contractors have been required to submit to the Minnesota Department of Health (MDH) a record (driller's log) for each well drilled. MDH then distributes copies to other agencies including DNR and MGS. An example of a water well record from Greenfield township in Hennepin County is shown in Figure B-1.

The location and geologic information contained in water well records range in quality from very good to poor. The MGS is responsible for organizing and interpreting water well records as part of state efforts to develop a ground water information system. In addition, the MGS is the lead agency for organizing the state's water well record library. A portion of the records on file at MGS have been field-located and interpreted by geologists, and are likely to portray the geology accurately. Other records which have not been field-located and geologically interpreted may have questionable accuracy.

Water well records suitable for assessing geologic sensitivity should have their location verified and the geological and hydrologic information interpreted. Field located well



WATER WELL RECORD — 171089

PLYMOUTH HENNEPIN
Plymouth 120 24 10 SW SW SW
Co. Rd. #10 & Greenfield Rd.
Jerome Begin
12615 Rockford Rd.
Plymouth, MN 55441
87 — 8/24/81

Formation	Color	From	To
CLAY & STONES	Brown	0	18
CLAY & STONES	Gray	18	23
CLAY & GRAVEL	Brown	23	28
GRAVEL	Mixed	28	35
CLAY & STONES	Brown	35	73
GRAVEL	Mixed	73	88

Aquifer QBAA - QBAA
119-24-10 ddddcc
elev 995'
121-C

Johnson
Stainless steel
plate bottom
4" flip top
69 — 8/28/81
Red Jacket
8/28/81

LOCATED BY
1. Address Verification
2. Name on Mailbox
3. Lot Block
4. Plat Book
5. Info. From Owner
6. Info. From Neighbor
7. Other
Can't Locate State Why

E.H. RENNER & SONS, INC. 02015
6300 Industry Ave. NW ANOKA, MN 55303
8/28/81
8/28/81

RECEIVED OCT 05 1981

MINN. GEOLOGICAL SURVEY COPY 171089

LOG OF TEST BORING

JOB NO 4220 88-55 VERTICAL SCALE 1" = 5' BORING NO G 1002
PROJECT Bedrock Pilot Borings, Hennepin County Siting Project, Greenfield Site
SURFACE ELEVATION 999.8

Depth in feet	Description of material	Geologic origin	N	Sample No	Type
2½	SANDY LEAN CLAY W/A LITTLE GRAVEL, brown and black mottled, medium, (may be fill) (CL)	MIXED ALLUVIUM OR FILL	6	1	SB
5½	SILTY SAND W/A LITTLE GRAVEL, fine to medium grained, brown, moist, very loose to loose (SM)	COARSE ALLUVIUM	4	2	SB
20½	SANDY LEAN CLAY W/A LITTLE GRAVEL, brown, medium to stiff (CL/SC)	TILL	18	3	SB
			20	4	SB
23	CLAYEY SAND W/A LITTLE GRAVEL, gray, stiff (SC)		21	5	SB
27	SILT, brown mottled, moist, very dense, a few lenses of silty sand (ML)	FINE ALLUVIUM	34	6	SB
35	SILTY SAND, fine to medium grained, brown, moist, very dense, some lenses of sand (SM)	COARSE ALLUVIUM	42	7	SB

Continued on Next Page

twin city testing corporation

Figure B-1: Comparison of Water Well Record (Driller's Log) to nearby engineering test boring. Note difference in level of detail. Also note MGS field location versus driller's location.

records have been plotted on 7.5 minute topographic quadrangles or more detailed maps such as housing subdivision plats. The MGS should be contacted for advice on locating and interpreting well record data. Interpreted water well records are available for many counties and are filed either manually or on a computer data base. Unlocated well logs can be used, but the user must verify their locations. This is a time consuming process.

As an example of the types of problems that result from unlocated well logs, the water well record in Figure B-1 was incorrectly located by the driller as being in the extreme southwest corner of section 10. Field location showed it to be in the extreme southeast corner. Without the additional field location effort by the MGS, the well location and any interpretations based on it would be in error by nearly a mile.

Many water well records list very brief descriptions of the material overlying bedrock. In Figure B-2, it is not possible to determine the texture of the vadose zone material or the presence of low permeability units because it is located within the zone labeled as "drift." Drift is a collective term used to describe all unconsolidated deposits left by glaciers. The term "drift" is too general to use to identify texture or permeability. The conclusion one should reach about such a well log is that it does not contain enough information to identify vadose zone materials for a Level 2 assessment. Vague terminology makes many well records useless for Level 2 or 3 assessments.

FIGURE B-2. Well log of a bedrock well.

UNIQUE NO.: 207284
WELL NAME: INVER GROVE HTS. NO. 3
LOCATION: TOWNSHIP 27 NORTH, RANGE 23 WEST, SECTION 3, CCBCCA
ELEVATION: 855 FT. **WATER LEVEL:** 132 FT.
DEPTH: 407 FT. **DATE:** 70/02/27
COMPLETED: 70/02/27 **AQUIFER(S):** JORDAN

From	To	Description
0	145	DRIFT
145	150	SANDSTONE
150	307	DOLOMITE
307	407	SANDSTONE

Descriptions of geologic material vary in quality from driller to driller. Soil and engineering terms such as "loam" and "silt" are not generally used by water well drillers. "Clay" has a wide range of meanings; it may be clay in the geological sense, or it may describe silt or loam containing as little as ten per cent clay.

Test boring logs - Various types of test drilling also provide valuable information about subsurface and hydrogeologic conditions. For example, the Minnesota Department of Transportation has many engineering test boring records acquired from road and bridge construction projects. Test boring records can be obtained for other types of construction projects from private consultants. Environmental borehole and monitoring well records from landfills and other types of environmental assessments are another source of data. Figure B-1 shows a record from test boring which is within a few hundred feet of the water well discussed earlier. Notice the difference between them in the level of detail used to describe subsurface geologic materials.

ASSESSING DATA COVERAGE

If little or no subsurface data are available or vague terms are used to describe the subsurface materials, it may not be possible to complete a Level 2 or Level 3 assessment. Unfortunately there are no set rules to define the amount of data that should be collected in order to have "enough." Data needs are dependent on the purpose for which the assessment is being prepared, the scale of the area being assessed and the complexity of local hydrogeologic conditions.

A Level 1 assessment using soil parent materials information can be used as a guide to evaluate the complexity. Large areas with the same parent material indicate relatively simple geology, at least near the surface. On the other hand, an intricate pattern of soil parent materials could indicate a complex setting. Also, if the subsurface data and soil parent materials map are in general agreement, the soil parent materials information can be used to fill in the data deficient areas. When subsurface conditions can be predicted by correlating other data points, the data coverage is probably adequate. If, however, the geologic setting appears to be complex, as indicated by a wide variety of geologic materials within a relatively small area, estimating the geology from soil parent materials becomes difficult. Most areas will not have enough data to map strictly by data points; geological interpretation will be necessary. The experienced geologist may interpret aerial photographs and topographic maps to identify landforms and infer geologic history to extrapolate available data points. Unfortunately, extrapolation of existing data may produce unreliable results. In this case, collection of additional subsurface data are required to complete a reliable evaluation of geologic sensitivity.

APPENDIX C

WORKING WITH MAPS

WORKING WITH MAPS

A map is a representation or abstraction of a portion of the world. A map is also a way of organizing information. A map never shows all the information or detail that an observer might actually see. Map makers must choose which information to show within the limited confines of a map. Much of the detail and complexity of the world must be simplified for clarity. This means a map is really an interpretation of a selected set of information describing the world.

Mapping projects start with choosing or making an appropriate map base. The choice is a balancing of a number of factors, including purpose, availability of various map bases, cost, reliability, the information that will be organized on the map, and how different maps will work together.

MAP SCALES

Maps are constructed in different proportions, or scales, to the world. A scale of 1:2 means that one measurement unit on the map equals two measurement units on the ground. The units of measurement can be anything, as long as the same "yardstick" is used for both the map and on the ground. In Table C-1, several different map scales are listed. A scale of 1:100,000 means that one inch on the map represents 100,000 inches on the ground. For convenience, 100,000 inches is normally converted into another unit that may be easier to work with. For example, 100,000 inches is the same as about 1 1/2 miles.

Different map scales may be more suitable for different purposes. A state road map, for instance, would not be much help when designing a neighborhood traffic plan. It is important to match the need to the right map with the most suitable scale. Table C-1 shows several common map scales and their suggested uses. The map scale of 1:100,000 is used by the Minnesota Geological Survey in the County Geologic Atlas program. The 1:24,000 topographic maps prepared by the U.S. Geological Survey are useful for many local-scale activities, including city, township and watershed planning. For many of the activities listed earlier in Table IV-1, one of the map scales listed in Table C-1 could be considered.

Table C-1. Suggested map scales and applications.

Map scales	Suggested Uses
1:200,000	Regional planning
1:100,000	County-wide planning
1:24,000	Local planning

Commonly, maps from different sources prepared at different scales must be combined to produce the desired map. Maps may need to be reduced from their published scale. Such changes should not be undertaken lightly. The next section discusses the problems of combining maps and introduces some specific techniques by which map combinations can be done in an appropriate manner.

COMBINING MAPS WITH DIFFERENT SCALES

Level 1 assessments are done at the scale of soil maps; the common scale for modern soil surveys is 1:15,840, or 4 inches to the mile. Higher level assessments may be done on topographic maps at the scale of 1:24,000, roughly 3 inches to the mile. In order to complete the higher level assessment, all data must be plotted at a common scale. Where two maps need to be combined, the larger one should be reduced to the scale of the smaller one. Enlarging the smaller one will give a false sense of precision to the combined map. Where two map scales are only moderately different, as in the case of 1:15,840 soil survey maps and 1:24,000 topographic maps, rules for combining maps become less stringent.

Combining maps of similar scale can be done several ways. Two methods that are generally suitable for sensitivity assessment maps are freehand sketching and mechanical/photographic. Either method can be used to enlarge or reduce.

When combining maps using freehand sketching, simply transfer the lines from one map to the other by constant reference to the original map. Most areas of the state have a fairly regular road network based on the one-mile grid of section lines. Other points of reference include houses, lakes and streams, which are shown on the topographic maps and can be recognized on the air-photo base of the soil maps. It is important to remember that some houses may not be on one map or the other, and lakes may be a different size and shape because the maps were made at different times. Even the road networks may be different.

Freehand sketching is adequate when the lines to be transferred are relatively simple and where there are enough landmark features on both maps. In areas where landmark features are sparse and the lines to be transferred are complex, some mechanical or photographic method must be used. The cheapest and simplest is photocopy machine reduction. Lines based on the soil survey at 1:15,840 can be copied at 66% reduction to 1:24,000, the scale of topographic maps. Then they can be traced onto the topographic base map. Even though nominally at the same scale, they will still not match perfectly because of paper shrink and swell and because the photos on the soil map base are unrectified. ("Rectified" air photos, corrected for the various distortions inherent in air photos, match a grid of surveyed control points.) Thus it is necessary to include some landmark features on the soil lines such as the road grid. This will allow the lines to be traced more accurately. The overlying map must be moved from time to time during tracing in order to achieve the best fit.

Various types of reflecting projectors and zoom transfer scopes may be used to change scale. Each has its own advantages and drawbacks. Each requires lining up landmark features on both maps. Accuracy is generally best in the center of the field of view, and the maps must be moved and realigned frequently. This method has been used successfully at the Minnesota Geological Survey but it is time-consuming and requires expensive specialized equipment. Photographic enlargement or reduction is more precise, but is not recommended for general use because the inherent imprecision of the lines does not justify the accuracy.

To easily examine geologic sensitivity on a county-wide basis, the assessment results shown on larger scale soils and/or topographic maps may be reduced in scale and traced onto a smaller-scale base map of the whole county. A county road map at 1 inch to the mile or 1/2 inch to the mile may be used. A drawback to the county road maps is that they greatly exaggerate the widths of the roads, showing them several hundred feet wide. They also normally show section lines as a regular grid, even though, in places, the section lines are irregular due to early survey errors.

The same principles and techniques discussed above for combining maps may be used for the county-wide maps, but one other factor must be considered. When a map is greatly reduced, its lines must be generalized because the line becomes "wider" in terms of the width that it covers on the ground. Small details cannot be shown. Small areas must be dropped, in effect absorbing them into surrounding areas with a different rating. Tight line squiggles need to be replaced with broad, sweeping curves, which in turn will reduce down to tight squiggles.

This process illustrates why small areas cannot be confidently rated by a county-wide map; the area in question may be an unmapped inclusion in an area of contrasting sensitivity. And of course the precision of the lines drawn in the first place is variable. County maps of geologic sensitivity should be used only to illustrate which parts of the county are generally sensitive, not to determine the geologic sensitivity of specific parcels of land. The advantage of small-scale maps is that they allow recognition of major trends, without the distraction of small details. This may be especially true when comparing a geologic sensitivity map with plotted water-quality data. Smaller-scale maps will be less affected by local ground water flow, and may give a better general look at the relationship between water quality and predicted sensitivity.

MAP RELIABILITY AND DATA COVERAGE

In addition to properly combining maps of different scales, users should carefully consider the reliability of the maps they use. High quality data are, of course, very important. However, <u>enough</u> data need to be collected and mapped. Interpretations or area boundaries based on too little information will be misleading. Determining when sufficient data has been collected should be a careful and deliberate decision. As a general rule of thumb, enough data have been collected when a user is able to <u>predict</u> most of the time the result of the next data collection effort. The issue of sufficient data collection must be carefully considered when assessing geologic sensitivity, especially when conducting Level 2 and Level 3 assessments. For example, in areas with relatively predictable geology and little topographic relief, less data may be needed than in areas of highly variable geology and greater relief. Reviewing available information before beginning an assessment project will help identify the level of effort needed to collect enough information to complete the assessment.

APPENDIX D

OTHER SENSITIVITY RATING METHODS

OTHER SENSITIVITY RATING METHODS

Many sensitivity assessment methods or techniques are currently available for estimating ground water vulnerability to contamination. The methods vary in the type of information produced, the information required and the scale of application. Each method is appropriate for certain applications and not others. Suitable applications for the proposed geologic sensitivity guidelines presented in this document were discussed in Chapter IV. This appendix provides a brief introduction to other techniques, primarily empirical, for evaluating ground water vulnerability.

GENERAL REVIEWS OF SENSITIVITY METHODS

Several reviews of various sensitivity assessment methods have been completed (Trojan, 1986; Canter et al., 1987; Geier and Perry, 1990). Trojan (1986) identified five general categories of methods: Predictive, general geologic criteria, mathematical modeling/routing, water balance and monitoring. Canter et al. (1987) provided a synopsis of nine empirical assessment methodologies. The nine methods were all pollutant source prioritizing methodologies, according to the authors. Geier and Perry (1990) evaluated in detail a more extensive group of empirical methodologies which would also belong to the predictive category of Trojan (1986). The evaluation by Geier and Perry (1990) included a comparison between methods of the intended application(s).

The sensitivity assessment methodologies reviewed and categorized by Trojan (1986) included the models listed in Table D-1. A predictive method such as EPA's DRASTIC model (Aller et al., 1985) assesses the potential for contamination to impact the subsurface. Predictive methods may evaluate a variety of factors, including the physical system, chemical characteristics, and perhaps land use or water use. Predictive methods may be site specific or they may be designed to assess larger areas not related to any particular use. General geologic criteria methods typically apply simplified rules based on physical attributes for determining vulnerability to contamination. These methods are also predictive and may or may not be site specific. Mathematical models are best applied to individual sites with identified or potential contamination problems. Mathematical models are constructed by developing a set of equations to describe the physical system. Equations of infiltration and ground water flow are matched to real conditions. If contaminants are a concern, existing or potential transport of contaminants is added to the physical system model. Water balance methods are site specific techniques for estimating leachate impact on local ground water conditions. Monitoring of wastes is an assessment technique that may be useful in limited situations where sources of potential contamination can be clearly identified and the quantities are limited.

The review by Canter et al. (1987) included the nine pollutant source prioritizing methodologies listed in Table D-2. Each method was summarized, with emphasis on the process by which a rating is obtained. The authors asserted that all the listed methodologies were suitable for site specific assessments, however DRASTIC was not designed for site specific application. Although the idea of geologic vulnerability and other assessment purposes were introduced several times, the authors focused their discussion on the technical development of site specific rating methods, particularly for pollution sources such as landfills. The authors also provided some limited information on the mysterious process of factor identification, setting factor weights and developing scaling functions.

Table D-1. Sensitivity assessment methodologies reviewed by Trojan (1986).

Type/Method	Source(s)
Predictive	
DRASTIC	Aller et al. (1985)
LeGrand	LeGrand (1964, 1983)
EPA SIA	Silka and Swearingen (1978)
Fuller Land Treatment	Fuller (1986)
EPA HRS	U.S. EPA (1985)
Florida DRASTIC	Higher and Waller (1986)
Kansas	Kansas Dept. of Health and Envir. (1986)
New Jersey	New Jersey Geological Survey (1983)
Massachusetts	Roy and Bowley (1986)
Wisconsin	Schmidt (1986)
Missouri	Duley (1983)
Illinois	Berg et al. (1984)
Michigan SAS	Mich. Dept. of Nat. Res. (1983)
General Geologic Criteria	
Septic tank fields	Waltz (1972)
Missouri	Stohr et al. (1981)
Ohio	Stein et al. (1981)
South Dakota	Meyer (1986)
Minnesota	Olsen et al. (1983)
Mathematical Modeling/Routing	
Contaminant transport	Watson (1984), Oberlander and Nelson (1984), Gray and Hoffman (1983), Enfield et al.(1982) MacFarland (1983)
Water Balance	
Landfill leachate	Fenn et al. (1975), Remson et al. (1986)
Monitoring	
Nebraska	Nebraska Dept. of Env. Control (1985)

Table D-2. Empirical pollutant source prioritizing methodologies reviewed by Canter et al., (1987)

Method	Source
Surface Impoundment Assessment (SIA)	U.S. EPA (1978)
Landfill Site Rating	(cited reference incorrect)
Waste-Soil-Site Interaction Matrix	Phillips et al. (1977)
Site Rating System	Hagerty et al. (1973)
Hazard Ranking System (HRS)	Caldwell et al. (1981)
Site Rating Methodology	Kufs et al. (1980)
Brine Disposal Methodology	Western Mich. Univ. (1981)
Pesticide Index	Rao et al. (1985)
DRASTIC	Aller et al. (1985)

Geier and Perry (1990) chose to catalogue and review different empirical assessment models according to their intended applications. The assessment models were organized into six categories based on intended use:

- selection of candidate waste disposal sites
- prioritize existing sites for remediation
- evaluate sensitivity over large areas
- rank and evaluate individual contaminants according to pollution potential
- evaluate candidate sites for Land Surface Treatment
- evaluate pollution potential from oil and gas field activities.

The organization into these categories is intended to help users identify the appropriate empirical method for a particular need. Table D-3 lists the models reviewed, the method categories and the applications.

ASSESSING SENSITIVITY IN AGRICULTURAL SETTINGS

In Chapter III, the surficial application of agricultural chemicals was introduced as one of several special cases. Agricultural practices apply specific chemicals directly on the surface of the earth or in the soil zone. Consideration of any particular chemical cannot be addressed by the general geologic sensitivity criteria. This kind of activity requires a specialized approach.

The U.S. Dept. of Agriculture Soil Conservation Service (SCS) in cooperation with the Agricultural Research Service (ARS) and the Minnesota Cooperative Extension System (MES) has developed a system for rating soils on their potential for pesticides to leach through them. Each soil mapping unit is assigned a rating of "nominal", "intermediate", or "high". Each pesticide is given a rating of "small", "medium", or "large", based on its

Table D-3. SUMMARY OF SELECTED SENSITIVITY ASSESSMENT METHODOLOGIES FOR VARIOUS NEEDS (Modified from Geier and Perry, 1990)

Section 1. Site Selection Methodologies

Empirical Assess-ment Method	Primary Source	Evaluates Geologic Sensitivity	Evaluates Contaminant Prop/Behav.	Explicitly Evaluates Hazardous Wastes	Screens Potential Indust. Waste Pond Sites	Screens Potential Septic Sys. Sites	Screens Potential Landfill Sites	Rates Land Treatment Sites	General Planning/ Regulatory Application
LeGrand (1964)	LeGrand, 1964	X			X	X		X	X
Surface Impound Assessment (SIA)	Silka and Swearingen, 1978	X	X	X	X	X		X	X
Soil/Waste Interaction Matrix	Phillips, et al., 1977	X	X	X	X	X		X	X
Hazardous Waste/Land-Fill Site Ranking System	Hagerty, et al., 1973	X	X	X			X	X	X
LeGrand (1983)	LeGrand, 1983	X	X		X	X	X	X	X

Table D-3. SUMMARY OF SELECTED SENSITIVITY ASSESSMENT METHODOLOGIES FOR VARIOUS NEEDS (Modified from Geier and Perry, 1990) (Cont'd)

Section 2. Site Remediation Methodologies

Empirical Assess-ment Method	Primary Source	Evaluates Geologic Sensitivity	Evaluates Contaminant Prop/Behav.	Explicitly Evaluates Hazardous Wastes	Rates Existing Industrial Waste Ponds	Rates Existing Septic Systems	Rates Existing Landfill Sites	Rates Land Treatment Sites	General Planning/ Regulatory Application
Geologic Ranking System	Nelson and Young, 1981	X					X		
Ground Water Contamination Site Ranking Method	Olivieri, et al., 1986	X	X	X	X		X	X	
New Jersey Site Ranking Method	Hutchinson and Hoffman, 1983	X	X	X	X		X		
Kansas Ranking System	Kansas DHE, 1986	X	X		X	X	X	X	
Site Rating Methodology	Kufs, et al., 1980	X	X	X	X		X		
Hazard (HRS)	CFR, 1989	X	X	X			X		

Table D-3. SUMMARY OF SELECTED SENSITIVITY ASSESSMENT METHODOLOGIES FOR VARIOUS NEEDS (Modified from Geier and Perry, 1990) (Cont'd)

Section 2. Site Remediation Methodologies (Cont'd)

Empirical Assess-ment Method	Primary Source	Evaluates Geologic Sensitivity	Evaluates Contaminant Prop/Behav.	Explicitly Evaluates Hazardous Wastes	Rates Existing Industrial Waste Ponds	Rates Existing Septic Systems	Rates Existing Landfill Sites	Rates Land Treatment Sites	General Planning/ Regulatory Application
Michigan Site Assess-ment System (SAS)	Michigan DNR, 1983	X	X	X			X		
California Ranking System	Dlugosz and Ingham, 1985	X	X	X			X		

Table D-3. SUMMARY OF SELECTED SENSITIVITY ASSESSMENT METHODOLOGIES FOR VARIOUS NEEDS (Modified from Geier and Perry, 1990) (Cont'd)

Section 3. Large-Scale Sensitivity Ranking Techniques

Empirical Assess ment Method	Primary Source	Evaluates Geologic Sensitivity	Evaluates Contaminant Prop/Behav	Explicitly Evaluates Hazardous Wastes	Screens Areas for Industrial Waste Ponds	Screens Areas for Septic Systems	Screens Areas for Landfill Sites	Screens Areas for Land Treat- ment Sites	General Planning/ Regulatory Application
Drastic	Aller, et al., 1985	X							X
Minnesota Sensitivity Map	Porcher, 1989	X							X
Wisconsin Sensitivity Map	Schmidt, 1987	X							X
Illinois Ground Water Contamination Potential Rating System	Berg, et al., 1984	X			X	X	X	X	X
Minnesota Sensitivity Rating Method	Minnesota DNR, 1990	X			X	X	X	X	X
Trojan-Perry Method	Trojan and Perry, 1988	X	X		X	X	X	X	X

Table D-3. SUMMARY OF SELECTED SENSITIVITY ASSESSMENT METHODOLOGIES FOR VARIOUS NEEDS (Modified from Geier and Perry, 1990) (Cont'd)

Section 4. Contaminant Indices (scale not applicable)

Empirical Assess-ment Method	Primary Source	Evaluates Geologic Sensitivity	Evaluates Contaminant Prop/Behav	Explicitly Evaluates Hazardous Wastes	Rates Industrial Waste Ponds	Rates Septic System Sites	Rates Landfill Sites	Rates Land Treatment Sites	General Planning/ Regulatory Application
Leaching Index	Laskowski, et al., 1982		X						X
Pesticide Index	Rao, 1985	X	X						X
Minnesota Pesticide Index	Becker, et, al., 1989		X						X

Table D-3. SUMMARY OF SELECTED SENSITIVITY ASSESSMENT METHODOLOGIES FOR VARIOUS NEEDS (Modified from Geier and Perry, 1990)(Cont'd)

Section 5. Land Treatment Site Methodologies

Empirical Assess-ment Method	Primary Source	Evaluates Geologic Sensitivity	Evaluates Contaminant Prop/Behav	Explicitly Evaluates Hazardous Wastes	Rates Industrial Waste Pond Sites	Rates Septic System Sites	Rates Landfill Sites	Rates Surface Application Sites	General Planning/ Regulatory Application
Fuller Land Treatement Methodology	Fuller, 1984	X						X	
Mobility Degradation Index	Mahmood, et al., 1986	X	X	X				X	

solubility, persistence, and soil absorption value. The two ratings are combined in a matrix to yield a potential for leaching through the soil, ranging from Potential 1 (largest) to Potential 3 (smallest). This system is simple, easy to use, and the necessary data for its application are available for most of Minnesota. It is a guide for managing individual fields. A similar matrix has also been developed for evaluating pesticide surface runoff potential. Local county agents should be contacted for further information.

The Nitrogen Fertilizer Task Force has developed voluntary Best Management Practices (BMP's) for nitrogen fertilizers. Nitrogen fertilizer BMP's have been formulated for five Minnesota regions based general soils, climatic and cropping conditions. Figure D-1 shows the five nitrogen fertilizer BMP regions. For each region, the Minnesota Department of Agriculture (MDA) developed specific recommendations for managing nitrogen fertilizer. In the future, the MDA will coordinate the promotion and overall plan of response where high levels of nitrogen fertilizer related compounds are found in surface and ground waters.

The MDA has also issued voluntary BMP's for atrazine, a commonly used pesticide with a high leaching potential.. The BMP's includes recommendations for two application rates; one for general use statewide and a maximum of one-half the statewide rate in sensitive areas. For atrazine management, the MDA has identified sensitive areas as those areas with highly permeable geologic materials such as fractured rock aquifers and sandy areas where the water table is less than thirty feet from the land surface. As shown in Figure D-2, the voluntary atrazine BMP indicates the counties where these conditions are common. The MDA should be consulted for further details.

Soil-based systems such as the SCS leaching index and the geological sensitivity guidelines may be applied to the same area. Table D-4 lists the Level 1 rating and the SCS leaching potential for some Douglas County soils. Experience shows that in many cases there will be good agreement between the systems. An area may be rated High in both soil leaching potential and geologic sensitivity. Another area may be rated Nominal in leaching potential and Moderate or Low in geologic sensitivity. However, some areas may be rated Nominal in leaching potential, but High in geological sensitivity. In many cases where such a discrepancy has been analyzed, it is the result of a relatively low-permeability soil overlaying a high-permeability parent material, for example, loess over outwash, or over carbonate bedrock. In such a case both systems are accurate, <u>in their area of application</u>. A contaminant such as a pesticide used in an area rated Nominal is unlikely to leach through the root zone, but if it does, it is likely to reach ground water if the area has High geologic sensitivity. There is less margin for error, and more need of caution in this case than in a situation where both the soil leaching potential and the geologic sensitivity are rated low.

The other case where discrepancies will commonly turn up between the general geologic criteria and the soil leaching system is in an area with a high water table. In Table V-1, (general geologic sensitivity ratings for Level 1 assessments), a water table of less than six feet changes Moderate ratings to High, and Low ratings to Moderate. This is done because the system is designed to estimate travel time to the first zone of saturation, regardless of whether it is seasonal, perched or the water table aquifer. In an area of a high water table, the water does not have far to go to reach saturated conditions. In an area rated Nominal in leaching potential but High in geologic sensitivity because of a high water table, pesticides are unlikely to leach through the soil, but if they do, they are likely to quickly enter the ground water. This situation is another indicator that extra care may be needed to protect the ground water system.

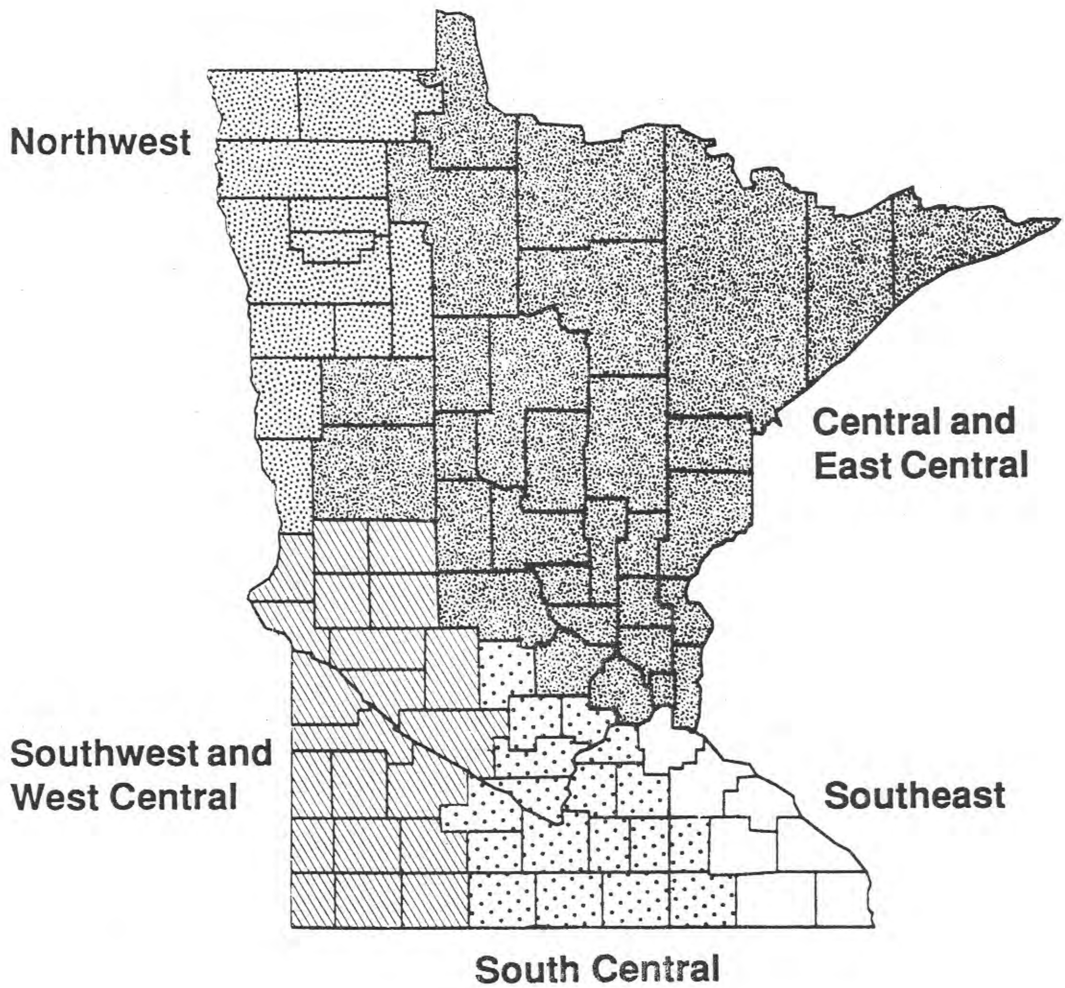


Figure D-1. The five Minnesota regions for which nitrogen BMP's are formulated.

MINNESOTA DEPARTMENT OF AGRICULTURE
AGRONOMY SERVICES DIVISION/4TH FLOOR
90 WEST PLATO BOULEVARD
SAINT PAUL, MINNESOTA 55107
(612) 296-6121

VOLUNTARY ATRAZINE BEST MANAGEMENT PRACTICES

HERBICIDE SELECTION RECOMMENDATIONS

1. **Use Integrated Pest Management techniques for pest control**
   a. Scout fields to identify weed species present.
   b. Assess population levels.
   c. Determine whether herbicide treatments are merited and if so, which herbicides are appropriate.
   d. Consider alternatives to atrazine use that may do the same job with potential negative impact on water resources.
   e. Apply the least amount of herbicide necessary to control the weeds, and only where weed problems exist or are anticipated.

2. **Maintain a field history** which includes soil test results, crops, pest problems, pesticides used (brand names, active ingredients, rates), application dates, and results.

MIXING AND LOADING

1. **Mix, load, or clean equipment containing atrazine a minimum of 150 feet from a sinkhole (outer edge of slope), streambed, lake, wetland, water impoundment, river or similar areas.**

2. **Mix, load and clean-out equipment on impervious surfaces.** Atrazine mixing/loading and equipment clean-out should be carried out on an impervious surface such as a mixing and loading pad. Equipment and container wash waters should be applied evenly over labeled areas or used as part of dilution make-up water.

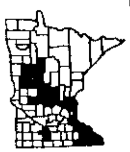
APPLICATION RATES

1. **Sensitive Areas**

   Limit to one and one-half pounds or less atrazine active ingredient (or 1.6 pounds atrazine active ingredient plus related compounds) per acre per calendar year in sensitive areas. The application rate for atrazine of 1.5 lbs. active ingredient is equivalent to 1.6 qts. of 4L, 2.0 lbs. of 80W, or 1.8 lbs. of 90% WDG or DF formulations. Sensitive areas, until further defined by the Deperment of Natural Resources, include highly permeable geologic material such as:

   a. fractured rock aquifers (including karst, sinkhole areas) or;

   b. where sands, loamy sands, and/or sandy loams are the prevalent soil texture within a field (greater than 50% of the soil surface) and where the water table is less than thirty feet below the surface.



Counties in which these conditions are prevalent include: Anoka, Becker, Benton, Brown, Chisago, Dakota, Fillmore, Goodhue, Houston, Hubbard, Isanti, Morrison, Mower, Olmsted, Ottertail, Pope, Sherburne, Stearns, Todd, Wabasha, Wadena, Washington, Watonwan, and Winona.

It should be noted that portions of every Minnesota county may include one, or all, of these conditions. For example, in addition to the counties listed above, sands, loamy sands, and/or sandy loams are prevalent in river valleys, especially in south western counties such as Rock and Pipestone. Contact your local Soil Conservation Service for further information on specific soil conditions on your farm.

2. **Statewide**

   Limit to no more that 3 lbs. atrazine active ingredient per acre per calendar year. The maximum application rate for atrazine is equivalent to 3 qts. of 4L, 3 3/4 lbs. of 80W, or 3.3 lbs. of 90% WDG or DF formulations except in sensitive areas where rate restrictions apply.

   Refrain from using atrazine for nonselective weed control on noncrop land.

ATRAZINE USE RECOMMENDATIONS

1. **Only apply atrazine between spring thaw and until corn reaches 12 inches in height.** Do not apply atrazine in the fall or winter.

2. **Establish and maintain buffer areas.** Buffer areas are grassy Water Ways or vegetation strips around sinkholes, drainage wells and other areas where distance limitations apply. Avoid atrazine drift into these buffer areas.

3. **Follow proven irrigation management practices to minimize leaching.** Do not over irrigate. Contact University of Minnesota Extension Service irrigation Specialists for irrigation recommendations.

CONTAINER MANAGEMENT

1. **Rinse containers immediately.** Delay in rinsing atrazine containers results in a residue that, upon drying, is highly resistent to rinsing. Proper rinsing may be accomplished by pressure rinsing or triple rinsing immediately after emptying container. Use rinsate as dilution make-up water. Apply rinsate evenly over a labeled site.

2. **Properly dispose of rinsed atrazine containers.** Recycle or dispose of container as a solid waste. Contact Minnesota Department of Agriculture for further information on recycling and disposal.

LEGAL REQUIREMENT

Atrazine must not be applied through an irrigation system.

ASSISTANCE TO ATRAZINE USERS

Contact the Minnesota Department of Agriculture or the Minnesota Extension service for further information on Atrazine Best Management Practices (BMPs).

****

Atrazine Best Management Practices are supplemental voluntary management practices. Users must also follow all legal requirements such as:

1. **Read and follow label directions.** Recent label changes have occurred on atrazine containing products. Be sure to read and follow all directions and precautions appearing on the label in your possession. Certain atrazine Best Management Practices recommendations are mandatory if listed on the label in the users possession.

2. **Atrazine is a Restricted Use Pesticide.** Purchasers and applicators must have proper Minnesota Department of Agriculture issued licensure or certification. All sales must be reported to Minnesota Department of Agriculture by the Restricted Use Pesticide dealer at the end of each year.

3. **Do not mix near wells.** Follow Minnesota Water Well Code which currently prohibits mixing, loading or cleaning of application equipment within 150 feet of a well (including, but not limited to, a farm well, drinking water well, abandoned well, irrigation well or drainage well).

4. **Properly calibrate equipment** so that label rates are accurately delivered to the target site.

5. **Avoid backsiphoning** by utilization of a fixed airgap or the Minnesota Department of Agriculture/Minnesota Department of Health approved anti-backsiphoning device.

Figure D-2. Voluntary Atrazine Best Management Practices (BMP's) for Minnesota

Table D-4. Partial listing of Douglas County Level 1 - Preliminary Geologic Sensitivity Assessment showing comparison of Level 1 rating and SCS Leaching Potential.

Symbol	Soil Name	Parent Material	Texture of lowest described horizon	Water Table*	Level 1 Rating	SCS Leaching Potential
AaA	Aastad clay loam	Loam till	Clay loam, loam	3->6	Moderate	Intermediate
Ad	Alluvial land	Alluvium	Variable, loamy to sandy	1-5	High	High
Ao	Arveson sandy clay loam	Sandy outwash or lacustrine	F. sand, lmy sand, s.loam	1-2	Very High	High/Interm.(D**)
AsA	Arvilla sandy loam, 0-2%	Outwash, stream terraces, beaches	Gravelly coarse sand	>6	Very High	High
AsB	Arvilla sandy loam, 2-6%	Outwash, stream terraces, beaches	Gravelly coarse sand	>6	Very High	High
AsC	Arvilla sandy loam, 6-12%	Outwash, stream terraces, beaches	Gravelly coarse sand	>6	Very High	High
AtA	Arvilla sandy loam, 0-3%	Outwash	Gravelly coarse sand	>6	Very High	Intermediate
BaB2	Barnes loam, 2-6%, eroded	Loam till	Loam	>6	Low	Intermediate
BaC2	Barnes loam, 6-12%, eroded	Loam till	Loam	>6	Low	Nominal
BlB2	Barnes-Langhei loams, 2-6%,	Loam till	Loam	>6	Low	Intermediate
BlC2	Barnes-Langhei loams, 6-12%	Loam till	Loam	>6	Low	Nominal
BmA	Beltrami loam, 1-3%	Loam till	Loam, clay loam	2-4	Moderate	Intermediate
Bp	Brophy peat	Peat	Organic	0	High	High/Interm.(D**)
Ca	Carlos muck	Mucky peat(peat interlayered w/ silt/clay	Organic	0	High	High/Interm.(D**)
Cc	Cathro muck	Muck over silt loam	Sandy lm, lm, silt loam	0	High	High/Interm.(D**)
Ch	Cathro muck, sandy subsoil	Muck over gravelly sand	Gravelly coarse sand	0	Very High	High/Interm.(D**)
ClB2	Clarion loam, 2-6% (Ves)	Loam till	Loam, clay loam	>6	Low	Intermediate
ClC2	Clarion loam, 6-12% (Ves)	Loam till	Loam, clay loam	>6	Low	Nominal
CmA	Clontarf sandy loam, 0-2%	Outwash, terraces, or gl. lacustr.	Sand, f. sand, lmy sand	3-5	Very High	High
Co	Colvin silt loam	Lacustrine, outwash channels	Lm., slt lm, slty cl lm	1-2	High	High/Interm.(D**)
Cp	Colvin silt loam, depress.	Lacustrine silt	Lm, slt lm, slty cl lm	0	High	High/Interm.(D**)
DaA	Darnen loam, 1-4%	Colluvium/alluvium	Loam, clay loam	>6	Moderate	Nominal
Dd	Dassel sandy loam (Darfur)	Outwash	Stratified f sand, f sndy lm	1-3	High	High
De	Dassel sandy loam, depress.	Outwash	Strat. lmy sand, coarse sand	0	Very High	High
DoA	Dorset sandy loam, 0-2%	Outwash	Gravelly coarse sand	>6	Very High	High
DoB	Dorset sandy loam, 2-6%	Outwash	Gravelly coarse sand	>6	Very High	High
DoC	Dorset sandy loam, 6-12%	Outwash	Gravelly coarse sand	>6	Very High	High
DpA	Dorset sandy loam, 0-2% .	Outwash	Gravelly coarse sand	>6	Very High	Intermediate

*Natural depth in feet to seasonal high and low zones of soil saturation is listed. This is not strictly equivalent to the "water table" in the hydrogeological sense. Drained areas, especially deeply ditched areas may need to be separately considered in assignment of Level 1 ratings and also the Level 2 vadose zone assessment.

**Rated High if undrained; rated Intermediate if drained.

The SCS soil leaching system is designed to be used where the chemical application is at or very near the surface and where the persistence of the chemical can be defined for local climatic conditions. The SCS system should not be used for evaluating threats to ground water that originate under the surface, such as landfills, underground storage tanks, or septic tank drain fields.

SUMMARY

From the discussion above, it should be clear that many sensitivity assessment models are available and include both mathematical models and empirical methods. The choice of an assessment model is area and user specific. Sometimes the choice of which model to use is relatively straightforward. In other cases the choice may be difficult such as when there are conflicting needs, limited data and/or constrained budget.

Using an assessment model is not an easy task. First, the purpose and information needed should be identified. Second, an appropriate method must be chosen to meet the specified purpose and within known information or other limits. Third, the chosen method must be used within the scope of the method design. Finally, the results of the sensitivity assessment must be interpreted and an evaluation conducted to determine if the goals of the assessment process have been achieved. Potential users of any model or method may need to work with experienced professionals to achieve the desired results.

The SCS soil leaching system is designed to be used where the chemical application is at or very near the surface and where the persistence of the chemical can be defined for local climatic conditions. The SCS system should not be used for evaluating threats to ground water that originate under the surface, such as landfills, underground storage tanks, or septic tank drain fields.

SUMMARY

From the discussion above, it should be clear that many sensitivity assessment models are available and include both mathematical models and empirical methods. The choice of an assessment model is area and user specific. Sometimes the choice of which model to use is relatively straightforward. In other cases the choice may be difficult such as when there are conflicting needs, limited data and/or constrained budget.

Using an assessment model is not an easy task. First, the purpose and information needed should be identified. Second, an appropriate method must be chosen to meet the specified purpose and within known information or other limits. Third, the chosen method must be used within the scope of the method design. Finally, the results of the sensitivity assessment must be interpreted and an evaluation conducted to determine if the goals of the assessment process have been achieved. Potential users of any model or method may need to work with experienced professionals to achieve the desired results.

BIBLIOGRAPHY

BIBLIOGRAPHY

BIBLIOGRAPHY

GENERAL

Armstrong, D., 1989. Minnesota Ground Water Bibliography. MN Department of Natural Resources, Division of Waters, 102 pp.

Melone, T.G., and Weiss., L.W., 1985. Bibliography of Minnesota's Geology (through 1950). Minnesota Geological Survey, St. Paul.

Morey, G.B., N.H. Balaban and L. Swanson, 1981. Bibliography of Minnesota's Geology (1951-1980). Minnesota Geological Survey, St. Paul.

Sims, P.K., and G.B. Morey, eds., 1972. Geology of Minnesota: A Centennial Volume. Minnesota Geological Survey, St. Paul.

Swanson, L., 1985. Publications of the Minnesota Geological Survey and its predecessor, the Geological and Natural History Survey of Minnesota. Minnesota Geological Survey, St. Paul.

Swanson, L., N.H. Balaban and G.B. Morey, 1986. Bibliography of Minnesota's Geology (1981-1985). Minnesota Geological Survey, St. Paul.

CHAPTER I - INTRODUCTION

Minnesota Environmental Quality Board, 1991. Minnesota Water Plan. Minnesota State Planning Agency, St. Paul, 44 pp.

Minnesota Department of Agriculture, 1990. Recommendations of the Nitrogen Fertilizer Task Force on the Nitrogen Fertilizer Management Plan. 97 pp.

Potter, Juliana, 1984. Local ground-water protection: A sampler of approaches used by local governments. University of Wisconsin-Extension, Geological and Natural History Survey, Misc. paper 84-2, 17 pp.

CHAPTER II - A GROUND WATER PRIMER

Freeze, R. Allan and John A. Cherry, 1979. Groundwater. Prentice-Hall, Inc., Englewood, NJ. 603 pp.

CHAPTER III - BACKGROUND AND APPROACH

Hobbs, Howard C., 1990. Sensitivity of the Prairie Du Chien-Jordan Aquifer to Pollution. In: Geologic Atlas Dakota County, Minnesota, N. H. Balaban and Howard C. Hobbs, eds. County Atlas Series, Atlas C-6, Plate 7, University of Minnesota, Minnesota Geological Survey, St. Paul.

Kanivetsky, Roman, 1982. Susceptibility of bedrock aquifers to contamination. In: Geologic Atlas Scott County, Minnesota. N.H. Balaban and Peter L. McSwiggen, eds. County Atlas Series, Map C-1, Plate 4, Figure 3. University of Minnesota, Minnesota Geologic Survey, St. Paul.

Kanivetsky, Roman, 1984. Susceptibility of the ground-water system to pollution. In: Geologic Atlas Winona County, Minnesota, N.H. Balaban and B.M. Olsen, eds. County Atlas Series, Atlas C-2, Plate 6, University of Minnesota, Minnesota Geological Survey, St. Paul.

Kanivetsky, R. and B.M. Olsen, 1986. Hydrogeologic Sensitivity Mapping in Minnesota: American Institute of Hydrology, Vol. 2, No. 2, pp. 45-50.

Meyer, Gary N., 1990. Sensitivity of Ground-Water Systems to Pollution. In: Geologic Atlas of Washington County, Minnesota, Lynn Swanson and Gary N. Meyer, eds. County Atlas Series, Atlas C-5, Plate 6. University of Minnesota, Minnesota Geological Survey, St. Paul.

Olsen, B.M., E.H. Mohring and P.A. Bloomgren, 1987. Using Groundwater Data for Water Planning. Minnesota Geological Survey Educational Series #8.

Olsen, Bruce M. and Howard C. Hobbs, 1988. Sensitivity of the ground-water system to pollution. In: Geologic Atlas Olmsted County, Minnesota, N.H. Balaban ed. County Atlas Series, Atlas C-3, Plate 6. University of Minnesota, Minnesota Geologic Survey.

Olsen, Bruce, et al., 1983. Regional Mapping of Bedrock Contamination Susceptibility in Southeastern Minnesota. Minnesota Geological Survey, 9 pp.

Piegat, James, 1989. Sensitivity of ground-water systems to pollution. In: Geologic Atlas of Hennepin County, Minnesota, N.H. Balaban, ed. County Atlas Series, Atlas C-4, Plate 7. University of Minnesota, Minnesota Geological Survey.

CHAPTER V - LEVEL 1 ASSESSMENT

University of Minnesota Agricultural Experiment Station, 1980. Minnesota Soil Atlas, Stillwater Sheet, Misc. Report 171-1980.

CHAPTER VII - LEVEL 3 ASSESSMENT

Alexander, Scott C. and E. Calvin Alexander, Jr., 1989. Residence Times of Minnesota Groundwaters. Journ. Minn. Acad. Sci., Vol. 55, No. 1, pp. 48-52.

APPENDIX D - OTHER SENSITIVITY RATING METHODS

Aller, Linda, Truman Bennett, Jay H.Lehr and Rebecca Petty, May 1985. DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeological Settings. EPA/600/2-85/018. U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratoy, Ada, Oklahoma. 163 pp.

Becker, R.L., D. Herzfeld, K.R. Ostlie and E.J. Stamm-Katovich, 1989. Pesticides: Surface Runoff, Leaching and Exposure Concerns. Minnesota Extension Service Publication AG-BU-3911, University of Minnesota.

Berg, R.C., J.P. Kempton and K. Cartwright, 1984. Potential for contamination of shallow aquifers in Illinois: Illinois State Geological Survey, Circular 532, 30 pp.

Born, Stephen M., Douglas A. Yanggen and Alexander Zaporozec, 1987. A Guide to Grounwater Quality Planning and Management for Local Governments. Wisconsin Geological and Natural History Survey. Special Report No. 9, 91 pp.

Caldwell, Steve, Kris W. Barrett and S. Steven Chang, 1981. Ranking System for Releases of Hazardous Substances. In National Conference on Management of Uncontrolled Hazardous Waste Sites. Washington D.C.: Hazardous Materials Control Research Institute. pp. 14-20.

Canter, Larry W. and Robert C. Knox, 1985. Septic Tank System Effects on Ground Water Quality. Chelsea MI: Lewis Publishers. pp. 103-180.

Canter, Larry W., Robert C. Knox and Deborah M. Fairchild, 1987. Ground Water Quality Protection. Chelsea MI: Lewis Publishers. pp. 277-323.

Dlugosz, Edward S. and Alan T. Ingham, 1985. The California Ranking System. In: The 6th Annual Conference on Management of Uncontrolled Hazardous Waste Sites. Hazardous Materials Control Research Institute, Washington, D.C., pp. 429-431.

Duley, W. 1983. Geologic Aspects of Individual Home Liquid-Waste Disposal in Missouri: Engineering Geology Report No. 7, 78 pp.

Enfield, G., et al., 1982. Approximating Pollutant Transport to Groundwater: Ground Water Vol. 20, No. 6, pp. 711-722.

Fenn, G., et al., 1975. Use of the Water Balance Method for Predicting Leachate Generation from Solid Waste Disposal Sites: U.S. EPA Solid Waste Report No. 168, Cincinnati, Ohio, 40 pp.

Fuller, Wallace H., 1986. Site Selection Fundamentals for Land Treatment. In Land Treatment: A Hazardous Waste Management Alternative. Edited by Raymond C. Loehr and Joseph F. Malina, Jr. Water Resources Symposium No. 13. Center for Research in Water Resources, Bureau of Engineering Research. University of Texas-Austin. pp. 87-99.

Geier, Theodore W. and James A. Perry, 1990. Groundwater Sensitivity Literature Review. Draft. Water Resources Research Center, University of Minnesota, St. Paul. 149 pp.

Gray, G. and J.L. Hoffman, 1983. A Numerical Study of Groundwater Contamination from Prices Landfill, New Jersey II. Sensitvity Analysis and Contaminant Plume Simulation, Groundwater Vol. 21, No., pp. 15-21.

Hagerty, D. Joseph, Joseph L. Pavoni and John E.Heer, Jr., 1973. Solid Waste Management. New York: Van Nostrand Reinhold Co. pp. 242-261.

Higher, B. and Waller, 1986. Procedure for Assessing Contamination Probability in the Sole-Source Aquifer System, Southeast Florida, Using a Geographic Information System: Project Proposal to Florida Department of Environmental Regulation and South Florida Water Management District, 18 pp.

Hughes, M., 1972. Hydrogeologic Considerations in the Siting and Design of Landfills: Illinois State Geological Survey, Environmental Geology Notes, No. 51, 22 pp.

Hutchinson, Wayne R. and Jeffrey L. Hoffman, 1983. A Groundwater Pollution Priority System. Division of Water Resources, New Jersey Geological Survey Open File Report No. 83-4, 32 pp.

Illinois Department of Energy and Natural Resources, 1985. An Assessment of Groundwater Quality and Hazardous Substance Activities in Illinois with Recommendations for a Statewide Monitoring Strategy: State Water Survey Report 367, 119 pp.

Kansas Department of Health and Environment, 1986. A System for Prioritizing Groundwater Contamination Sites. KDHE Division of Environment, Bureau of Water Protection and Bureau of Environmental Remediation, 10 pp.

Keefer, Donald A. and Richard C. Berg, 1990. Potential for Aquifer Recharge in Illinois. Illinois State Geological Survey. 1 sheet.

Kufs, C., D. Twedell, S. Paige, R. Wetzel, P. Spooner, R. Colonna and M. Kilpatrick, 1980. Rating the Hazard Potential of Waste Disposal Facilities. In: Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites. Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 30-41.

Laskowski, Dennis A., Cleve A.I. Goring, P.J. McCall and R.L. Swann, 1982. Terrestrial Environment. In: Environmental Risk Analysis for Chemicals. Ed., Richard A. Conway. Van Nostrand Reinhold Co., New York, pp. 226-233.

LeGrand, Harry E, 1964. System for Evaluation of Contamination Potential of Some Waste Disposal Sites. Journal of the American Water Works Association, Vol. 56, No. 8, pp. 242-261.

LeGrand, Harry E., 1983. A Standardized System for Evaluating Waste-Disposal Sites, 2nd ed. National Water Well Association, Worthington OH, 49 pp.

MacFarlane, D. S., et al., 1983. Migration of Contaminants in Groundwater at a Landfill: A Case Study 1. Groundwater Flow and Plume Delineation. Journal of Hydrology, Vol. 63, No. 1, pp. 1-29.

Mahmood, Ramzi, A.M. ASCE and Ronald D. Sims, 1986. Mobility of Organics in Land Treatment Systems. Journal of Environmental Engineering, Vol. 112, No. 2, pp. 236-245.

Meyer, 1986. Assessment of the Feasibility of Establishing an Aquifer Classification System for South Dakota, South Dakota Department of Water and Natural Resources, 61 pp.

Michigan Department of Natural Resources, 1980. Michigan Surface Impoundment Assessment: Michigan Department of Natural Resources.

Michigan Department of Natural Resources, 1983. Site Assessment System (SAS) for the Michigan Priority Ranking System Under the Michigan Environmental Response Act (Act 307, P.A. 1982). 91 pp.

Michigan Department of Natural Resources, 1984. Review Report, Michigan Site Assessment System, Michigan Department of Natural Resources, Act 307, 19 pp.

Nebraska Department of Environmental Control, 1985. Nebraska Ground Water Quality Protection Strategy: Water Programs and Assessment Section, Water Quality Division, Final Report, 61 pp.

Nelson, Ann B. and Richard A. Young, 1981. Location and Prioritizing of Abandoned Dump Sites for Future Investigations. In: National Conference on Management of Uncontrolled Hazardous Waste Sites. Washington D.C.: Hazardous Materials Control Research Institute. pp. 52-62.

New Jersey Geological Survey, 1983. A Groundwater Pollution Priority System: New Jersey Geological Survey, Open File Report No. 83-4, 32 pp.

Olivieri, Adam W., Don M. Eisenberg, M. ASCE and Robert C. Cooper, 1986. Groundwater Contamination Site Ranking Methodology. Journal of Environmental Engineering, Vol. 112, No. 4, pp. 757-769.

Oberlander, L. and R.W. Nelson, 1984. An Idealized Groundwater Flow and Chemical Transport Model (S-PATHS). Groundwater,Vol. 22, No. 4, pp. 441-449.

Phillips, C.R., J.S. Nathwani and H. Mooij, 1977. Development of a Soil-Waste Interaction Matrix for Assessing Land Disposal of Industrial Wastes. Water Research, Vol. 11, No. 10, pp. 859-868.

Porcher, Eric, 1989. Ground Water Contamination Susceptibility in Minnesota. Minnesota Pollution Control Agency. 29 pp.

Rao, P.S.C., A.G. Hornsby and R. E. Jessup, 1985. Indices for Ranking the Potential for Pesticide Contamination of Groundwater. In: Proceedings of the Soil and Crop Science Society of Florida, Vol.44, pp. 1-8.

Remson, et al., 1968. Water Movement in an Unsaturated Sanitary Landfill: Journal of the Sanitary Engineering Division, ASCE, SA2, No. 5904, pp. 307-317.

Roy, S. and D.R. Bowley, 1986. Testing of a Standardized System for Evaluating Waste Disposal and Groundwater Pollution in Massachusetts, Department of Environmental Quality Control, 7 pp.

Schmidt, R., 1986. Groundwater Contamination Susceptibility in Wisconsin, Wisconsin Department of Natural Resources, 50 pp.

Schmidt, Robin R., 1987. Groundwater Contamination Susceptibility in Wisconsin. Wisconsin's Groundwater Management Plan Report No. 5. Wisconsin Department of Natural Resources. Bureau of Water Resources Management. 27 pp.

Silka, R. and T. L. Swearingen, 1978. A Manual for Evaluating Contamination Potential of Surface Impoundments. U.S. Environmental Protection Agency. PA/570/9-78-003. Office of Drinking Water, Washington, D.C. 73 pp.

Steayk, A. N., et al., 1984. Geology for Planning in Boone and Winnebago Counties, Illinois State Geological Survey, Circular 531, 69 pp.

Stein, B. and J.A. Noyes, 1981. Groundwater Contamination Potential at 21 Industrial Wastewater Impoundments in Ohio, Groundwater, Vol. 19, No. 1, pp. 70-80.

Stohr, J., et al., 1981. Geologic Aspects of Hazardous-Waste Isolation in Missouri, Engineering Geology Report No. 6, 5 pp.

Sutherland, A.W., C.C. Leigh and F.W. Madison, 1987. Soils of Pierce County and Their Ability to Attenuate Contaminants. Wisconsin Geological and Natural History Survey, Map 87-9. 1 sheet.

Trojan, M.D., 1986. Methods of Assessing Ground Water Susceptibility to Contamination, Minnesota Pollution Control Agency, 118 pp.

Trojan, Michael D. and James A. Perry, 1988. Assessing Hydrogeologic Risk Over Large Geographic Areas. Station Bulletin 585-1988 (Item No. AD-SB-3421). Minnesota Agricultural Experiment Station. University of Minnesota, 65 pp.

United States Environmental Protection Agency, 1983. Surface Impoundment Assessment National Report, U.S. EPA 570/9-84-002, 116 pp.

United States Environmental Protection Agency, 1985. Code of Federal Regulations, Part 300, Appendix A, pp. 699-729.

United States Environmental Protection Agency, 1989. Code of Federal Regulations, Title 40, Part 30, Appendix A, pp. 55-84.

Walsh, J. J., et al., 1981. Waste Impoundment Assessment in the State of Indiana, Groundwater, Vol. 19, No. 1, pp. 81-87.

Waltz, P., 1972. Methods of Geologic Evaluation of Pollution Potential of Mountain Homesites, Groundwater, Vol. 10, No. 1, pp. 42-47.

Western Michigan University, 1981. Hydrogeologic Atlas of Michigan, Plate 33. Department of Geology, Kalamazoo, Michigan.

Zaporozec, A., ed., 1985. Groundwater Protection Principles and Alternatives for Rock County, Wisconsin. Wisconsin Geological and Natural History Survey. Special Report No. 8, 73 pp.