DRASTIC: A STANDARDIZED SYSTEM TO EVALUATE GROUND WATER POLLUTION POTENTIAL USING HYDROGEOLOGIC SETTINGS

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DRASTIC is a methodology which allows the pollution potential of any area to be systematically evaluated anywhere in the United States. The system optimizes the use of existing data and has two major portions: the designation of mappable units, termed hydrogeologic settings, and the superposition of a relative ranking system called DRASTIC. Hydrogeologic settings incorporate the major hydrogeologic factors which are used to infer the potential for contaminants to enter ground water. These factors form the acronym DRASTIC and include depth to water, net recharge, aquifer media, soil media, topography, impact of the vadose zone and hydraulic conductivity of the aquifer. The relative ranking scheme uses a combination of weights and ratings to produce a numerical value, called the DRASTIC Index, which helps prioritize areas with respect to pollution potential.

Introduction

National reliance on ground water has increased dramatically over the past twenty years. 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 occured 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. The potential for ground water contamination to occur is affected by the physical characteristics of the area, the chemical nature of the pollutant, the rate frequency and the method of application. This paper presents a standardized system which incorporates physical characteristics of any area into a methodology which can be used to evaluate the ground water pollution potential of any hydrogeologic setting in the United States. The system has been designed to use existing information which is available from 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.

The system 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. Only a basic knowledge of hydrogeology and the processes which govern ground water contamination are necessary to use the system. The methodology is designed as a broad brush planning tool and is not intended to replace on site inspections or detailed hydrogeologic investigations. Rather it is intended to provide a basis for comparative evaluation of the areas with respect to potential for pollution of ground water. The system presented herein is part of a more complete document developed for the United States Environmental Protection Agency. A complete description of that methodology is contained in the draft document EPA #600/2-85/018.

The DRASTIC methodology has two major portions: the designation of mappable units, termed hydrogeologic settings; and the application of a scheme for relative ranking of hydrogeologic parameters, called DRASTIC, which helps the user evaluate the relative ground water pollution potential of any hydrogeologic setting. Although the two parts of the system are interrelated, they are discussed separately in a logical progression.

Hydrogeologic Settings

This methodology has been prepared using the concept of hydrogeologic settings. A hydrogeologic setting is a composite description of all the major geologic and hydrologic factors which affect and control ground water movement into, through, and out of an area. It is defined as a mappable unit with common hydrogeologic characteristics, and as a consequence, common vulnerability to contamination by introduced pollutants. From these factors it is possible to make generalizations about both ground water availability and ground water pollution potential.

In order to assist users who may have a limited knowledge of hydrogeology, the entire standardized system for evaluating ground water pollution potential has been developed within the framework of an existing classification system of ground water regions of the United States. Heath (1984) divided the United States into 15 ground-water regions based on the features in a ground water system which affect the occurrence and availability of ground water (Figure 1). These regions include:

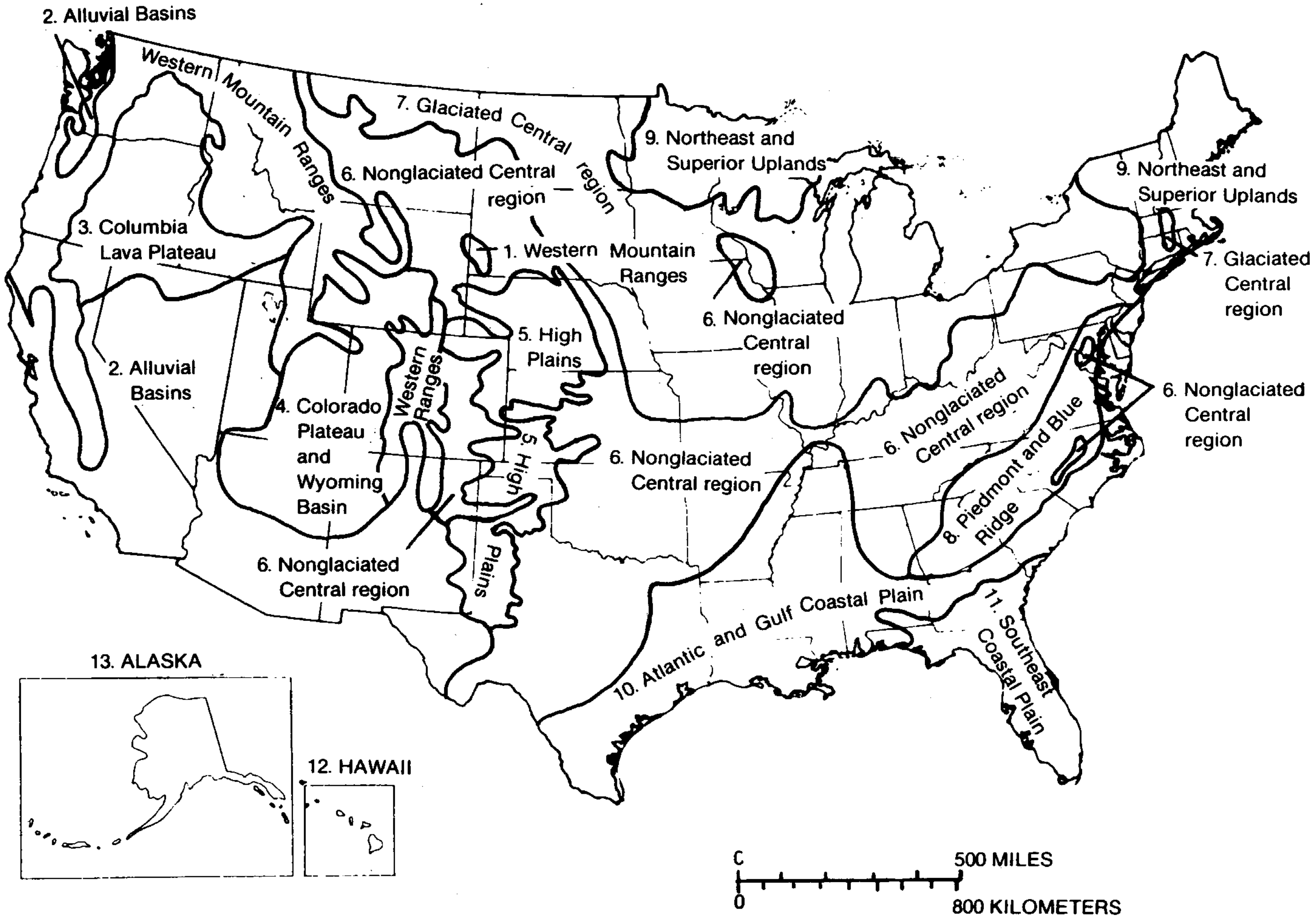

Figure 1. Ground-water regions of the United States (After Heath, 1984).

1. Western Mountain Ranges
2. Alluvial Basins
3. Columbia Lava Plateau
4. Colorado Plateau and Wyoming Basin
5. High Plains
6. Nonglaciated Central Region
7. Glaciated Central Region
8. Piedmont and Blue Ridge
9. Northeast and Superior Uplands
10. Atlantic and Gulf Coastal Plain
11. Southeast Coastal Plain
12. Alluvial Valleys
13. Hawaiian Islands
14. Alaska
15. Puerto Rico and Virgin Islands

Region 12, Alluvial Valleys is "distributed" throughout the United States.

For the purposes of the present system, Region 12 (Alluvial Valleys) has been reincorporated into each of the other regions and Region 15 (Puerto Rico and Virgin Islands) has been omitted. Since the factors which influence ground water occurrence and availability also influence the pollution potential of an area, this regional framework is used to help familiarize the user with the basic hydrogeologic features of the region.

Because pollution potential cannot be determined on a regional scale, smaller "hydrogeologic setings" were developed within each of the regions described by Heath (1984). These hydrogeologic settings create units which are mappable and, at the same time, permit further delineation of the factors which affect pollution potential.

Each hydrogeologic setting is described in a written narrative section and illustrated in a block diagram. (Figure 2 shows the format.) The descriptions are used to help orient the user to typical geologic and hydrologic configurations which are found in each region and to help focus attention on significant parameters which are important in pollution potential assessment. The block diagram enables the user to visualize the described setting by indicating its geology, geomorphology and hydrogeology.

Factors Affecting Pollution Potential

Inherent in each hydrogeologic setting are the physical characteristics which affect the ground water pollution potential. Many different biological, physical and chemical mechanisms may actively affect the attenuation of a contaminant and, thus, the pollution potential of that system. Because it is neither practical nor feasible to obtain quantitative evaluations of intrinsic mechanisms from a regional perspective, it is necessary to look at the broader parameters which incorporate the many processes. After a complete evaluation of

ALLUVIAL BASINS

(2C) Alluvial Fans

This hydrogeologic setting is characterized by gently sloping alluvial deposits which are coarser near the apex in the mountains and grade toward finer deposits in the basins. Within the alluvial deposits are layers of sand and gravel which extend into the central parts of the adjacent basins. The alluvial fans serve as local sources of water and also as the recharge area for the deposits in the adjacent basin. The portion of the fan extending farthest into the basin may function as a discharge area, especially during seasons when the upper portion of the fan is receiving substantial recharge. Discharge zones are usually related to flow along the top of stratified clay layers. Ground water discharge zones are less vulnerable to pollution than recharge zones. Where the discharge/recharge relationship is reversible the greater vulnerability of the recharge condition must be evaluated. Ground water levels are extremely variable, and the quantity of water available is limited because of the low precipitation and low net recharge. Ground water depth varies from over 100 feet near the mountains to zero in the discharge areas. The alluvial fans are underlain by fractured bedrock of sedimentary, metamorphic or igneous origin which are typically in direct hydraulic connection with the overlying deposits. Limited supplies of ground water are available from the fractures in the bedrock.

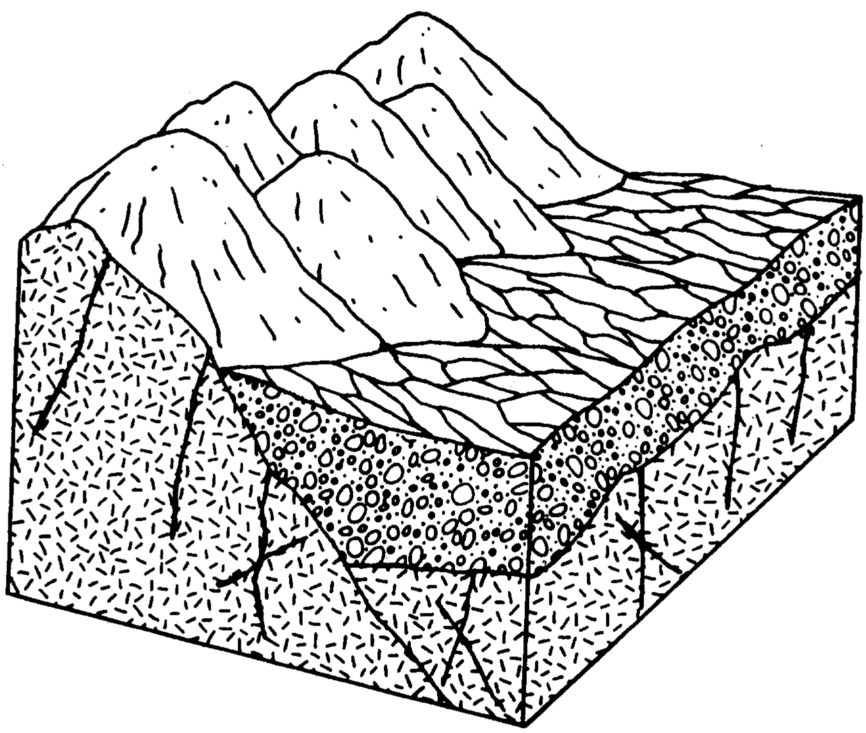

Figure 2 - Format of Hydrogeologic Setting

many characteristics and the mappability of the data, the most important mappable factors that control the ground water pollution 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
C - (Hydraulic) Conductivity of the Aquifer

These factors have been arranged to form the acronym, DRASTIC for ease of reference. 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. It is recognized that many of the factors may be considered to be overlapping. However, great care has been taken to try to separate the factors for purposes of developing the system. A complete description of the important mechanisms considered within each factor and a description of the significance of the factors follows.

Depth to Water

The water table is the expression of the surface below the ground level where all the pore spaces are filled with water. Above the water table, the pore spaces are partially filled with water and air. The water table may be present in any type of media and may be either permanent or seasonal. For purposes of this document, depth to water refers to the depth to the water surface in an unconfined aquifer. Confined aquifers may also be evaluated using the system. In this case, depth to water is used to delineate the depth to the top of the aquifer. When dealing with confined aquifers, saturated zones above the top of the aquifer would not be considered separately.

The depth to water is important primarily because it determines the depth of material through which a contaminant must travel before reaching the aquifer, and it may help to determine the amount of time during which contact with the surrounding media is maintained. In general, there is a greater chance for attenuation to occur as the depth to water increases because deeper water levels infer longer travel times.

Net Recharge

The primary source of ground water is precipitation which infiltrates through the surface of the ground and percolates to the water table. Net recharge indicates the amount of water per unit area of land, which penetrates the ground surface and reaches the water table. This recharge water is thus available to transport a contaminant vertically to the water table and horizontally within the aquifer. In addition, the quantity of water available for dispersion and dilution in the vadose zone and in the saturated zone is controlled by this parameter.

In areas where the aquifer is unconfined, recharge to the aquifer usually occurs more readily and the pollution potential is generally greater than in areas with confined aquifers. Confined aquifers are partially protected from contaminants introduced at the surface by layers of low permeability media which retard water movement to the confined aquifer. In parts of some confined aquifers, head distribution is such that movement of water is through the confining bed from the confined aquifer into the unconfined aquifer. In this situation, there is little opportunity for local contamination of the confined aquifer. The principal recharge area for the confined aquifer is often many miles away. Many confined aquifers are not truly confined and are partially recharged by migration of water through the confining layers. The more water that leaks through, the greater the potential for recharge to carry pollution into the aquifer. Recharge water, then, is a principal vehicle for leaching and transporting solid or liquid contaminants to the water table. Therefore, the greater the recharge, the greater the potential for pollution.

Net recharge may be enhanced by practices such as irrigation or artificial recharge. These practices may add significant volumes of water and should be taken into account when evaluating this parameter.

Aquifer Media

Aquifer media refers to the consolidated or unconsolidated medium which serves as an aquifer (such as sand and gravel or limestone). An aquifer is defined as a rock formation which will yield sufficient quantities of water for use. Water is held by aquifers in the pore spaces of granular and clastic rock and in the fractures and solution openings of non-clastic and non-granular rock. Rocks which yield water from pore spaces have primary porosity; rocks where the water is held in openings such as fractures and solution openings which were created after the rock was formed have secondary porosity. The aquifer medium exerts the major control over the route and path length which a contaminant must follow. The path length is an important control (along with hydraulic conductivity and gradient) in determining the time available for attenuation processes such as sorption, reactivity, and dispersion and also the amount of effective surface area of materials contacted in the aquifer. The route which a contaminant will take can be strongly influenced by fracturing or by any other feature such as an interconnected series of solution openings which may provide pathways for easier flow. In general, the larger the grain size and the more fractures or openings within the aquifer, the higher the permeability and the lower the attenuation capacity; consequently the greater the pollution potential.

Soil Media

Soil media refers to that uppermost portion of the vadose zone characterized by significant biological activity. For purposes of this document, soil is commonly considered the upper weathered zone of the earth which averages six feet or less. Soil has a significant impact on the amount of recharge which can infiltrate into the ground and hence on the ability of a contaminant to move vertically into the vadose zone. Moreover, where the soil zone is fairly thick, the attenuation processes of filtration, biodegradation, sorption, and volatilization may be quite significant. In general, the pollution potential of a soil is largely affected by the type of clay present, the shrink/swell potential of that clay, and the grain size of the soil. In general, the less the clay shrinks and swells and the smaller the grain size, the less the pollution potential. The quantity of organic material present in the soil may also be an important factor. Soil media are best described by referring to the basic soil types as classified by the Soil Conservation Service.

Topography

Topography refers to the slope and slope variability of the land surface. Topography helps control the likelihood that a pollutant will run off or remain on the surface in one area long enough to infiltrate. Therefore, the greater the chance of infiltration, the higher the pollution potential associated with the slope. Topography influences soil development and therefore has an effect on attenuation. Topography is also significant from the standpoint that the gradient and direction of flow often can be inferred for water table conditions from the general slope of the land. Typically, steeper slopes signify higher ground water velocity.

Impact of Vadose Zone

The vadose zone is defined as the zone above the water table which is unsaturated. For purposes of this document, this strict definition can be applied to all water table aquifers. However, when evaluating a confined aquifer, the "impact" of the vadose zone is expanded to include both the vadose zone and any saturated zones which overlie the aquifer. In the case of a confined aquifer, the significantly restrictive zone above the aquifer which forms the confining layer is used as the type of media which has the most significant impact.

The type of vadose zone media determines the attenuation characteristics of the material below the typical soil horizon and above the water table. Biodegradation, neutralization, mechanical filtration, chemical reaction, volatilization and dispersion are all processes which may occur within the vadose zone with a general lessening of biodegradation and volatilization with depth. The media also control the path length and routing, thus affecting the time available for attenuation and the quantity of material encountered. The routing is strongly influenced by any fracturing present. The materials at the top of the vadose zone also exert an influence on soil development.

Hydraulic Conductivity of the Aquifer

Hydraulic conductivity refers to the ability of the aquifer materials to transmit water, which in turn, controls the rate at which ground water will flow under a given hydraulic gradient. The rate at which the ground water flows also controls the rate at which a contaminant will be moved away from the point at which it enters the aquifer. Hydraulic conductivity is controlled by the amount and interconnection of void spaces within the aquifer which may occur as a consequence of factors such as intergranular porosity, fracturing and bedding planes.

DRASTIC

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 1). The most significant factors have weights of 5; the least significant, a weight of 1. This exercise was accomplished by a committee using a Delphi (consensus) approach. These weights are a constant and may not be changed.

Table 1. Assigned Weights for DRASTIC Features

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

(2) Ranges

Each DRASTIC factor has been divided into either ranges or significant media types which have an impact on pollution potential (Tables 2-8). The media types have been assigned descriptive names to assist the user.

Table 2. 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

Table 3. 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

(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. The range for each DRASTIC factor has been assigned a rating which varies between 1 and 10 (Tables 2-8). 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.

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:

$D_R D_W + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W = \text{Pollution Potential}$

where:

R = rating
W = weight

Table 4. 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
Thin Bedded Sandstone, Limestone 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

Table 5. 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

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.

Table 6. Ranges and Ratings for Topography

Topography
(percent slope)

Range	Rating
0-2	10
2-6	9
6-12	5
12-18	3
18+	1

Table 7. Ranges and Ratings for Impact of Vadose Zone Media

Impact of Vadose Zone Media

Range	Rating	Typical Rating
Silt/Clay	1-2	1
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

Table 8. 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

Table 9 shows a typical index computed for the hydrogeologic setting, 7H Beaches, Beach Ridges, and Sand Dunes, which is described in Figure 3. In contrast, Table 10 and Figure 4 illustrate a very different hydrogeologic setting 7Ad Glacial Till Over Sandstone with a pollution potential that is significantly lower. These numbers, although not unique values, can be evaluated with respect to one another by knowing that for all hydrogeologic settings evaluated in the united States, DRASTIC Indices ranged from 53 to 224. This relative comparison helps the user evaluate pollution potential with respect to any other area. In areas of widely variable hydrogeology, the pollution potential may also vary widely with an associated spread of DRASTIC Indices. In areas with more subtle changes in hydrogeology, the DRASTIC Indices would reflect more subtle changes. The system does not attempt to define "good" or "bad" areas, but simply offers the user a tool to evaluate the relative pollution potential of whatever areas are desired. The user may wish to then consider additional factors such as importance of the aquifer, the site of the population served or other factors in fully assessing the importance of pollution potential in any area.

Testing and Displaying the System

The mappable hydrogeologic units and the DRASTIC Index, when combined, provide the user with an indication of the relative pollution potential for any hydrogeologic setting in the United States. The most graphic way to display such a system is through the use of a map. In order to test the system and to demonstrate the graphic display of the system, ten counties in the United States were mapped using the DRASTIC methodology. These counties were chosen for their hydrogeologic variability, the availability of information on the counties, their diversity between rural and urban, the willingness of individuals in those counties to assist in the data gathering and review process, and the ability of the people in the county to use such a map once it was completed. The

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.

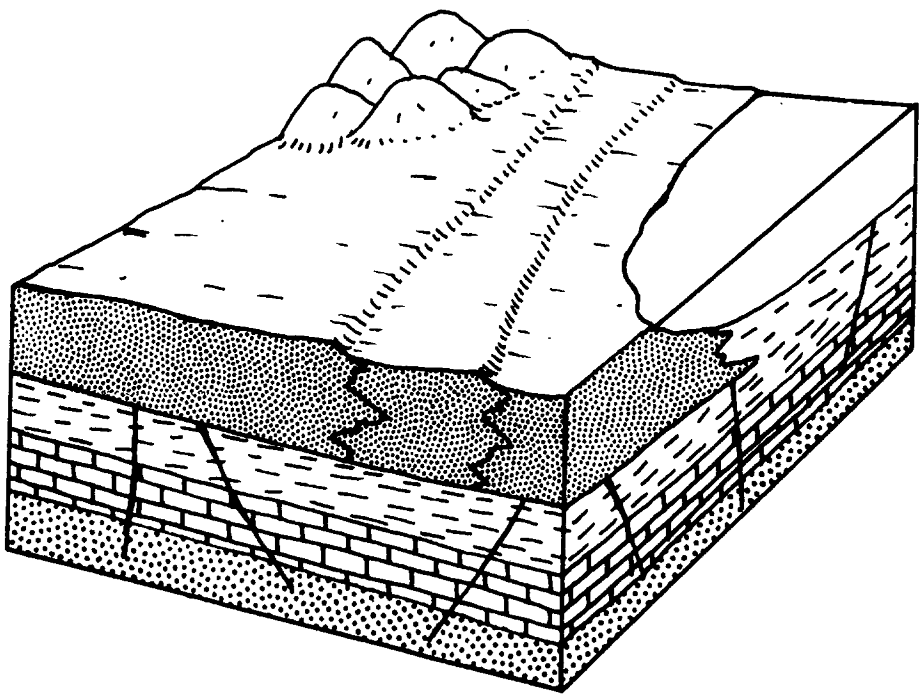

Figure 3 - Description and Illustration for Setting 7H - Beaches, Beach Ridges and Sand Dunes

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 chiefly 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 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 table is extremely variable, depending in part on the thickness of the glacial till, but tends to average around 40 feet.

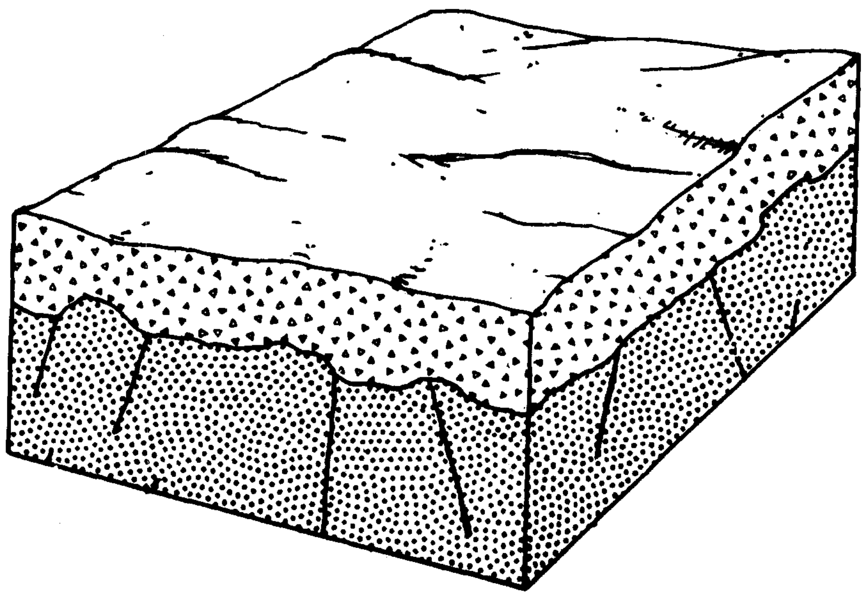

Figure 4 - Description and Illustration for Setting 7Ad - Glacial Till Over Sandstone

SETTING 7H Beaches, Beach Ridges and Sand Dunes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water Table	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

Table 9 - DRASTIC Chart for Setting 7H - Beaches, Beach Ridges and Sand Dunes

SETTING 7 Ad Glacial Till Over Sandstone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water Table	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	1	5
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	99

Table 10 - DRASTIC Chart for Setting 7Ad - Glacial Till Over Sandstone

ten counties for which maps have been produced are listed below:

Cumberland County, Maine
Finney County, Kansas
Gillespie County, Texas
Greenville County, South Carolina
Lake County, Florida
Minidoka County, Idaho
New Castle County, Delaware
Pierce County, Washington
Portage County, Wisconsin
Yolo County, California

The maps of each county were produced by using either a 7 1/2 minute or 15 minute topographic quadrangle map published by the United States Geological Survey as a base map. Each of the seven DRASTIC factors were evaluated and appropriate lines were drawn on mylar overlays. Once this process was completed, a composite overlay was created and both the hydrogeologic setting and the DRASTIC Index were indicated for each area. A standard way of displaying this information was developed. An example set of symbols is shown below:

7Ba1 } defines the hydrogeologic setting
200 } defines the relative pollution potential of the ground water

The first number (7) stands for the ground water region in which the hydrogeologic setting is located. The second letter or letters (Ba) denotes the basic hydrogeologic setting. The third part of the symbol (1) indicates that the user should refer to a chart to see a listing of the ranges which were chosen for the seven DRASTIC factors. This is very important because in many cases parameters may change enough to warrant attention but may not change enough to create a different hydrogeologic setting Therefore, it is possible to have many designations for the same hydrogeologic setting but with different associated values which should be evaluated differently.

The number underneath the hydrogeologic setting designation denotes the DRASTIC Index for that particular hydrogeologic setting. As indicated above, it is possible to have the same setting with a different DRASTIC Index when one or a combination of parameters varies slightly within the hydrogeologic setting. These two symbols, when used in combination, provide the user with a complete description of the hydrogeologic setting and the relative pollution potential and allow the user to obtain a more detailed perspective about the area.

Once both hydrogeologic settings and DRASTIC Indices have been established, it is possible to create a color-coded map which provides the user with a quick and easy reference of relative pollution potential. For purposes of a national system, a national color-code has been developed using the full spectrum of colors. Table 11 contains a listing of the color ranges and associated colors.

Table 11. Color Codes for DRASTIC Indices

Less than 79	Violet
80 - 99	Indigo
100 - 119	Blue
120 - 139	Dark Green
140 - 159	Light Green
160 - 179	Yellow
180 - 199	Orange
200 and above	Red

Conclusions

It is evident that all of the DRASTIC parameters are interacting, dependent variables. Their selection is based on available data quantitatively developed and rigorously applied coupled with a subjective understanding of "real world" conditions at a given area. The value of the DRASTIC parameters is in the fact that they are based on information that is readily available for most portions of the United States, and which can be obtained and meaningfully mapped in a minimum of time and at minimum cost. The DRASTIC ranking scheme can then be applied by enlightened laymen for valid comparative evaluations with acceptable results.

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Biographical Sketch

Linda Aller, Co-Director of Research and Education for the National Water Well Association (NWWA) holds a B.A. in geology from the Ohio State University and has done postgraduate work in hydrology at both Ohio University and the Ohio State University. Prior to joining NWWA's research staff, Mrs. Aller was the principal geologist responsible for the development of Ohio's private water system rules including those rules governing well construction. Since joining NWWA, she has been involved with many research projects including DRASTIC, a system to evaluate ground water pollution potential and state-of-the-art documents on methods to determine the location of abandoned wells and ways to insure mechanical integrity of injection wells. She is also the author of many slide shows which are used all over the world to educate people about all aspects of ground water. Mrs. Aller is a Certified Professional Geologist with AIPG and a Registered Sanitarian in the state of Ohio.