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DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings

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DRASTIC: A STANDARDIZED SYSTEM FOR EVALUATING GROUND WATER POLLUTION POTENTIAL USING HYDROGEOLOGIC SETTINGS

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DISCLAIMER

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ABSTRACT

A methodology is described that will allow the pollution potential of any hydrogeologic setting to be systematically evaluated anywhere in the United States. The system has two major portions: the designation of mappable units, termed hydrogeologic settings, and the superposition of a relative rating system called DRASTIC.

Hydrogeologic settings form the basis of the system and incorporate the major hydrogeologic factors which affect and control ground-water movement including depth to water, net recharge, aquifer media, soil media, topography, impact of the vadose zone media and hydraulic conductivity of the aquifer. These factors, which form the acronym DRASTIC, are incorporated into a relative ranking scheme that uses a combination of weights and ratings to produce a numerical value called the DRASTIC Index.

Hydrogeologic settings are combined with DRASTIC Indexes to create units which can be graphically displayed on a map. The application of the system to 10 hydrogeologically variable counties resulted in maps with symbols and colors which illustrate areas of ground-water contamination vulnerability. The system optimizes the use of existing data to rank areas with respect to pollution potential to help direct investigations and resource expenditures and to prioritize protection, monitoring and clean-up efforts.

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SECTION 1

INTRODUCTION

OBJECTIVES AND SCOPE

The purpose of this project is to create a methodology that will permit the ground-water pollution potential of any hydrogeologic setting to be systematically evaluated with existing information anywhere in the United States. Pollution potential is a combination of hydrogeologic factors, anthropogenic influences and sources of contamination in any given area. This methodology has been designed to include only the hydrogeologic factors which influence pollution potential.

This document has been prepared to assist planners, managers and administrators in the task of evaluating the relative vulnerability of areas to ground-water contamination from various sources of pollution. Once this evaluation is complete, it can be used to help direct resources and land-use activities to the appropriate areas. The methodology may also assist in helping to prioritize protection, monitoring or clean-up efforts. This document will also be useful to industry personnel who desire to understand the relationship between various practices and the ground-water pollution potential associated with them and to university personnel who teach the fundamentals of hydrogeology and ground-water contamination. It has been assumed that the reader has only a basic knowledge of hydrogeology and the processes which govern ground-water contamination. However, the greater the hydrogeologic experience of the user, the more useful the system will become because the system can expand to be beneficial at any level of expertise. **This report is neither designed nor intended to replace on-site inspections, or specifically to site any type of facility or practice.** Rather, it is intended to provide a basis for comparative evaluation of areas with respect to potential for pollution of ground water.

The scope of this project includes not only the development of a standardized system for evaluating pollution potential, but also the creation of a system which can be readily displayed on maps. For purposes of relative evaluation, a system has been designed which produces a numerical rating. For purposes of mapping, the United States has been divided into hydrogeologic settings. These settings incorporate the many hydrogeologic factors which will influence the vulnerability of that setting to ground-water pollution. The settings have been chosen to represent areas larger than 100 acres in size, thereby limiting the system to use as a screening tool and not as a site assessment methodology. The two portions of the system may be used separately or combined for more in-depth evaluation. Individuals without specific geologic or hydrogeologic expertise can effectively use the numerical rating portion of the document, but may desire assistance when producing a pollution potential map. Professional hydrogeologic expertise greatly enhances and facilitates the application of the methodology particularly in locating, evaluating and estimating parameter values.

The scope of this project did not include producing pollution potential maps of the entire United States. Rather, a set of demonstration maps were prepared to 1) demonstrate the use of the rating system and 2) show how the system could display the information on a map for ease of use and reference. Ten widely hydrogeologically varied counties across the United States were selected as part of the testing and demonstration portion of the project including:

1) Cumberland County, Maine,
2) Finney County, Kansas,
3) Gillespie County, Texas,
4) Greenville County, South Carolina,
5) Lake County, Florida,
6) Minidoka County, Idaho,
7) New Castle County, Delaware,
8) Pierce County, Washington,
9) Portage County, Wisconsin, and
10) Yolo County, California.

These counties were chosen to represent both rural and urban areas and to exemplify both an abudance and scarcity of available hydrogeologic data.

In the formulation of this document an attempt was made to try to assimilate the thought processes of knowledgable professional hydrogeologists when evaluating the ground-water pollution potential of any area. From this thought process a simple-to-use and easy-to-understand methodology has been developed. It is important to remember that this document is intended to be used as a screening tool and is not intended to replace the need for professional expertise and field work in assessing the pollution potential in specific areas.

The system has been designed to use information which is available through a variety of sources. Information on the parameters including the depth to water in an area, net recharge, aquifer media, soil media, general topography or slope, vadose zone media and hydraulic conductivity of the aquifer is necessary to evaluate the ground-water pollution potential of any area using hydrogeologic settings. Although much of this information is available in existing reports, some might require estimation. In addition to existing reports and data, estimates for parameters can usually be obtained from experts employed by the United States Geological Survey, state geological surveys, Soil Conservation Service, colleges and universities, professional hydrogeologic consultants and other qualified individuals. In choosing parameters for which information is already available in some form, this system does not include many parameters and types of information which would be available from a more detailed site investigation. Therefore, it is important to realize that this document provides only a general, broad assessment to be used to evaluate areas for potential pollution.

To help illustrate two potential uses of this document, examples have been included: 1) When a professional hydrogeologist is asked to recommend the most hydrogeologically acceptable setting for municipal waste disposal in a county area, he begins by reviewing many types of different information. From the information, he immediately rejects settings which are obviously unsuitable and continues to narrow his focus until a number of the most promising areas are identified. He will usually then recommend that more detailed information be obtained and/or site investigations be made on the most promising areas before any type of further action is taken. This is analogous to the purpose of this document. It provides the user with an idea of where to direct resources for further evaluation. 2) When state or local administrators have limited resources available to devote to ground-water protection, they are forced to focus these resources in certain areas. The system presented in this document helps identify areas which are more or less vulnerable than others to contamination. This delineation allows administrators to direct their resources to those more vulnerable areas most critical to the management problems thereby making the most of the limited resources which are available.

PROJECT BACKGROUND

With the scope of the project in mind it is necessary to understand the importance of this document. Ground water is clearly regarded to be one of our nation's most valuable resources. Americans have long depended on ground water for many uses, but the primary use has been as a source of drinking water. Over 90 percent of the nation's public water supplies obtain their source water from ground water (Lappenbusch, 1984). Additionally, 97 percent of the water needs for domestic use in rural areas is served by ground-water resources (Solley et al., 1983).

National reliance on ground water has increased dramatically over the past 20 years. In the last 10 years alone, ground-water use has increased almost 30 percent while surface water withdrawals have increased only 15 percent (Solley et al., 1983). It is anticipated that the nation's reliance on ground water will continue to increase as demand for water increases in the future.

Concomitant with our reliance on ground water has come the need to protect our ground-water resources from contamination. Although contamination due to man has occurred for centuries, only in the past few years has the nation become aware of the dangers of ground-water contamination and of the many ways in which ground water can become contaminated. Moreover, in recent decades, the diversity of potential pollutants produced and used by man has increased dramatically. Since 1974, the Congress of the United States has been making an attempt to protect the nation's ground-water resources through legislation. The Safe Drinking Water Act (SDWA) (Public Law 93-523) as first passed in December, 1974 and amended in 1976, 1977, 1979, 1980, 1984 and 1986 mandated the establishment of drinking water standards to protect the public health, established the underground injection control (UIC) program to protect underground sources of drinking water from subsurface injection of wastes through wells, and established the Sole-Source Aquifer program. The Resource Conservation and Recovery Act (RCRA) (Public Law 94-580), as first passed in October, 1976 and amended in 1978, 1980, 1982, 1984 and 1986, is the legislation which controls the management and disposal of solid and hazardous waste in such a manner that ground water will not be contaminated. RCRA also mandated the establishment of an underground storage tank program which will address leak detection, prevention, monitoring and corrective action. The amended Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) (Public Law 92-516) as first passed in October, 1972 and amended in 1975, 1978, 1980 and 1983 allows EPA to prohibit or mitigate ground-water contamination by pesticides by denying registrations, by modifying application methods and through cancellations and suspensions of pesticide registrations. FIFRA also explicitly requires EPA to monitor environmental pollution. The Toxic Substances Control Act (TSCA) (Public Law 94-469), signed into law in October, 1976, and amended in 1981 has no direct impact on ground-water protection, but has the potential to be used as a mechanism in ground-water protection because the act provides EPA with the power to regulate the use and manufacture of specific chemicals, some of which may pose ground water contamination potential. The Surface Mining Control and Reclamation Act (SMCRA) (Public Law 95-87) as first passed in August, 1977 and amended in 1978, 1980, 1982 and 1984, is the legislation which controls environmental impacts resulting from all mining activities. By establishing standards for these facilities, ground water may once again be protected. Finally the Comprehensive Emergency Response Compensation and Liability Act (CERCLA) (Public Law 96-510), also known as "Superfund" was passed in December, 1980 and amended in October, 1986. This law provides a mechanism for the clean-up of ground water which has been contaminated at abandoned hazardous waste sites. A more complete discussion of these acts and their provisions which relate to ground water is given by Lehr, et al. (1984). This host of legislative measures has sought to help prevent the pollution of ground water in the future and to help mitigate some of the problems which have been created in the past.

Because prevention is the key to helping ensure that future practices do not result in ground-water contamination, it is now more important than ever to use planning and management tools to help recognize the places where certain activities pose a higher risk. This document addresses this need by providing an approach which can be used to help direct resources to protect ground water for future generations.

CLASSIFICATION SYSTEMS

One of the fundamental needs of any natural science is the development of an effective system to group similar entities into categories. Well-established systems exist in the fields of botany, geology and many other sciences (Joel, 1926). These systems permit an appropriately trained person to gain certain insight about an entity simply by knowing the appropriate category in which it is grouped.

This systematic and logical way of imposing an artificial system on natural entities has long been used in the field of geology also. For example, rocks have been classified according to origin and minerals grouped according to crystal systems. However, as a science expands and changes, so must the types of systems used to describe those characteristics which need to be studied. The field of hydrogeology is one area of geology which has only been overtly recognized since the term was coined by Lucas in 1879 (Davis and Dewiest, 1966). Since that time hydrogeology has expanded, from a discipline devoted to water occurrence and availability, to include the broad aspect of water quality and solute chemistry. Definition of water quality is fundamental to the protection of the ground-water resource from pollution.

The idea of an organized way to describe ground-water systems is not new. Meinzer (1923) prepared a small-scale map of the United States showing general ground-water provinces. Thomas (1952) and Heath (1984) prepared similar but more detailed maps and descriptions which grouped aquifers mainly on their water bearing characteristics within certain geographic areas. Blank and Schroeder (1973) attempted to classify aquifers based on the properties of rocks which affect ground water. Of all these systems, geographic ones have been more widely accepted as ways to describe the quantity of water which is available in various regions.

SOME EXISTING SYSTEMS WHICH EVALUATE GROUND-WATER POLLUTION POTENTIAL

Within the last twenty years the need to expand these systems or to create a new system to address ground-water quality has become evident. Many different systems have been developed to address site selection for waste disposal facilities such as sanitary landfills or liquid waste ponds. Among these, the LeGrand System (LeGrand, 1983) and the modified version used by the U.S. EPA in the Surface Impoundment Assessment (SIA) are probably the most well known. The LeGrand system uses numerical weighting to evaluate ground-water pollution potential from a given waste disposal site. By evaluating the site through a series of four stages, a description of the hydrogeology of the site, the relative aquifer sensitivity combined with the contaminant severity, the natural pollution potential presented at that site, and the engineering modifications which might change that potential are all evaluated.

The LeGrand system presupposes only a limited technical knowledge but encourages the user to become familiar with the concepts presented in the manual so that skilled judgements can be made in the subjective portion of the system. The similarities between sites are emphasized and the uniqueness of each site is downplayed.

The U.S. EPA methodology (U.S. EPA, 1983) uses the basic LeGrand System to define the hydrogeologic framework, but modifies the system to place emphasis on establishing a monitoring priority for the facility. Once the hydrogeologic characteristics have been rated, a table is used to define the monitoring priority. This priority may be adjusted by the rater using prescribed techniques. Once again only a limited technical knowledge is presupposed.

Other systems have been designed to tailor the results to more specific purposes. Thornthwaite and Mather (1957) and Fenn et al. (1975) developed water-balance methods to predict the leachate generation at solid waste disposal sites. This approach is based on the premise that by knowing the amount of infiltration into the landfill and the design of the cell, the leachate quantity for the landfill can be determined. The system is intended as a tool to be used by engineers in the early design phase of a facility.

Gibb et al., (1983) devised a rating scheme to establish priorities for existing waste disposal sites with respect to their threat to human health via ground water. By ranking the site through four factors, 1) health risk of the waste and handling mode, 2) population at risk, 3) proximity to wells or aquifers, and 4) susceptibility of aquifers, a number that ranges from 0-100 was used to display the relative risk. The system was used in a specific 2-county assessment by technically qualified individuals.

Another rating scheme, developed by the Michigan Department of Natural Resources (1983), is designed to rank large numbers of sites in terms of risk of environmental contamination. By evaluating the five categories: 1) release potential, 2) environmental exposure, 3) targets, 4) chemical hazard and 5) existing exposure, the user obtains a number ranging from 0 to 2000 points which evaluates the relative hazard of that site with respect to other sites in Michigan.

Hutchinson and Hoffman (1983) developed a rating system used by the New Jersey Geological Survey to prioritize ground-water pollution sites. By first evaluating the site geology using eleven separate factors and then evaluating the waste characteristics using eight criteria, the user generates separate scores which can then be combined to obtain a total site score. The scores range from 0 to 100 with high scores depicting a high degree of hazard.

Seller and Canter (1980) evaluated seven empirical methods to determine their usefulness in predicting the ground-water pollution effects of a waste disposal facility at a particular site. The methods they reviewed included rating schemes, a decision tree approach, a matrix and a criteria-listing method. They determined that each method took into account the natural conditions and facility design and construction, but that each method was best applied to the specific situation for which it was designed.

Since the first draft of this document was published in May, 1985 other rating systems have been developed which attempt to assess ground water vulnerability. The U.S. EPA (1986a) developed statutory interpretive guidance for hazardous waste land treatment, storage and disposal facilities which includes a section for determining ground-water vulnerability at hazardous waste facilities regulated under the Resource Conservation and Recovery Act (RCRA). By evaluating three parameters: 1) hydraulic conductivity, 2) hydraulic gradient and 3) effective porosity, the user calculates a time of travel (TOT) of a contaminant along a 100-foot flow line originating at the base of the hazardous waste management unit. Sites with a TOT of 100 years or less are considered vulnerable and typically trigger more detailed site assessments.

The United States Air Force has developed a rating model to establish priorities for further environmental action at air force bases (Engineering-Science, 1985). The model uses information which is typically gathered during the record search phase of the Installation Restoration Program and includes an evaluation in three main areas: 1) possible receptors of contamination, 2) the waste characteristics and 3) potential pathways for waste contaminant migration. The result is single number which can be adjusted to account for any efforts to contain the contaminants.

This brief review of selected existing systems reveals that there are a number of methods that can be applied to site specific situations or to evaluation of the pollution potential of existing sites. However, a planning tool is needed for application to broader geographic areas before the site-specific methods are employed. The system must: 1) function as a management tool, 2) be simple and easy-to-use, 3) utilize available information and 4) be able to be used by individuals with diverse backgrounds and levels of expertise. This document contains a system which attempts to meet these needs and to provide the planning tool necessary before site specific evaluations.

ORGANIZATION OF THE DOCUMENT

This document contains seven sections and thirteen supporting appendices. Each section and Appendices A through C contain a reference section. A complete list of references can be found immediately following Section 7. Section 2, Development of the System and Overview, provides a description of the process used to develop the methodology, including the potential uses of the system, the fundamental parts of the methodology, the designation of mappable units and the numerical ranking scheme. Section 3, DRASTIC: A Description of the Factors, explains those factors which most significantly influence ground-water pollution potential and the assumptions fundamental to the methodology. This section also discusses the relationship between hydrogeology and the effects of ground-water contamination, and details the use of the numerical ranking scheme to adequately portray the ground-water pollution potential. Section 4, How to Use Hydrogeologic Settings and DRASTIC, illustrates in greater detail how hydrogeologic settings are combined with the relative rating scheme to determine the ground-water pollution potential of an area. This section also explains how to evaluate the special condition of confined aquifers, use media ranges and acknowledge the presence of single factor overrides. Section 5, Application of DRASTIC to Maps, describes the stepwise process used to produce a completed DRASTIC map from the initial data collection to the printing of a final map using the National Color Code. This section also includes an explanation of how the system was applied in 10 hydrogeologically variable counties. Section 6, Impact - Risk Factors, discusses the influence of other parameters that may need to be considered in addition to the DRASTIC Index when evaluating the ground-water pollution potential in an area. Section 7, Hydrogeologic Settings of the United States by Ground-Water Regions, contains an annotated description, a geographic location map and an illustration of the major hydrogeologic features of each ground-water region. Descriptions, illustrations and example charts are also included for each hydrogeologic setting.

Also included within DRASTIC are Appendices A through M. Appendix A discusses the various processes and properties which affect contaminant fate and transport. Appendix B reviews the physical and chemical characteristics of contaminants and associated reactions in the environment. Appendix C discusses the sources of ground-water contamination and related impacts on ground-water quality. Appendices D through M contain detailed pollution potential maps produced using the methodology. The 10 demonstration maps of counties contain hydrogeologic setting designations and individual DRASTIC Index computations. Charts immediately follow each map and include the ranges of the seven DRASTIC parameters chosen for each area and the system for computing the DRASTIC Index.

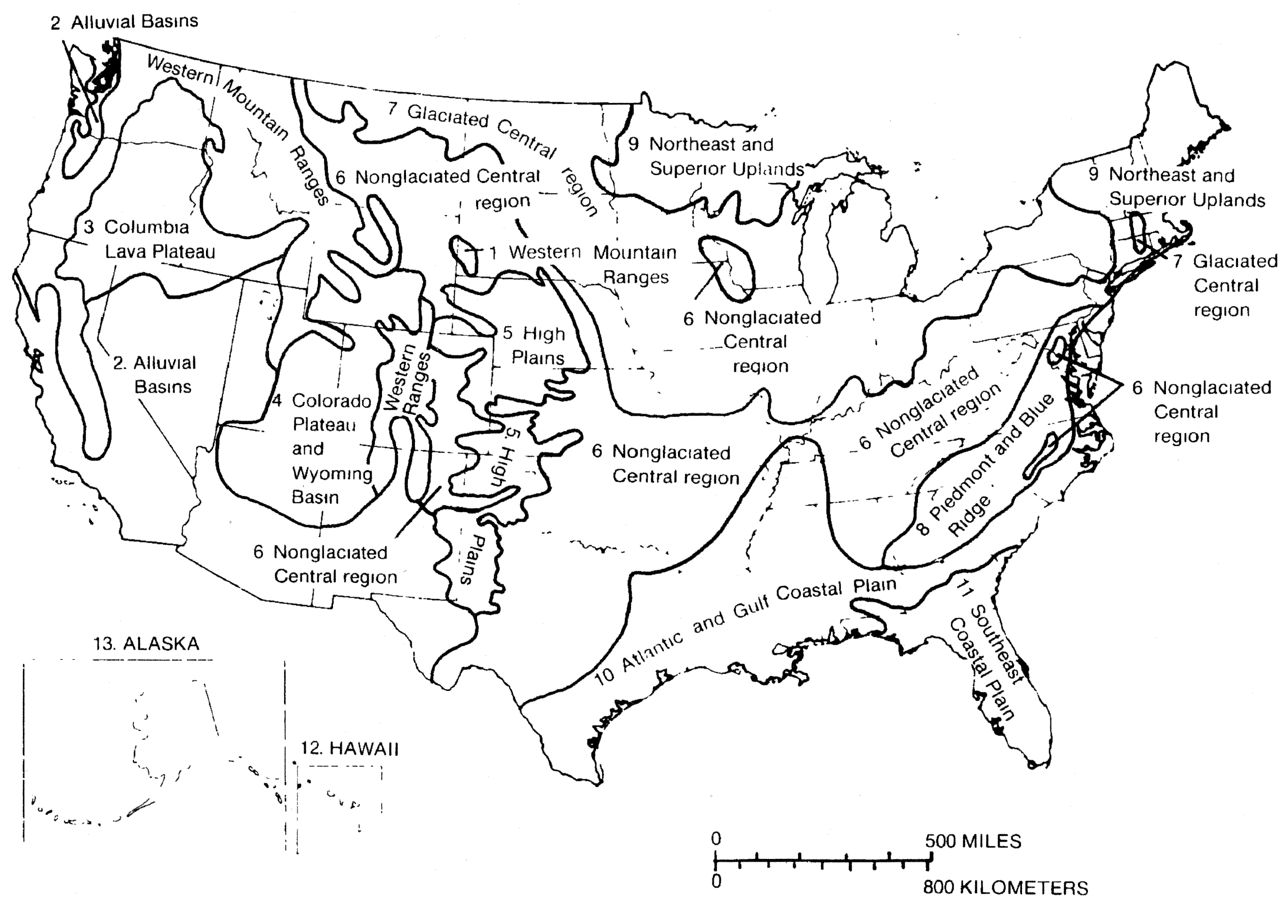


Figure 1. Ground-water regions of the United States (After Heath, 1984).

DRASTIC

Inherent in each hydrogeologic setting are the physical characteristics which affect the ground-water pollution potential. A wide range of technical positions was considered regarding the relative importance of the many physical characteristics that affect pollution potential. Factors including aquifer chemistry, temperature, transmissivity, tortuosity, gaseous phase transport and others were evaluated. The availability of mappable data has also been considered. As a result of this evaluation, the most important mappable factors that control the ground-water pollution potential were determined to be:

D - Depth to Water
R - (Net) Recharge
A - Aquifer Media
S - Soil Media
T - Topography (Slope)
I - Impact of the Vadose Zone Media
C - Conductivity (Hydraulic) of the Aquifer

These factors have been arranged to form the acronym, DRASTIC for ease of reference. A complete description of the important mechanisms considered within each factor and a description of the significance of the factor are included in Section 3, DRASTIC: A Description of the Factors. While this list is not all inclusive, these factors, in combination, were determined to include the basic requirements needed to assess the general pollution potential of each hydrogeologic setting. The DRASTIC factors represent measurable parameters for which data are generally available from a variety of sources without detailed reconnaissance. Sources of this information are listed in Table 1.

A numerical ranking system to assess ground-water pollution potential in hydrogeologic settings has been devised using the DRASTIC factors. The system contains three significant parts: weights, ranges and ratings. A description of the technique used for weights and ratings can be found in Dee et al., (1973).

1) Weights

Each DRASTIC factor has been evaluated with respect to the other to determine the relative importance of each factor. Each DRASTIC factor has been assigned a relative weight ranging from 1 to 5 (Table 2). The most significant factors have weights of 5; the least significant, a weight of 1. This exercise was accomplished by the committee using a Delphi (consensus) approach. These weights are a constant and may not be changed. A second weight has been assigned to reflect the agricultural usage of pesticides (Table 3). These weights are also constants and cannot be changed. A description of the usage of this second system can be found in Section 2 under the heading, "Pesticide DRASTIC".

TABLE 1. SOURCES OF HYDROGEOLOGIC INFORMATION

Source	Depth to Water	Net Recharge	Aquifer Media	Soil Media	Topography	Impact of the Vadose Media	Hydraulic Conductivity of the Aquifer
U S Geological Survey	X	X	X		X	X	X
State Geological Surveys	X	X	X			X	X
State Department of Natural/Water Resources	X	X	X			X	X
U S Department of Agriculture-Soil Conservation Service		X		X	X		
State Department of Environmental Protection	X	X	X			X	X
Clean Water Act "208" and other Regional Planning Authorities	X	X	X			X	X
County and Regional Water Supply Agencies and Companies (private water suppliers)	X		X			X	X
Private Consulting Firms (hydrogeologic, engineering)	X		X			X	X
Related Industry Studies (mining, well drilling, quarrying, etc)	X		X			X	
Professional Associations (Geological Society of America, National Water Well Association, American Geophysical Union)	X	X	X			X	X
Local Colleges and Universities (Departments of Geology, Earth Sciences, Civil Engineering	X	X	X			X	X
Other Federal/State Agencies (Army Corps of Engineers, National Oceanic and Atmospheric Administration)	X	X	X			X	

TABLE 2. ASSIGNED WEIGHTS FOR DRASTIC FEATURES

Feature	Weight
Depth to Water	5
Net Recharge	4
Aquifer Media	3
Soil Media	2
Topography	1
Impact of the Vadose Zone Media	5
Hydraulic Conductivity of the Aquifer	3

TABLE 3. ASSIGNED WEIGHTS FOR PESTICIDE DRASTIC FEATURES

Feature	Pesticide Weight
Depth to Water	5
Net Recharge	4
Aquifer Media	3
Soil Media	5
Topography	3
Impact of the Vadose Zone Media	4
Hydraulic Conductivity of the Aquifer	2

2) Ranges

Each DRASTIC factor has been divided into either ranges or significant media types which have an impact on pollution potential (Tables 4-10). A discussion of the media types is included in Section 3, Aquifer Media, Soil Media and Impact of the Vadose Zone Media. The ranges and media types are graphed to show the linearity and non-linearity of the factor (Figures 3-9).

3) Ratings

Each range for each DRASTIC factor has been evaluated with respect to the others to determine the relative significance of each range with respect to pollution potential. Based on the graphs, the range for each DRASTIC factor has been assigned a rating which varies between 1 and 10 (Tables 4-10). The factors of D, R, S, T, and C have been assigned one value per range. A and I have been assigned a "typical" rating and a variable rating. The variable rating allows the user to choose either a typical value or to adjust the value based on more specific knowledge. The ratings are the same for both the DRASTIC Index and the modified Pesticide DRASTIC Index.

This system allows the user to determine a numerical value for any hydrogeologic setting by using an additive model. The equation for determining the DRASTIC Index is:

$$D_RD_W + R_RR_W + A_RA_W + S_RS_W + T_RT_W + I_RI_W + C_RC_W = \text{Pollution Potential}$$

Where:

R = rating
W = weight

Once a DRASTIC Index has been computed, it is possible to identify areas which are more likely to be susceptible to ground water contamination relative to one another. The higher the DRASTIC Index, the greater the ground-water pollution potential. The DRASTIC Index provides only a relative evaluation tool and is not designed to provide absolute answers. Therefore, the numbers generated in the DRASTIC index and in the Pesticide DRASTIC index cannot be equated.

PESTICIDE DRASTIC

Pesticide DRASTIC is designed to be used where the activity of concern is the application of pesticides to an area. It represents a special case of the DRASTIC Index. The only way in which Pesticide DRASTIC differs from DRASTIC is in the assignment of relative weights for the seven DRASTIC factors. All other parts of the two indexes are identical; the ranges, ratings and instructions for use are the same. If the user is concerned with the ground-water pollution potential of an area by pesticides, then the weights for Pesticide DRASTIC should be used.

TABLE 4. RANGES AND RATINGS FOR DEPTH TO WATER

DEPTH TO WATER (FEET)	
Range	Rating
0-5	10
5-15	9
15-30	7
30-50	5
50-75	3
75-100	2
100+	1
Weight. 5	Pesticide Weight: 5

TABLE 5. RANGES AND RATINGS FOR NET RECHARGE

NET RECHARGE (INCHES)	
Range	Rating
0-2	1
2-4	3
4-7	6
7-10	8
10+	9
Weight 4	Pesticide Weight 4

TABLE 6. RANGES AND RATINGS FOR AQUIFER MEDIA

AQUIFER MEDIA		
Range	Rating	Typical Rating
Massive Shale	1-3	2
Metamorphic/Igneous	2-5	3
Weathered Metamorphic/Igneous	3-5	4
Glacial Till	4-6	5
Bedded Sandstone, Limestone and Shale Sequences	5-9	6
Massive Sandstone	4-9	6
Massive Limestone	4-9	6
Sand and Gravel	4-9	8
Basalt	2-10	9
Karst Limestone	9-10	10
Weight 3	Pesticide Weight 3	

TABLE 7. RANGES AND RATINGS FOR SOIL MEDIA

SOIL MEDIA	
Range	Rating
Thin or Absent	10
Gravel	10
Sand	9
Peat	8
Shrinking and/or Aggregated Clay	7
Sandy Loam	6
Loam	5
Silty Loam	4
Clay Loam	3
Muck	2
Nonshrinking and Nonaggregated Clay	1
Weight: 2	Pesticide Weight 5

TABLE 8. RANGES AND RATINGS FOR TOPOGRAPHY

TOPOGRAPHY (PERCENT SLOPE)	
Range	Rating
0-2	10
2-6	9
6-12	5
12-18	3
18+	1
Weight: 1	Pesticide Weight: 3

TABLE 9. RANGES AND RATINGS FOR IMPACT OF THE VADOSE ZONE MEDIA

IMPACT OF THE VADOSE ZONE MEDIA		
Range	Rating	Typical Rating
Confining Layer	1	1
Silt/Clay	2-6	3
Shale	2-5	3
Limestone	2-7	6
Sandstone	4-8	6
Bedded Limestone, Sandstone, Shale	4-8	6
Sand and Gravel with significant Silt and Clay	4-8	6
Metamorphic/Igneous	2-8	4
Sand and Gravel	6-9	8
Basalt	2-10	9
Karst Limestone	8-10	10
Weight 5	Pesticide Weight 4	

TABLE 10. RANGES AND RATINGS FOR HYDRAULIC CONDUCTIVITY

HYDRAULIC CONDUCTIVITY (GPD/FT^2)	
Range	Rating
1-100	1
100-300	2
300-700	4
700-1000	6
1000-2000	8
2000+	10
Weight 3	Pesticide Weight: 2

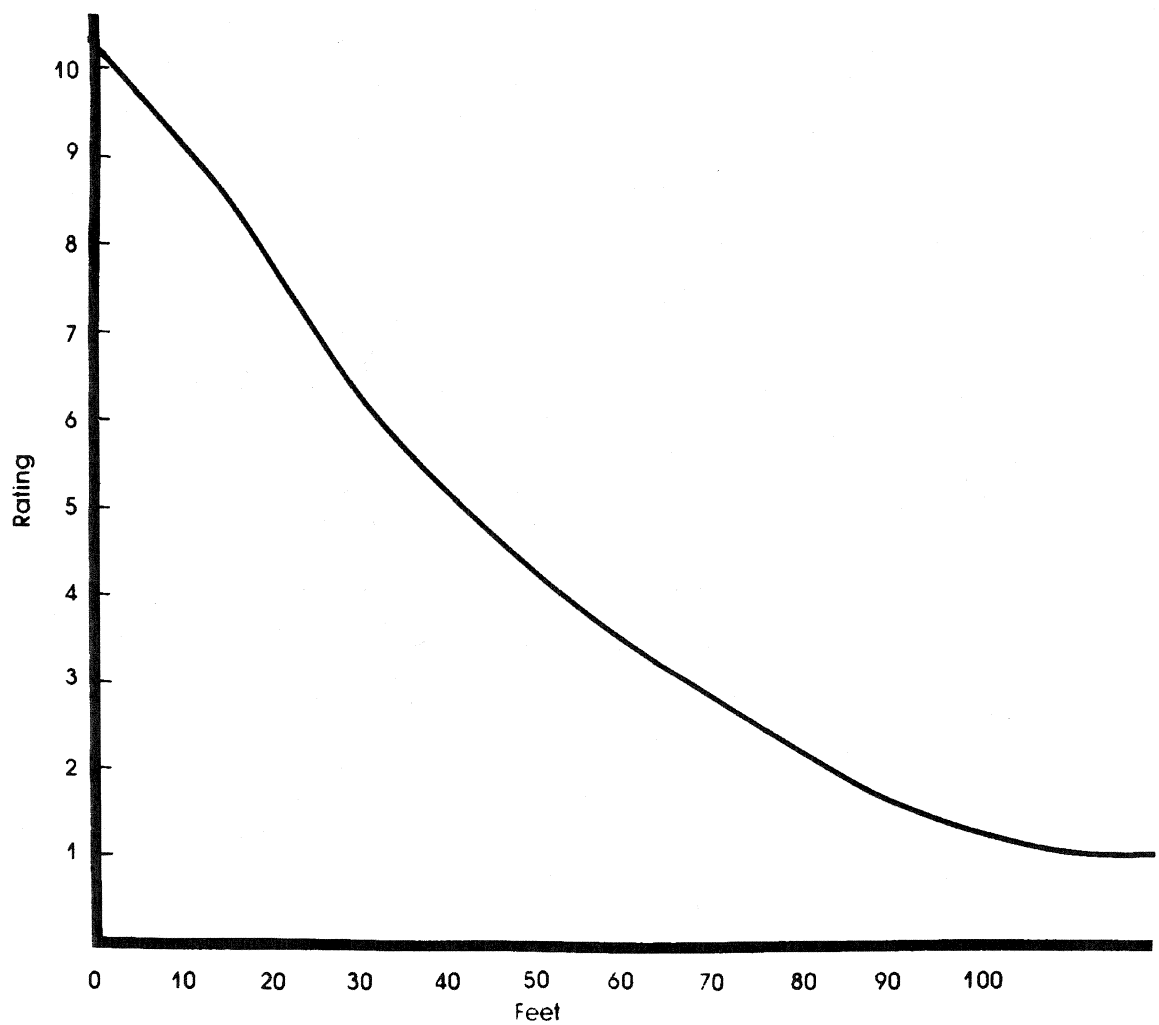


Figure 3. Graph of ranges and ratings for depth to water.

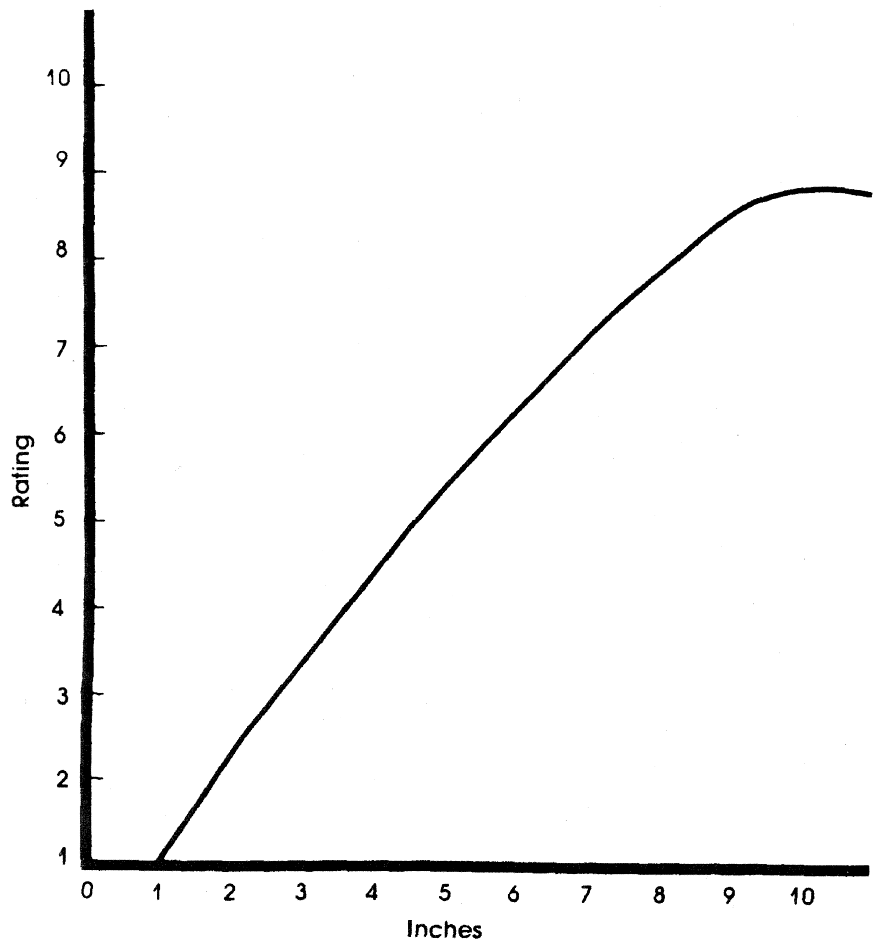
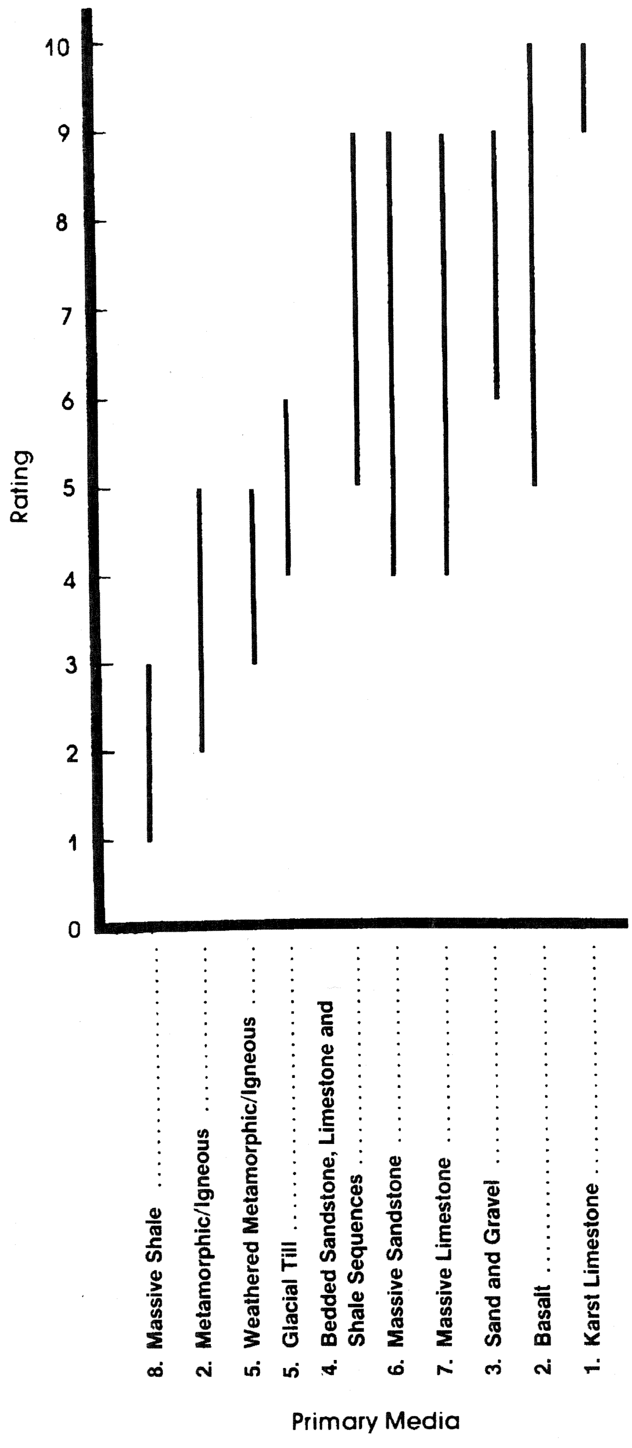


Figure 4. Graph of ranges and ratings for net recharge.



Relative ranges of ease of pollution for the principal aquifer types.
Ranges are based upon consideration of
a) route length and tortuosity
b) potential for consumptive sorption
c) dispersion
d) reactivity and
e) degree of fracturing
The primary factors controlling the rating of each rock are given below

Primary factors affecting rating:
① Reactivity (solubility and fracturing)
② Fracturing.
③ Route length and tortuosity, sorption dispersion All essentially determined by grain size sorting, and packing.
④ Route length and tortuosity as determined by bedding and fracturing
⑤ Sorption and dispersion
⑥ Fracturing, route length and tortuosity, influenced by intergranular relationships.
⑦ Reactivity (solubility) and fracturing
⑧ Fracturing and sorption

Figure 5. Graph of ranges and ratings for aquifer media.

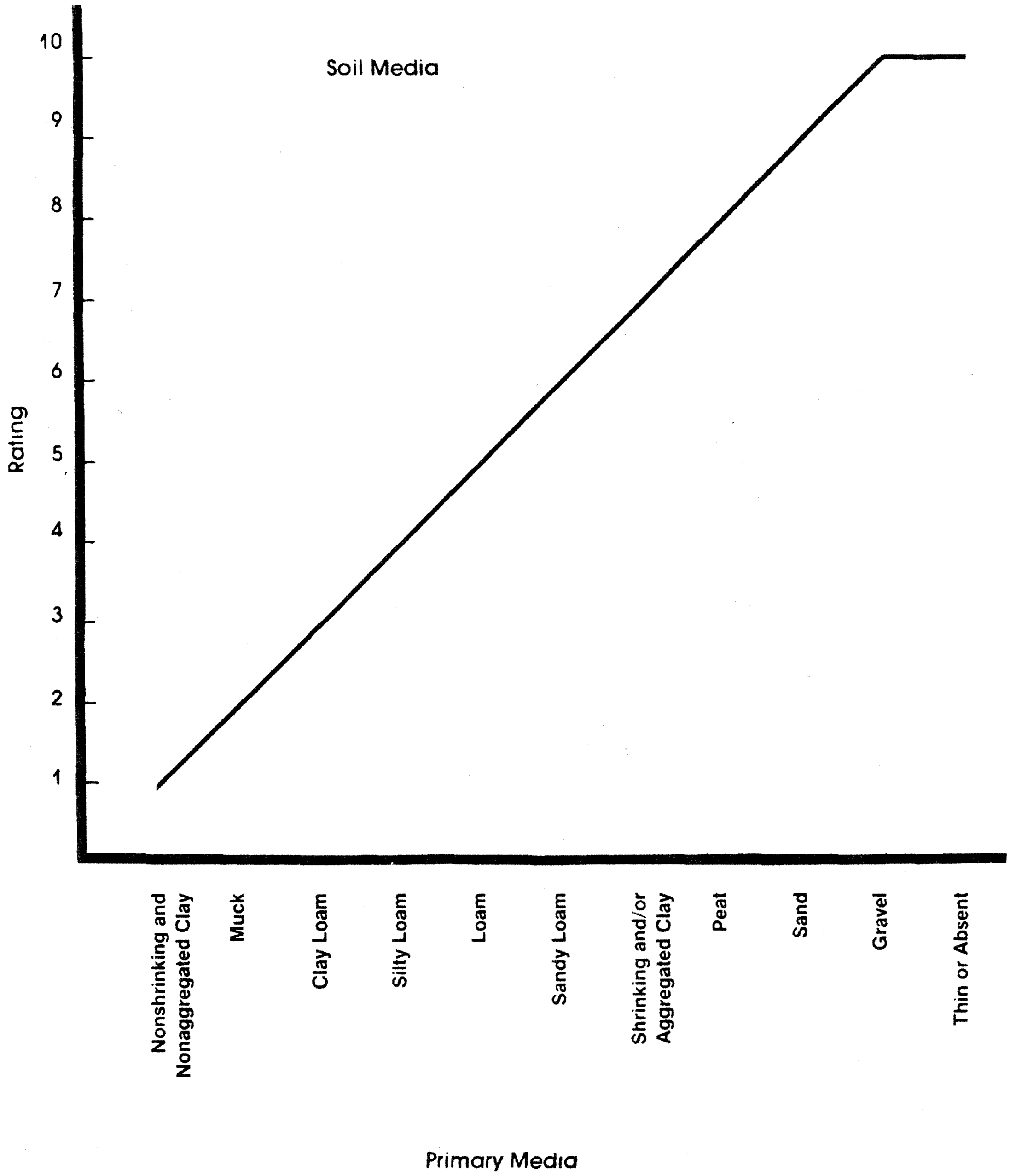


Figure 6. Graph of ranges and ratings for soil media.

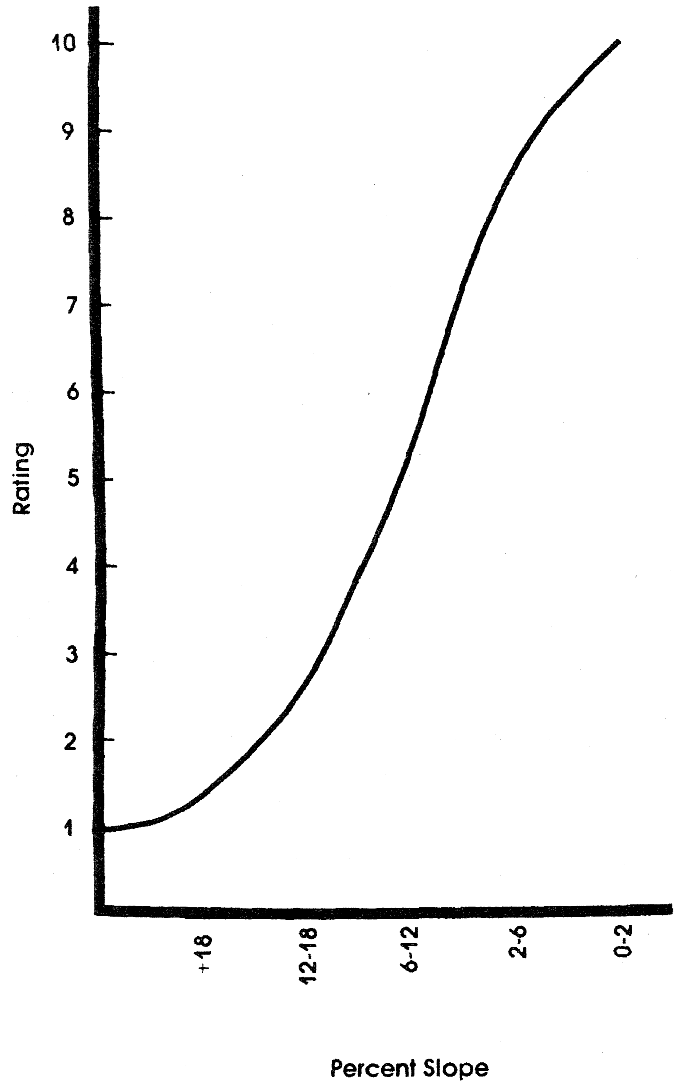
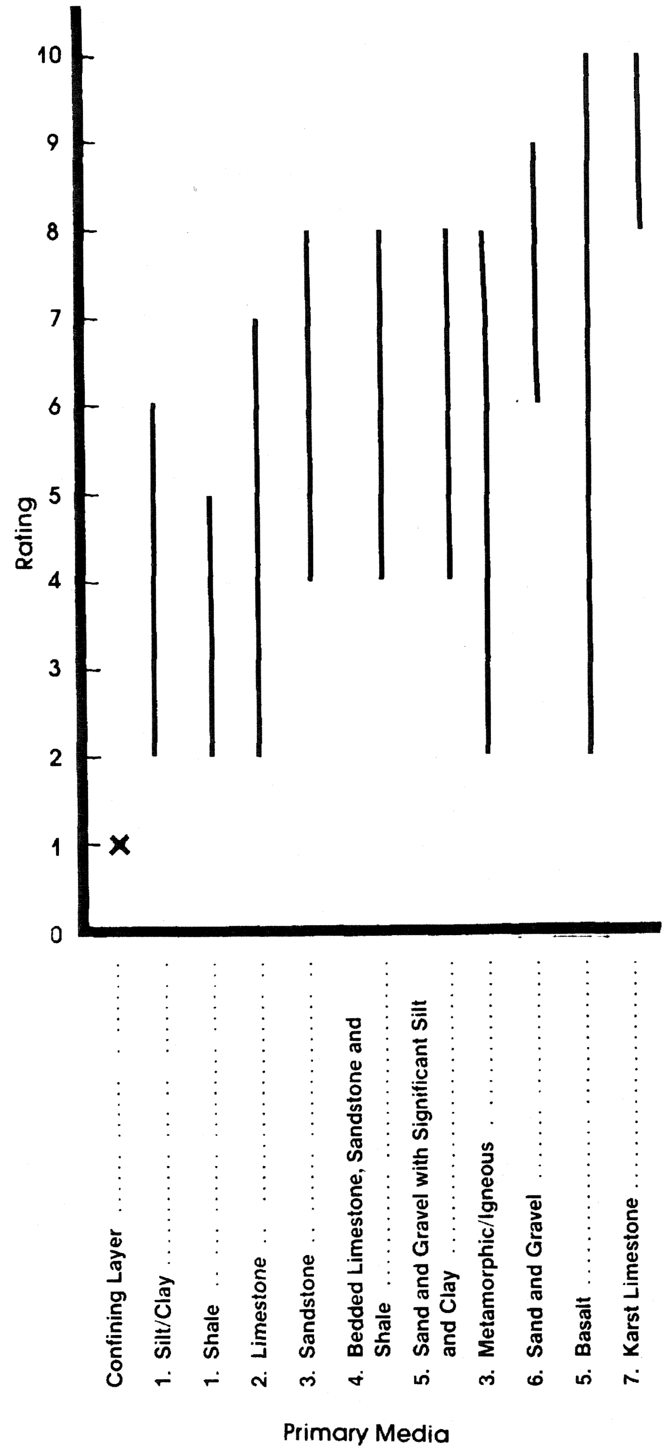


Figure 7. Graph of ranges and ratings for topography.



Relative impact of the principal Vadose Zone Media types.
Range based upon:
a) path length and tortuosity,
b) potential for dispersion and consequent dilution,
c) reactivity (solubility),
d) consumptive sorption,
e) fracturing

Primary factors affecting rating:
① Consumptive sorption and fracturing,
② Fracturing and reactivity,
③ Fracturing, path length as influenced by intergranular relationships,
④ Fracturing, path length and tortuosity as influenced by *bedding planes, sorption, and reactivity,*
⑤ Path length and tortuosity as impacted by bedding; grain size, sorting and packing, sorption,
⑥ Path length and tortuosity as influenced by grain size, sorting, and packing,
⑦ Reactivity and fracturing

Figure 8. Graph of ranges and ratings for impact of the vadose zone media.

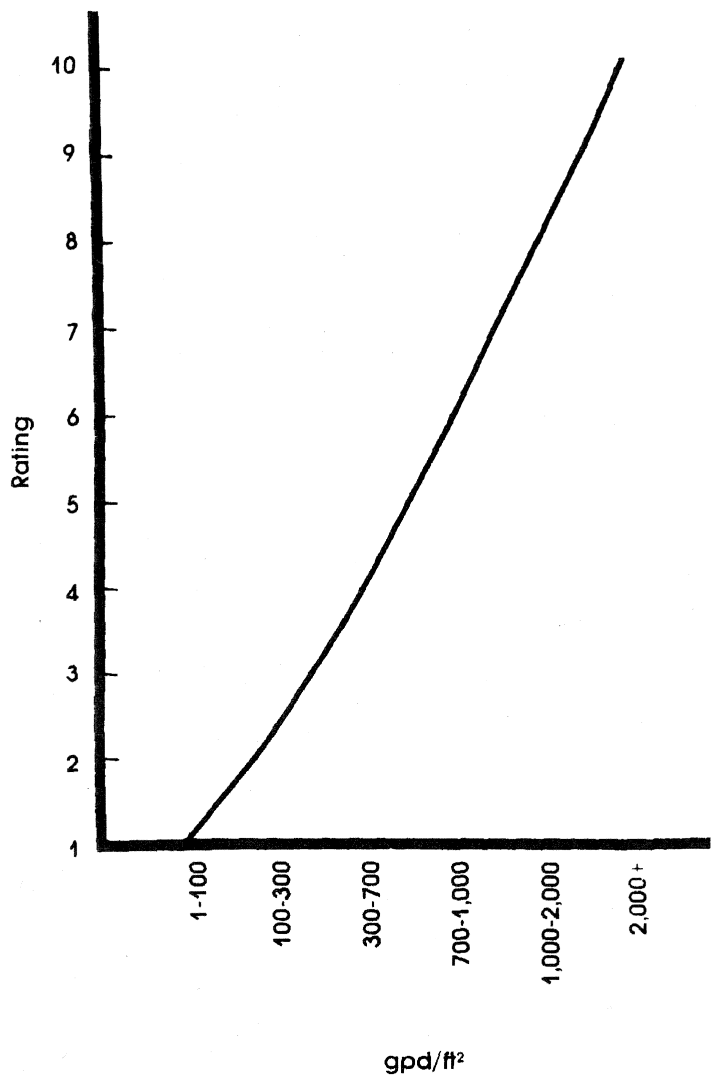


Figure 9. Graph of ranges and ratings for hydraulic conductivity.

Pesticide DRASTIC was created to address the important processes which specifically offset the fate and transport of pesticides in the soil. These processes, however, may not be as significant when assigning weights to the other DRASTIC factors for non-agricultural activities. Thus, by comparing Tables 2 and 3, it can be seen that for non-agricultural activities, Soil Media is assigned a weight of 2, while for the modified Pesticide DRASTIC, the Soil Media is assigned a weight of 5. Topography, Impact of the Vadose Zone Media and Hydraulic Conductivity of the Aquifer are also slightly different. By making these adjustments, the committee addressed the special conditions which influence the potential for ground-water contamination by pesticides. It is important to note that the relative relationship between the DRASTIC factors was not deemed significantly different enough to warrant the development of any other modified DRASTIC indexes. The user should be reminded that weights may not be changed for any of the DRASTIC factors. These relative weights form the basis for the system and any changes will make the system invalid.

INTEGRATION OF HYDROGEOLOGIC SETTINGS AND DRASTIC

The mappable hydrogeologic units and the DRASTIC Index have been combined to provide the user with a relative pollution potential for all typical hydrogeologic settings in the United States. A "typical" range for each DRASTIC factor is assigned to each hydrogeologic setting and a DRASTIC INDEX is determined for each typical hydrogeologic setting. These settings are developed as guides and are not designed to be representative of each and every area. The ranges for each factor may be adjusted by the user and the rating adjusted accordingly when available data indicate different conditions. These hydrogeologic settings provide units which are mappable and permit the drafting of pollution potential maps. Thus, the user can use hydrogeologic settings as a mappable unit, define the area of interest by modifying the ranges within a setting to reflect specific conditions within an area, choose corresponding ratings and calculate a pollution potential DRASTIC Index or a specialized index for pesticides.

TABLE 11. POTENTIAL SOURCES OF GROUND-WATER CONTAMINATION AND MODE OF EMPLACEMENT (AFTER LEHR ET AL., 1976)

On The Land Surface	In The Ground Above the Water Table	In The Ground Below the Water Table
1. Land disposal of either solid or liquid waste materials	1 Leaching tile fields, cesspools and privies	1 Waste disposal in wet excavations
2 Stockpiles	2 Holding ponds and lagoons	2. Drainage wells and canals
3. Disposal of sewage and water-treatment plant sludge	3 Sanitary landfills	3. Abandoned/improperly constructed wells
4 Salt spreading on roads, airport runways and parking lots	4 Waste disposal in excavations	4 Exploratory wells
5 Animal feed lots	5 Leakage from underground storage tanks	5 Water supply wells
6 Fertilizers and pesticides	6. Leakage from underground pipelines	6 Waste disposal wells
7 Accidental spills of hazardous materials	7 Artificial recharge	7 Mines
8 Particulate matter from airborne sources	8 Sumps and dry wells	8 Salt water intrusion
	9 Graveyards	

aquifer. A contaminant with an assumed mobility of water will migrate through the sandstone aquifer in response to the ground-water flow system. Upon reaching a restrictive layer depicted in Figure 16 by the shale, the contaminant will typically travel along that boundary particularly when head differential is upward. When a breach in the restrictive layer occurs the contaminant may migrate into other adjacent formations. Removal of the contaminant as it migrates through the aquifer will be influenced by the natural attenuation process present within this setting and the contaminant characteristics. Natural attenuation processes which affect contaminant fate and transport may differ significantly between hydrogeologic settings.

Diverse hydrogeologic conditions such as karst limestone shown in Figure 17 pose special problems with regard to contaminant transport and attenuation. Contaminants introduced at the surface and flushed into the aquifer by precipitation are transported through the solution channels and cavities within the limestone. The interconnected solution channels allow for rapid dispersal of the contaminant throughout the limestone aquifer. Although attenuation within the aquifer is limited, dilution of the contaminant may be significant.

A similarly diverse hydrogeologic condition is depicted in Figure 18. This hydrogeolgic setting represents extensively fractured igneous/metamorphic bedrock. Contaminants introduced into this aquifer system are transported rapidly through the network of interconnected fractures. Processes affecting the attenuation of the contaminant within the aquifer are limited due to the non-reactive nature of the bedrock and limited contact between the contaminant and the aquifer materials.

The above examples demonstrate that it is possible to infer the pollution potential of the setting by understanding the hydrogeology. Inherent assumptions and generalizations about ground-water flow and contaminant mobility are incorporated into the numerical score generated by using DRASTIC. When both the hydrogeologic setting and the DRASTIC Index are used simultaneously, the user generates a clearer picture of the true potential for ground-water pollution.

ASSUMPTIONS OF DRASTIC

DRASTIC and the modified Pesticide DRASTIC have been developed using four major assumptions:

1) the contaminant is introduced at the ground surface;
2) the contaminant is flushed into the ground water by precipitation;
3) the contaminant has the mobility of water; and
4) the area evaluated using DRASTIC is 100 acres or larger.

When deviations from these assumptions occur, there may be special conditions which would need to be more fully evaluated. For example, the methodology assumes that a contaminant will start at the surface, enter the soil, travel through the vadose zone and enter the aquifer much like water. However, a contaminant may have unique chemical and physical properties which

The next step is to evaluate whether the typical rating adequately characterizes the pollution potential of a contaminant in the media. For example, the selection of sandstone as a vadose zone media allows the user to choose a rating from 4 to 8. If the sandstone has very little primary porosity and very few bedding planes which would provide secondary porosity, the pollution potential would be low and the user would assign a rating of 4 to the media. If, however, the sandstone has a relatively high amount of primary porosity and is extensively fractured, a contaminant could migrate more rapidly through the media. The pollution potential would be higher, thus, the user would select a rating of 8 for this media.

A second example illustrates the adjustment of the rating to reflect depositional or formational conditions which affect the movement of a contaminant in the media. The rating for basalt may range from 2 to 10 in both the aquifer and vadose media. The environment in which the basalt was formed can significantly affect the interconnection of openings within the basalt and may also affect the degree of fracturing. This may be illustrated by examining the basalts in the Columbia River Plateau. In parts of this region, the basalts are dense, impermeable and have few fractures. Ground-water movement is restricted to the interflow zones formed between lava flows. For this type of basalt, the user would assign a rating of 2 to the media because the pollution potential is low. However, in other areas of the plateau, the basalts are comprised of thin lava flows with extensive fracturing and jointing, permeable interflow zones, and highly interconnected lava tubes. Contaminants introduced into this media would be dispersed rapidly; thus, pollution potential would be high. In these basalts, the user would assign a rating of 10.

Adjustments to unconsolidated media ratings can also be made. For example, a typical sand and gravel would receive a rating of 8. If the sand and gravel was coarse-grained, very well sorted, and contained only a small percentage of silt and clay, the user would assign a rating of 9 to this media. If the sand and gravel was poorly sorted, and contained some significant amounts of fine-grained materials, the user would assign a rating of 6 to the media. A complete discussion of the use of media ranges for aquifers and vadose media may be found in Section 3, DRASTIC: A Description of the Factors under Aquifer Media and Vadose Zone Media.

HOW TO EVALUATE CONFINED AQUIFERS

The evaluation of a confined aquifer requires the use of special definitions for several of the DRASTIC factors. The presence of a confining layer restricts contaminant movement into the aquifer. The associated reduction in pollution potential can be incorporated into the system by modifying several DRASTIC parameters to reflect the conditions which affect pollution movement.

The confined aquifer may have either an upward or downward leakage component. Hydraulic gradients which result in upward flow are not taken into consideration because a) the aquifer already has a degree of protection and b) upward gradients are easily reversed by local pumpage. Therefore, for purposes of the DRASTIC Index, the worst case scenario of a gradient into the aquifer is always assumed.

A judgement must be made in several of the DRASTIC factors as to the proper way to evaluate that factor in the specific setting. A detailed discussion of the impacts of confined aquifers on the DRASTIC parameters of depth to water, net recharge, aquifer media and the impact of the vadose zone media may be found in Section 3, DRASTIC: A Description of the Factors. Factors that must be varied, and the guidance for making the judgement of variation are as follows:

1. Depth to Water - For a confined aquifer, depth to water is defined as the depth from the ground surface to the top of the aquifer. This depth also corresponds to the base of the confining layer. The presence of a restrictive layer will limit the migration of contaminants into the aquifer. The confining layer will also restrict the rate of water movement thus providing additional time for contaminant attenuation.

2. Net Recharge - Values of net recharge may be adjusted to reflect restrictions in recharge to the aquifer due to the presence of the confining layer. If the user is uncertain as to whether the aquifer is truly confined, the aquifer should be evaluated as unconfined. Recharge areas are often located miles away from the confining aquifer. Values of net recharge can be chosen to reflect the amount of water which may actually recharge the aquifer. In portions of some confined aquifers, the ground-water gradients are upward from the confined aquifer into the confining layer. In this situation, recharge to the confined aquifer is negligible and a low recharge value may be chosen.

3. Aquifer Media - The user must make a judgement, based on available information, whether an aquifer is confined or unconfined. The hydraulic conditions of an aquifer may exhibit spatial variation. Varying degrees of confinement are not uncommon particularly when the aquifer is of large areal extent.

4. Impact of the Vadose Zone Media - When evaluating a confined aquifer, the user must choose "confining layer" as the impact of the vadose zone media. The impact of the vadose zone media reflects the ability of the geologic materials to affect a contaminant moving from the base of the soil to the top of the aquifer. Because the confining layer is the media which most significantly impacts pollution potential, the user is choosing the true impact of the vadose zone. Confining layer is used regardless of the other media composition within the vadose zone.

From this discussion, it can be seen that the vulnerability of an aquifer can be significantly impacted by the presence of a confining layer. The modifications to the DRASTIC parameters under confined conditions produce a lower DRASTIC Index, thus suggesting a reduced vulnerability to ground-water contamination. Under confined conditions, the methodology assumes that the confining layer significantly limits the migration of fluids, either contaminants or water across the restrictive layer. In many areas confining layers are not truly impermeable, but are leaky or semi-confining. Because the methodology does not allow the evaluation of a semi-confined aquifer, the user must choose to evaluate the aquifer as either confined or unconfined. The user must evaluate the degree of confinement of the aquifer.

TABLE 16. CHART FOR EXAMPLE SETTING 7Ac — GLACIAL TILL OVER SOLUTION LIMESTONE SHOWING UNCONFINED CONDITIONS

Setting 7Ac Glacial Till Over Solution Limestone		General		
Feature	Range	Weight	Rating	Number
Depth to water	30-50	5	5	25
Net recharge	4-7	4	6	24
Aquifer media	Karst limestone	3	10	30
Soil media	Clay loam	2	3	6
Topography	2-6%	1	9	9
Impact vadose zone	Silt/clay	5	3	15
Hydraulic conductivity	2000+	3	10	30
			Drastic Index	139

TABLE 17. CHART FOR EXAMPLE SETTING 7Ac — GLACIAL TILL OVER SOLUTION LIMESTONE SHOWING CONFINED CONDITIONS

Setting 7Ac Glacial Till Over Solution Limestone		General		
Feature	Range	Weight	Rating	Number
Depth to water	50-75	5	3	15
Net recharge	2-4	4	3	12
Aquifer media	Karst limestone	3	10	30
Soil media	Clay loam	2	3	6
Topography	2-6%	1	9	9
Impact vadose zone	Confining layer	5	1	5
Hydraulic conductivity	2000+	3	10	30
			Drastic Index	107

The effects of evaluating an aquifer as confined versus unconfined can be illustrated using the following example. Setting 7Ac, Glacial Till Over Solution Limestone is typified by conditions in northeastern Indiana. The aquifer is a solution limestone overlain by varying thicknesses of glacial till. The till is comprised of unsorted deposits of sand, silt and clay which may be interbedded with localized lenses of sand and gravel. Surficial deposits have weathered to a clay loam. Although the limestone is the principal aquifer, the overlying till may also be saturated. Despite the restrictive permeability of the till, recharge to the limestone aquifer is relatively high. The glacial till is in direct hydraulic connection with the aquifer and serves as a source of recharge to the limestone.

The low permeability glacial till partially confines the limestone aquifer. Because DRASTIC cannot be used to evaluate semi-confined aquifers, the aquifer must be evaluated as either confined or unconfined. If the limestone is treated as an unconfined aquifer, the depth to water will be the depth from the ground surface to the water table. In this setting, the depth to water would be the depth to the level of saturation of the till. A typical depth to water might be 30 feet which would have a rating of (5). The aquifer would still be evaluated as karst limestone and be assigned a rating of (10). The hydraulic conductivity would also be high. A typical value for high hydraulic conductivity might be 2000+ gallons per day per square foot with an associated rating of 10. Soil media would typically be a clay loam with an associated rating of (3). Topography would be 2 to 6 percent with an associated rating of (9). The vadose zone would be represented by the till and the vadose zone media would be called silt/clay with a typical rating of (3). The DRASTIC Index can be calculated to be 139 (Table 16).

It is also possible to evaluate a similar aquifer for confined conditions. Based on the modifications necessary for confined aquifers, several parameter ratings must be changed. Depth to water is now considered to be the depth from the ground surface to the top of the aquifer. In this setting, the depth to the aquifer is 60 feet. The rating for depth to water would change from a (5) to a (3). Because net recharge may be limited by the confining layer, recharge values might be adjusted from 4 to 7 inches per year (6) to 2 to 4 inches per year (3). The impact of the vadose zone media must now become "confining layer" with a rating of (1). The other parameter ratings remain unchanged. The DRASTIC index can now be calculated to be 107 (Table 17).

By comparing the two indexes for this setting, 139 (unconfined) versus 107 (confined), the impact of evaluating an aquifer as confined is demonstrated. The confined aquifer is less vulnerable to contamination than the unconfined aquifer. Although the geology of the site is unchanged, there is a major difference in the hydrogeology of the two examples and thus the relative degree of confinement affects the pollution potential of the area.

7. GLACIATED CENTRAL REGION

(Glacial deposits over fractured sedimentary rocks)

The Glaciated Central region occupies an area of 1,297,000 km^2 extending from the Triassic Basin in Connecticut and Massachusetts and the Catskill Mountains in New York on the east to the northern part of the Great Plains in Montana on the west. The part of the region in New York and Pennsylvania is characterized by rolling hills and low, rounded mountains that reach altitudes of 1,500 m. Westward across Ohio to the western boundary of the region along the Missouri River, the region is flat to gently rolling. Among the more prominent topographic features in this part of the region are low, relatively continuous ridges (moraines) which were formed at the margins of ice sheets that moved southward across the area one or more times during the Pleistocene.

The Glaciated Central region is underlain by relatively flat-lying consolidated sedimentary rocks that range in age from Paleozoic to Tertiary. They consist primarily of sandstone, shale, limestone, and dolomite. The bedrock is overlain by glacial deposits which, in most of the area, consist chiefly of till, an unsorted mixture of rock particles deposited directly by the ice sheets. The till is interbedded with and overlain by sand and gravel deposited by meltwater streams, by silt and clay deposited in glacial lakes, and, in large parts of the North-Central States, by loess, a well-sorted silt believed to have been deposited primarily by the wind.

On the Catskill Mountains and other uplands in the eastern part of the region, the glacial deposits are typically only a few to several meters thick, but localized deposits as much as 30 m thick are common on southerly slopes. In much of the central and western parts of the region, the glacial deposits exceed 100 m in thickness. The principal exception is the "driftless" area in Wisconsin, Minnesota, Iowa, and Illinois, where the ice, if it invaded the area, was too thin to erode preexisting soils or to deposit a significant thickness of till. Thus, the bedrock in this area is overlain by thin soils derived primarily from weathering of the rock. This area, both geologically and hydrologically, resembles the Nonglaciated Central region and is, therefore, included as part of that region.

The glacial deposits are thickest in valleys in the bedrock surface; thicknesses of 100 to 300 m occur in the valleys of the Finger Lakes in New York. In most of the region westward from the Ohio to the Dakotas, the thickness of the glacial deposits exceeds the relief on the preglacial surface, with the result that the locations of valleys and stream channels in the preglacial surface are no longer discernible from the land surface. The glacial deposits in valleys include, in addition to till and lacustrine silts and clays, substantial thicknesses of highly permeable sand and gravel.

Ground water occurs both in the glacial deposits and in the bedrock. Water occurs in the glacial deposits in pores between the rock particles and in the bedrock primarily along fractures. The dominant water-bearing fractures in the bedrock are along bedding planes. Water also occurs in the bedrock in steeply dipping fractures that cut across the beds and, in some sandstones and conglomerates, in primary pores that were not destroyed in the process of cementation and consolidation.

Large parts of the region are underlain by limestones and dolomites in which the fractures have been enlarged by solution. Caves are relatively common in the limestones where the ice sheets were relatively thin, as near the southern boundary of the region and in the "driftless" area. A few caves occur in other parts of the region, notably in the Mohawk River valley in central New York, where they were apparently protected from glacial erosion by the configuration of the bedrock surface over which the ice moved. However, on the whole, caves and other large solution openings, from which large springs emerge and which yield large quantities of water to wells in parts of the Nonglaciated Central region, are much less numerous and hydrologically much less important in the Glaciated Central region.

The glacial deposits are recharged by precipitation on the interstream areas and serve both as a source of water to shallow wells and as a reservoir for recharge to the underlying bedrock. Precipitation ranges from about 400 mm per year in the western part of the region to about 1,000 mm in the eastern part. Recharge also depends on the permeability of the glacial deposits exposed at the land surface and on the slope of the surface. On sloping hillsides underlain by clay-rich till, the annual rate of recharge, even in the humid eastern part of the region, probably does not exceed 50 mm. In contrast, relatively flat areas underlain by sand and gravel may receive as much as 300 mm of recharge annually in the eastern part of the region. Recharge of the ground-water system in the Glaciated Central region occurs primarily in the fall, after plant growth has stopped and cool temperatures have reduced evaporation, and again during the spring thaw before plant growth begins. Of these recharge periods, the spring thaw is usually dominant except when fall rains are unusually heavy. Minor amounts of recharge also may occur during midwinter thaws and during unusually wet summers.

Ground water in small to moderate amounts can be obtained anyplace in the region, both from the glacial deposits and from the bedrock. Large to very large amounts are obtained from the sand and gravel deposits and from some of the limestones, dolomites, and sandstones in the North-Central States. The shales are the least productive bedrock formations in the region.

As is the case in the Nonglaciated Central region, mineralized water occurs at relatively shallow depth in the bedrock in large parts of this region. Because the principal constituent in the mineralized water is sodium chloride (common salt), the water is commonly referred to as saline or salty. The thickness of the freshwater zone in the bedrock depends on the vertical hydraulic conductivity of both the bedrock and the glacial deposits and on the effectiveness of the hydraulic connection between them. Both the freshwater and the underlying saline water move toward the valleys of perennial streams to discharge. As a result, the depth to saline water is less under valleys than under uplands, both because of lower altitudes and because of the upward movement of the saline water to discharge. In those parts of the region underlain by saline water, the concentration of dissolved solids increases with depth. At depths of 500 to 1,000 m in much of the region, the mineral content of the water approaches that of seawater (about 35,000 mg/L). At greater depths, the mineral content may reach concentrations several times that of seawater.

Because the Glaciated Central region resembles in certain aspects both the Nonglaciated Central region (region 6) to the south and the Northwest and Superior Uplands region (region 9) to the north, it may be useful to comment on the principal differences among these three regions. First, and as is already apparent, the bedrock in the Glaciated Central and the Nonglaciated Central regions is similar in composition and structure. The difference in these two regions is in the composition and other characteristics of the overlying unconsolidated material. In the Nonglaciated Central region this material consists of a relatively thin layer that is derived from weathering of the underlying bedrock and that in any particular area is of relatively uniform composition. In the Glaciated Central region, on the other hand, the unconsolidated material consists of a layer, ranging in thickness from a few meters to several hundred meters, of diverse composition deposited either directly from glacial ice (till) or by meltwater streams (glaciofluvial deposits). From a hydrologic standpoint, the unconsolidated material in the Nonglaciated Central region is of minor importance both as a source of water and as a reservoir for storage of water for the bedrock. In contrast, the glacial deposits in the Glaciated Central region serve both as a source of ground water and as an important storage reservoir for the bedrock.

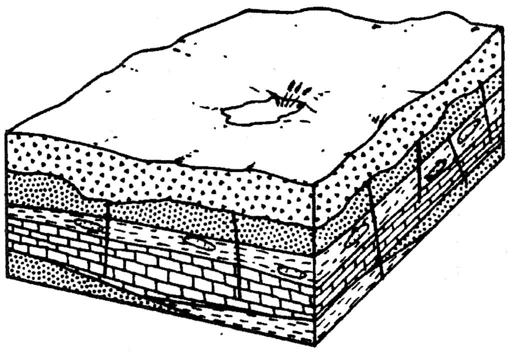
The Glaciated Central region and the Northeast and Superior Uplands region are similar in that the unconsolidated material in both consists of glacial deposits. However, the bedrock in the two regions is different. The bedrock in the Glaciated Central region, as we have already seen, consists of consolidated sedimentary rocks that contain both steeply dipping fractures and fractures along bedding planes. In the Northeast and Superior Uplands, on the other hand, the bedrock is composed of intrusive igneous and metamorphic rocks (nonbedded) in which most water-bearing openings are steeply-dipping fractures. As a result of the differences in fractures, the bedrock in the Glaciated Central region is, in general, a more productive and more important source of ground water than the bedrock in the Northeast and Superior Uplands region.

The largest fresh-water supply in North America, the Great Lakes, is located in this region. Bordering the Great Lakes, there are abandoned beach ridges, present-day beaches and sand dunes, all of which are very sensitive environmental areas.

GLACIATED CENTRAL

(7Aa) Glacial Till Over Bedded Sedimentary Rocks

This hydrogeologic setting is characterized by low topography and relatively flat-lying, fractured sedimentary rocks consisting of sandstone, shale and limestone which are covered by varying thicknesses of glacial till. The till is principally unsorted deposits which may be interbedded with loess or localized deposits of sand and gravel. Although ground water occurs in both the glacial deposits and in the intersecting bedrock fractures, the bedrock is typically the principal aquifer. The glacial till serves as a source of recharge to the underlying bedrock. Although precipitation is abundant in most of the region, recharge is moderate because of the glacial till and soils which are typically clay loams. Depth to water is extremely variable depending in part on the thickness of the glacial till, but averages around 30 feet.



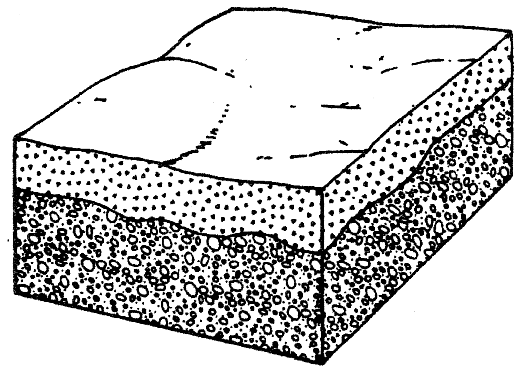
ING 7 Aa Glacial Till Over Bedded Sedimentary Rock		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	103

SETTING 7 Aa Glacial Till Over Bedded Sedimentary Rock		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Clay Loam	5	3	15
Topography	2-6%	3	9	27
Impact Vadose Zone	Silt/Clay	4	3	12
Hydraulic Conductivity	100-300	2	2	4
			Pesticide Drastic Index	125

GLACIATED CENTRAL

(7Ab) Glacial Till Over Outwash

This hydrogeologic setting is characterized by low topography and outwash materials which are covered by varying thicknesses of glacial till. The till is principally unsorted deposits which may be interbedded with loess or localized deposits of sand and gravel. Surficial deposits have usually weathered to a clay loam. Although ground water occurs in both the glacial deposits and in the underlying outwash, the outwash typically serves as the principal aquifer because the fine-grained deposits have been removed by glacial meltwater. The outwash is in direct hydraulic connection with the glacial till and glacial till serves as a source of recharge for the underlying outwash. This setting is similar to (7Aa) Glacial Till Over Bedded Sedimentary Rock and (7Ac) Glacial Till Over Solution Limestone in that although precipition is abundant in most of the region, recharge is moderate because of the relatively low permeability of the overlying glacial till. Depth to water is extremely variable depending in part on the thickness of the glacial till, but averages around 30 feet.



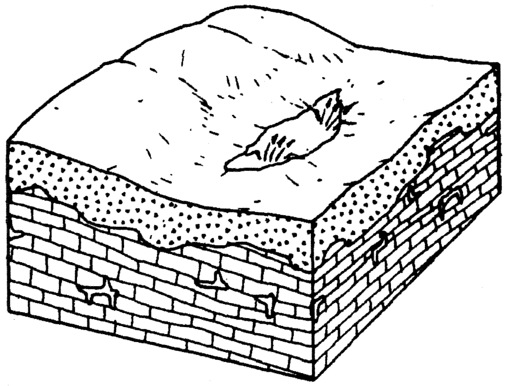
SETTING 7 Ab Glacial Till Over Outwash		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	137

SETTING 7 Ab Glacial Till Over Outwash		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Clay Loam	5	3	15
Topography	2-6%	3	9	27
Impact Vadose Zone	Silt/Clay	4	3	12
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	153

GLACIATED CENTRAL

(7Ac) Glacial Till Over Solution Limestone

This hydrogeologic setting is characterized by low topography and solution limestone which are covered by varying thicknesses of glacial till. The till is principally unsorted deposits which may be interbedded with loess or localized deposits of sand and gravel. Surficial deposits have usually weathered to a clay loam. Although ground water occurs in both the glacial deposits and in the underlying limestone, the limestone, which typically contains solution cavities, typically serves as the principal aquifer. The limestone is in direct hydraulic connection with the glacial till and the glacial till serves as a source of recharge for the underlying limestone. This setting is similar to (7Aa) Glacial Till Over Bedded Sedimentary Rock and (7Ab) Glacial Till Over Outwash in that although precipitation is abundant in most of the region, recharge is moderate because of the relatively low permeability of the overlying glacial till. Depth to water is extremely variable depending in part on the thickness of the glacial till, but is typically moderately deep.



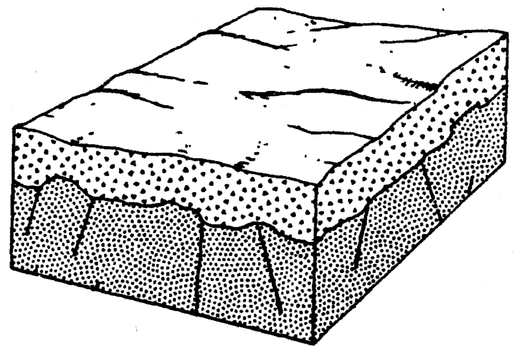
SETTING 7 Ac Glacial Till Over Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	139

SETTING 7 Ac Glacial Till Over Solution Limestone		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Clay Loam	5	3	15
Topography	2-6%	3	9	27
Impact Vadose Zone	Silt/Clay	4	3	12
Hydraulic Conductivity	2000+	2	10	20
			Pesticide Drastic Index	153

GLACIATED CENTRAL

(7Ad) Glacial Till Over Sandstone

This hydrogeologic setting is characterized by low topography and relatively flat-lying, fractured sandstones which are covered by varying thicknesses of glacial till. The till is principally unsorted deposits which may be interbedded with loess or localized deposits of sand and gravel. Although ground water occurs in both the glacial deposits and in the intersecting bedrock fractures, the bedrock is typically the principal aquifer. The glacial till serves as a source of recharge to the underlying bedrock. Although precipitation is abundant in most of the region, recharge is moderate because of the glacial tills which typically weather to clay loam. Depth to water is extremely variable, depending in part on the thickness of the glacial till, but averages around 40 feet.



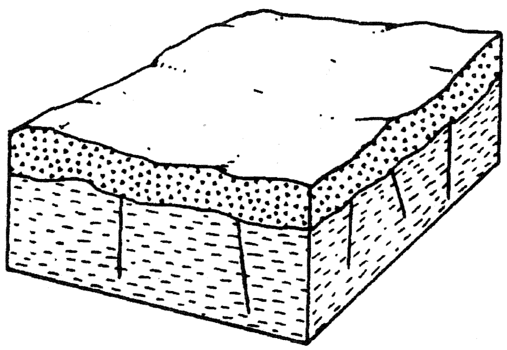
SETTING 7 Ad Glacial Till Over Sandstone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	Massive Sandstone	3	6	18
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	109

SETTING 7 Ad Glacial Till Over Sandstone		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	Massive Sandstone	3	6	18
Soil Media	Clay Loam	5	3	15
Topography	2-6%	3	9	27
Impact Vadose Zone	Silt/Clay	4	3	12
Hydraulic Conductivity	300-700	2	4	8
			Pesticide Drastic Index	129

GLACIATED CENTRAL

(7Ae) Glacial Till Over Shale

This hydrogeologic setting is similar to (7Ad) Glacial Till Over Sandstone except that varying thickness of till overlie fractured, flat-lying shales. The till is principally unsorted deposits with interbedded lenses of loess and sand and gravel. Ground water is derived from either localized sources in the overlying till or from deeper, more permeable formations. The shale is relatively impermeable and does not serve as a source of ground water. Although precipitation is abundant, recharge is minimal from the till to deeper formations and occurs only by leakage of water through the fractures.



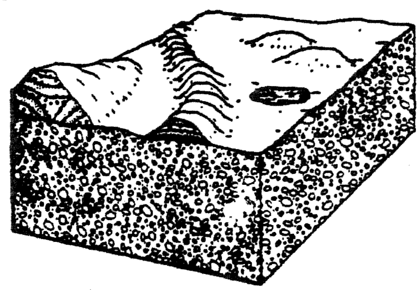
SETTING 7 Ae Glacial Till Over Shale		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	Massive Shale	3	2	6
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	88

SETTING 7 Ae Glacial Till Over Shale		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	Massive Shale	3	2	6
Soil Media	Clay Loam	5	3	15
Topography	2-6%	3	9	27
Impact Vadose Zone	Silt/Clay	4	3	12
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	111

GLACIATED CENTRAL

(7Ba) Outwash

This hydrogeologic setting is characterized by moderate to low topography and varying thicknesses of outwash which overlie sequences of fractured sedimentary rocks. The outwash consists of water-washed deposits of sand and gravel which serve as the principal aquifer in the area. The outwash also serves as a source of recharge to the underlying bedrock. Precipitation is abundant throughout most of the area and recharge is moderate to high. Recharge is somewhat restricted by the sandy loam soil which typically develops in this setting. Water levels are extremely variable, but relatively shallow. Outwash generally refers to water-washed or ice-contact deposits, and can include a variety of morphogenic forms. Outwash plains are thick sequences of sands and gravels that are laid down in sheet-like deposits from sediment-laden waters draining off, and from within a glacier. These deposits are well-sorted and have relatively high permeabilities. Kames and eskers are ice-contact deposits. A kame is an isolated hill or mound of stratified sediments deposited in an opening within or between ice blocks, or between ice blocks and valley walls. An esker is a sinuous or meandering ridge of well-sorted sands and gravels that are remnants of streams that existed beneath and within the glaciers. These deposits may be in direct hydraulic connection with underlying fractured bedrock.



SETTING 7 Ba Outwash		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	176

SETTING 7 Ba Outwash		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	2-6%	3	9	27
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	196

GLACIATED CENTRAL

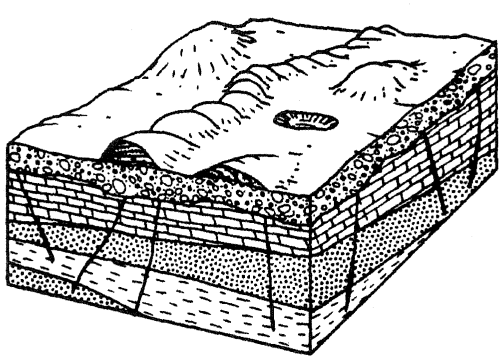
(7Bb) Outwash Over Bedded Sedimentary Rock

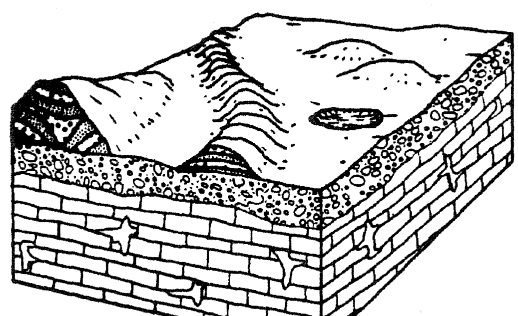
This hydrogeologic setting is characterized by moderate to low topography and relatively flat-lying, fractured sedimentary rocks consisting of sandstones, shales and limestone which are covered by varying thicknesses of glacial outwash. The outwash consists of a variety of water-washed deposits of sand and gravel which serve as the principal aquifer in the area. The outwash also serves as a source of recharge to the underlying bedrock. Precipitation is abundant throughout most of the area and recharge is moderate to high. Water levels are extremely variable, but typically shallow.

GLACIATED CENTRAL

(7Bc) Outwash Over Solution Limestone

This hydrogeologic setting is characterized by low topography and solution limestone which is covered by varying thicknesses of glacial outwash. The outwash consists of varying types of water-washed deposits that typically weather to sandy loam soils. Both the outwash and the solution limestone serve as principal aquifers in the area. The solution limestone is in direct hydraulic connection with the glacial outwash and the outwash serves as a source of recharge for the underlying limestone. Water levels are extremely variable and in part dependent on the thickness of the overlying outwash.





SETTING 7 Bb Outwash Over Bedded Sedimentary Rock		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	156

SETTING 7 Bb Outwash Over Bedded Sedimentary Rock		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Sandy Loam	5	6	30
Topography	2-6%	3	9	27
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	100-300	2	2	4
			Pesticide Drastic Index	182

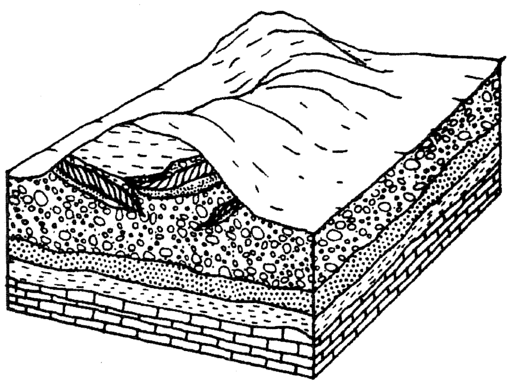
SETTING 7 Bc Outwash Over Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	186

SETTING 7 Bc Outwash Over Solution Limestone		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sandy Loam	5	6	30
Topography	2-6%	3	9	27
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	206

GLACIATED CENTRAL

(7C) Moraine

This hydrogeologic setting is characterized by moderate to moderately steep topography and varying thicknesses of mixed glacial deposits which overlie sequences of relatively flat-lying fractured sedimentary rocks. This setting is similar to (7Ba) Outwash in that the sand and gravel within the morainal deposits may be well-sorted and serve as the principal aquifer in the area. These deposits also serve as a source of recharge for the underlying bedrock. Moraines also contain sediments that are typically unsorted and unstratified; these deposits contain more fines than outwash deposits, are less permeable and characteristic of glacial till. Moraines are typically mounds or ridges of till which were deposited along the margin of a stagnant or retreating glacier. Surficial deposits often weather to sandy loam. Precipitation is abundant throughout the region and ground-water recharge is moderate. Water levels are extremely variable, based in part on the thickness of the glacial till, but are typically fairly shallow.



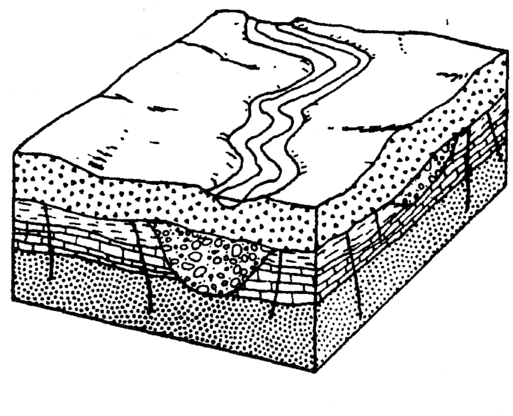
SETTING 7 C Moraine		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	6-12%	1	5	5
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	135

SETTING 7 C Moraine		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	6-12%	3	5	15
Impact Vadose Zone	Silt/Clay	4	3	12
Hydraulic Conductivity	300-700	2	4	8
			Pesticide Drastic Index	156

GLACIATED CENTRAL

(7D) Buried Valley

This hydrogeologic setting is characterized by thick deposits of sand and gravel that have been deposited in a former topographic low (usually a pre-glacial river valley) by glacial meltwaters. These deposits are capable of yielding large quantities of ground water. The deposits may or may not underlie a present-day river and may or may not be in direct hydraulic connection with a stream. Glacial till or recent alluvium often overlies the buried valley. Usually the deposits are several times more permeable than the surrounding bedrock, with finer-grained alluvium covering the underlying sand and gravel. Soils are typically a sandy loam. Recharge to the sand and gravel is moderate and water levels are commonly relatively shallow, although they may be quite variable.



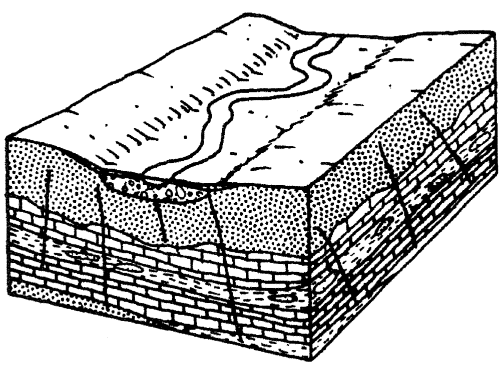
SETTING 7 D Buried Valley		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	S & G w/sig. Silt and Clay	5	6	30
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	156

SETTING 7 D Buried Valley		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	2-6%	3	9	27
Impact Vadose Zone	S & G w/sig. Silt and Clay	4	6	24
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	178

GLACIATED CENTRAL

(7Ea) River Alluvium With Overbank Deposits

This hydrogeologic setting is characterized by low topography and thin to moderately thick deposits of flood-deposited alluvium along portions of the river valley. The alluvium is underlain by fractured bedrock of sedimentary, metamorphic or igneous origin. Water is obtained from sand and gravel layers which are interbedded with finer-grained alluvial deposits. The floodplain is covered by varying thicknesses of fine-grained silt and clay called overbank deposits. The overbank thickness is usually greater along major streams (as much as 40 feet) and thinner along minor streams. Precipitation in the region varies, but recharge is somewhat reduced because of the silty and clayey overbank soils which typically cover the surface. Water levels are moderately shallow. Ground water may be in direct hydraulic contact with the surface stream. The alluvium may serve as a significant source of water and may also be in direct hydraulic with the underlying sedimentary rocks.



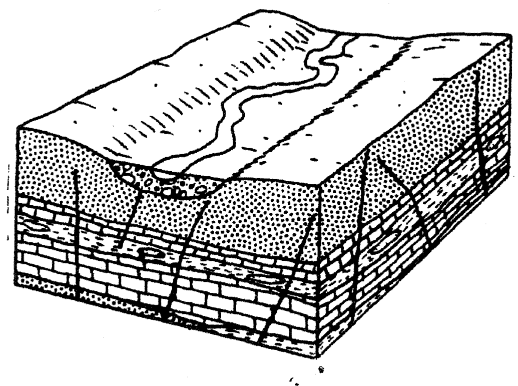
SETTING 7 Ea River Alluvium With Overbank Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	2	4	8
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	134

SETTING 7 Ea River Alluvium With Overbank Deposits		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	5	4	20
Topography	0-2%	3	10	30
Impact Vadose Zone	Silt/Clay	4	3	12
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	157

GLACIATED CENTRAL

(7Eb) River Alluvium Without Overbank Deposits

This setting is identical to (6Fa) River Alluvium with Overbank Deposits except that no significant fine-grained floodplain deposits occupy the stream valley. This results in significantly higher recharge where precipitation is adequate and sandy soils occur at the surface. Water levels are moderate to shallow in depth. Hydraulic contact with the surface stream is usually excellent, with alternating recharge/discharge relationships varying with stream stage. These deposits also serve as a good source of recharge to the underlying fractured bedrock.



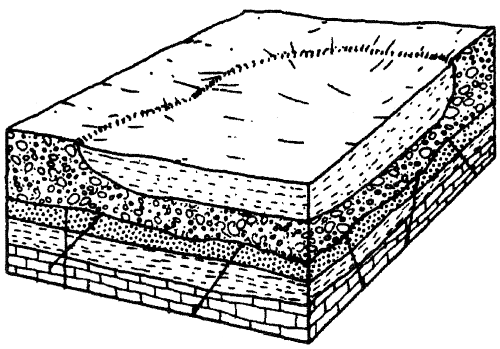
SETTING 7 Eb River Alluvium Without Overbank Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	191

SETTING 7 Eb River Alluvium Without Overbank Deposits		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	5	9	45
Topography	0-2%	3	10	30
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	224

GLACIATED CENTRAL

(7F) Glacial Lake Deposits

This hydrogeologic setting is characterized by flat topography and varying thicknesses of fine-grained sediments that overlie sequences of fractured sedimentary rocks. The deposits are composed of fine-grained silts and clays interlayered with fine sand that settled out in glacial lakes and exhibit alternating layers relating to seasonal fluctuations. As a consequence of the thin, alternating layers there is a substantial difference between the vertical and horizontal permeability with the horizontal commonly two or more orders of magnitude greater than the vertical. Due to their fine-grained nature, these deposits typically weather to organic-rich sandy loams with a range in permeabilities reflecting variations in sand content. Underlying glacial deposits or bedrock serve as the major source of ground water in the region. Although precipitation is abundant, recharge is controlled by the permeability of the surface clays; however, in all instances recharge is moderately high because of the impact of the low topography. Water levels are variable, depending on the thickness of the lake sediments and the underlying materials.



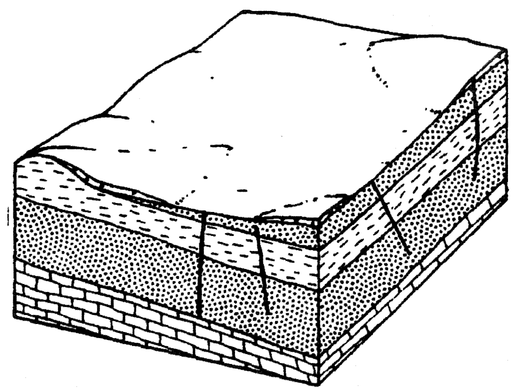
SETTING 7 F Glacial Lake Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	S & G w/ sig. Silt and Clay	5	6	30
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	135

SETTING 7 F Glacial Lake Deposits		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Sandy Loam	5	6	30
Topography	0-2%	3	10	30
Impact Vadose Zone	S & G w/ sig. Silt and Clay	4	6	24
Hydraulic Conductivity	100-300	2	2	4
			Pesticide Drastic Index	165

GLACIATED CENTRAL

(7G) Thin Till Over Bedded Sedimentary Rock

This hydrogeologic setting is characterized by moderate to low topography and deposits of thin, patchy glacial till overlying alternating layers of fractured consolidated sedimentary rocks. The till, where present, is primarily unsorted deposits of clay, sand and gravel. Although ground water occurs in both the till and in the intersecting fractures of the bedrock, the bedrock is the principal aquifer. The glacial till serves as a source of recharge to the underlying bedrock. Although precipitation is abundant in most of the region, recharge is moderate because of the glacial tills and clayey soils. Water levels are extremely variable, but usually moderate.



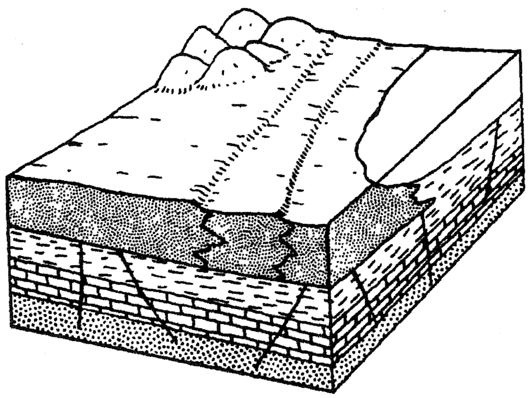
SETTING 7 G Thin Till Over Bedded Sedimentary Rock		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	121

SETTING 7 G Thin Till Over Bedded Sedimentary Rock		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Clay Loam	5	3	15
Topography	2-6%	3	9	27
Impact Vadose Zone	Silt/Clay	4	3	12
Hydraulic Conductivity	100-300	2	2	4
			Pesticide Drastic Index	143

GLACIATED CENTRAL

(7H) Beaches, Beach Ridges and Sand Dunes

This hydrogeologic setting is characterized by low relief, sandy surface soil that is predominantly silica sand, extremely high infiltration rates and low sorptive capacity in the thin vadose zone. The water table is very shallow beneath the beaches bordering the Great Lakes. These beaches are commonly ground-water discharge areas. The water table is slightly deeper beneath the rolling dune topography and the vestigial inland beach ridges. All of these areas serve as recharge sources for the underlying sedimentary bedrock aquifers, and they often serve as local sources of water supply.



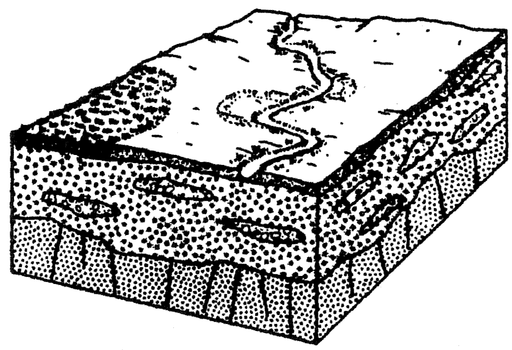
SETTING 7 H Beaches, Beach Ridges and Sand Dunes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	202

SETTING 7 H Beaches, Beach Ridges and Sand Dunes		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	5	9	45
Topography	0-2%	3	10	30
Impact Vadose Zone	Sand and Gravel	4	8	24
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	225

GLACIATED CENTRAL

(7I) Swamp/Marsh

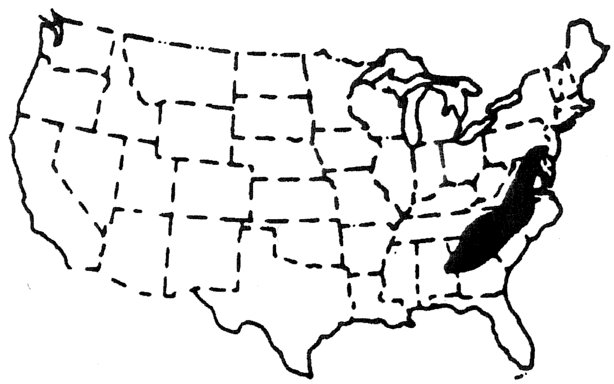
This hydrogeologic setting is characterized by low topographic relief, high water levels and high organic silt and clay deposits. These wetlands occur along the courses of floodplains and in upland areas as a result of vertically restricted drainage. Common features of upland wetlands include those characteristics attributable to glacial activity such as filled-in glacial lakes, potholes and cranberry bogs. Recharge is moderate in most of the region due to restriction by clayey soils and limited by precipitation. The swamp deposits very rarely serve as significant aquifers but frequently recharge the underlying sand and gravel or bedrock aquifers.

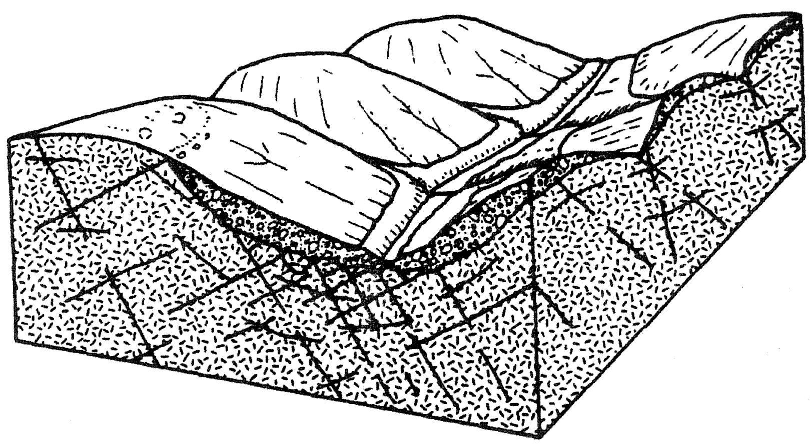


SETTING 7 I Swamp/Marsh		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Muck	2	2	4
Topography	0-2	1	10	10
Impact Vadose Zone	S & G w/sig. Silt and Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	160

SETTING 7 I Swamp/Marsh		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	6	24
Soil Media	Muck	5	2	10
Topography	0-2	3	10	30
Impact Vadose Zone	S & G w/sig. Silt and Clay	4	6	24
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	174

8. PIEDMONT BLUE RIDGE GROUND-WATER REGION





8A	Mountain Slopes
8B	Alluvial Mountain Valleys
8C	Mountain Flanks
8D	Regolith
8E	River Alluvium
8F	Mountain Crests
8G	Swamp/Marsh

8. PIEDMONT BLUE RIDGE REGION

(Thick regolith over fractured crystalline and metamorphosed sedimentary rocks)

The Piedmont and Blue Ridge region is an area of about 247,000 km2 extending from Alabama on the south to Pennsylvania on the north. The Piedmont part of the region consists of low, rounded hills and long, rolling, northeast-southwest trending ridges whose summits range from about a hundred meters above sea level along its eastern boundary with the Coastal Plain to 500 to 600 m along its boundary with the Blue Ridge area to the west. The Blue Ridge is mountainous and includes the highest peaks east of the Mississippi. The mountains, some of which reach altitudes of more than 2,000 m, have smooth-rounded outlines and are bordered by well-graded streams flowing in relatively narrow valleys.

The Piedmont and Blue Ridge region is underlain by bedrock of Precambrian and Paleozoic age consisting of igneous and metamorphosed igneous and sedimentary rocks. These include granite, gneiss, schist, quartzite, slate, marble, and phyllite. The land surface in the Piedmont and Blue Ridge is underlain by clay-rich, unconsolidated material derived from in situ weathering of the underlying bedrock. This material, which averages about 10 to 20 m in thickness and may be as much as 100 m thick on some ridges, is referred to as saprolite. In many valleys, especially those of larger streams, flood plains are underlain by thin, moderately well-sorted alluvium deposited by the streams. When the distinction between saprolite and alluvium is not important, the term regolith is used to refer to the layer of unconsolidated deposits.

The regolith contains water in pore spaces between rock particles. The bedrock, on the other hand, does not have any significant intergranular porosity. It contains water, instead, in sheetlike openings formed along fractures (that is, breaks in the otherwise "solid" rock). The hydraulic conductivities of the regolith and the bedrock are similar and range from about 0.001 to 1 m day^{-1}. The major difference in their water-bearing characteristics is their porosities, that of regolith being about 20 to 30 percent and that of the bedrock about 0.01 to 2 percent. Small supplies of water adequate for domestic needs can be obtained from the regolith through large-diameter bored or dug wells. However, most wells, especially those where moderate supplies of water are needed, are relatively small in diameter and are cased through the regolith and finished with open holes in the bedrock. Although, as noted, the hydraulic conductivity of the bedrock is similar to that of the regolith, bedrock wells generally have much larger yields than regolith wells because, being deeper, they have a much larger availble drawdown.