Assessment of the Use of DRASTIC Results by Local Governments in Virginia

by

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Introduction

Groundwater is an important resource in Virginia, for close to a third of the state's population depends on groundwater as a primary source of drinking water.[1] This valuable resource is increasingly threatened by land use and other human activities which can lead to contamination. Natural features, such as soils, geology, and topography, also influence the likelihood of groundwater pollution. These features dictate the rate at which water seeps into the groundwater system and the amount of filtration it receives while on this journey. The DRASTIC methodology takes these natural features into consideration in evaluating the potential for groundwater pollution. DRASTIC aims to identify and map differing levels of groundwater vulnerability within an area. Local governments in Virginia may be better able to protect groundwater quality by using DRASTIC evaluation information as a basis for zoning measures and comprehensive plans.

Weigmann and Kroehler[2] identify the following threats to Virginia's groundwater: septic systems, nitrates (fertilizers), pesticides, underground storage tanks, landfills (municipal solid waste and hazardous waste), waste ponds and lagoons, mining, saltwater intrusion, stockpiles and bulk stor-

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[1] Groundwater Protection Steering Committee, *A Groundwater Protection Strategy for Virginia.* Richmond, VA: Virginia Water Control Board, 1987. p. vi.

[2] Weigmann, Diana L. and Carolyn J. Kroehler, *Threats to Virginia's Groundwater.* Blacksburg, VA: Virginia Water Resources Research Center, 1988. pp. 10-34.

age, spills (of petroleum products and hazardous materials), underground injection, abandoned wells, and natural constituents of groundwater. Septic systems, which are used by about 650,000 households in the state (34 percent of Virginia's housing units), have been identified by the U.S. Environmental Protection Agency as the major source of groundwater contamination.[3] In Virginia, the most commonly reported type of groundwater contamination complaint involves leaking underground petroleum storage tanks. Virginia Water Control Board estimates place the number of leaking tanks in the state as high as 20,000.[4]

Because local governments have the power to regulate land use, they are equipped to play an important role in preventing groundwater pollution. If local governments have access to adequate information concerning natural features, such information could be used as a basis for land use regulations aimed at preventing groundwater pollution. In 1988, the Virginia General Assembly modified the comprehensive planning statutes (Virginia Code 15.1 - 446.1) and the zoning statutes (Virginia Code 15.1 - 486). As a result, surface and groundwater quality may be considered in planning activities and protected through zoning measures by local governments.[5]

The DRASTIC methodology provides a base of information that can be used as the foundation for zoning measures and comprehensive plan elements, which aim to protect groundwater quality. Maps produced as a result of DRASTIC analyses should not be used to assign land uses, but are intended only as general planning guides. The DRASTIC methodology generalizes the pollution potential for areas of 100 acres or more in size.[6] DRASTIC analyses, and the maps they produce, provide a general assessment of groundwater vulnerability. They should not be used in place of site specific analysis and the consideration of site specific characteristics.

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[3] Ibid., pp. 11-12.

[4] Ibid., p. 18.

[5] Groundwater Protection Steering Committee, *Virginia Groundwater Management Handbook*. Richmond, VA: Virginia Water Control Board, 1988. pp.12-2 - 12-3.

[6] Aller, Linda, et al., *DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings*. Ada, OK: U.S. Environmental Protection Agency, in cooperation with the National Water Well Association, 1987. p.11.

The Virginia Groundwater Protection Steering Committee, made up of representatives from state agencies with programs affecting groundwater quality, was formed in 1985 under the leadership of the Virginia Water Control Board. This group was charged with the task of developing a groundwater protection strategy for the state. One of the Committee's recommendations was that the Virginia Water Control Board should pursue a demonstration program for the development of DRASTIC maps at the county scale.[7] The Virginia Water Control Board conducted a demonstration mapping project as a result. This project involved the production of DRASTIC maps for six counties. DRASTIC maps for additional counties have been produced through the efforts of other organizations.

The State Water Control Board demonstration project maps were each produced by a different mapping team. A State Water Control Board regional geologist, a county staff person, and, in most cases, a planning district commission staff person made up each mapping team. Mapping team members were required to participate in a two-day DRASTIC mapping workshop, conducted by the State Water Control Board in association with the National Water Well Association. Following the workshop, the mapping teams collected the necessary information for preparation of their maps and met for a three-day preliminary mapping session, during which drafts of maps were produced. These drafts were subjected to a quality control review by Terry Wagner, of the State Water Control Board, and Linda Aller, an author of the DRASTIC methodology. After this preliminary session, the DRASTIC maps were independently completed by the teams over a period of nine months. The maps were subjected to another quality control review before printing. The demonstration project expenses were approximately $60,000, not including the labor of the mapping teams. This represents a cost of about $10,000 per county DRASTIC map.[8]

The State Water Control Board demonstration project was funded by an EPA Section 106 Groundwater Protection Grant. DRASTIC mapping projects undertaken by the Virginia Water

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[7] Groundwater Protection Steering Committee, 1987. pp. 70-71.

[8] Wagner, Terry D., et al., *DRASTIC: A Demonstration Mapping Project.* Richmond, VA: Virginia Water Control Board, 1988. pp. 15-16.

Project have been funded by the Virginia Environmental Endowment and the Public Welfare Foundation. Other sources of funding have been used to conduct DRASTIC evaluations. Table 1 contains a list of the counties included in this study, the organizations which conducted studies of the counties, and the sources of project funding. The EPA Section 205-J Planning Grants are administered through the State Water Control Board to other agencies, such as planning district commissions. The 205-J grant program will be phased out at the end of 1990, but a similar program, 604-B, will take its place.[9]

Table 1.

DRASTIC Counties, Organizations Responsible for Conducting DRASTIC Investigations, and Sources of Project Funding

Counties	Organization	Source of Funding
Botetourt, Carroll, Henrico, Middlesex, Prince William, Rockingham (1988)	State Water Control Board	106 grant (EPA)
Giles (1989), Shenandoah and Warren (1988)	Virginia Water Project	Virginia Environmental Endowment and the Public Welfare Foundation
Bedford (1989)	Central Virginia Planning District Commission	205-J grant (EPA)
Rappahannock (1988)	Piedmont Environmental Council	Rappahannock League for Environmental Protection and Rappahannock County

[9] Chumney, Carrie, State Water Control Board. Personal Communication. May 1990.

This study provided the opportunity to document and analyze the use of DRASTIC information in eleven (11) Virginia counties (see Figure 1) for which DRASTIC assessments had been conducted and maps produced. The chapters that follow briefly describe the DRASTIC evaluation system, summarize the county DRASTIC assessments, report on the views of individuals involved in conducting the assessments, and present observations and findings of the study, as well as conclusions regarding the appropriate use of DRASTIC results. A short description of the study methodology is given below.

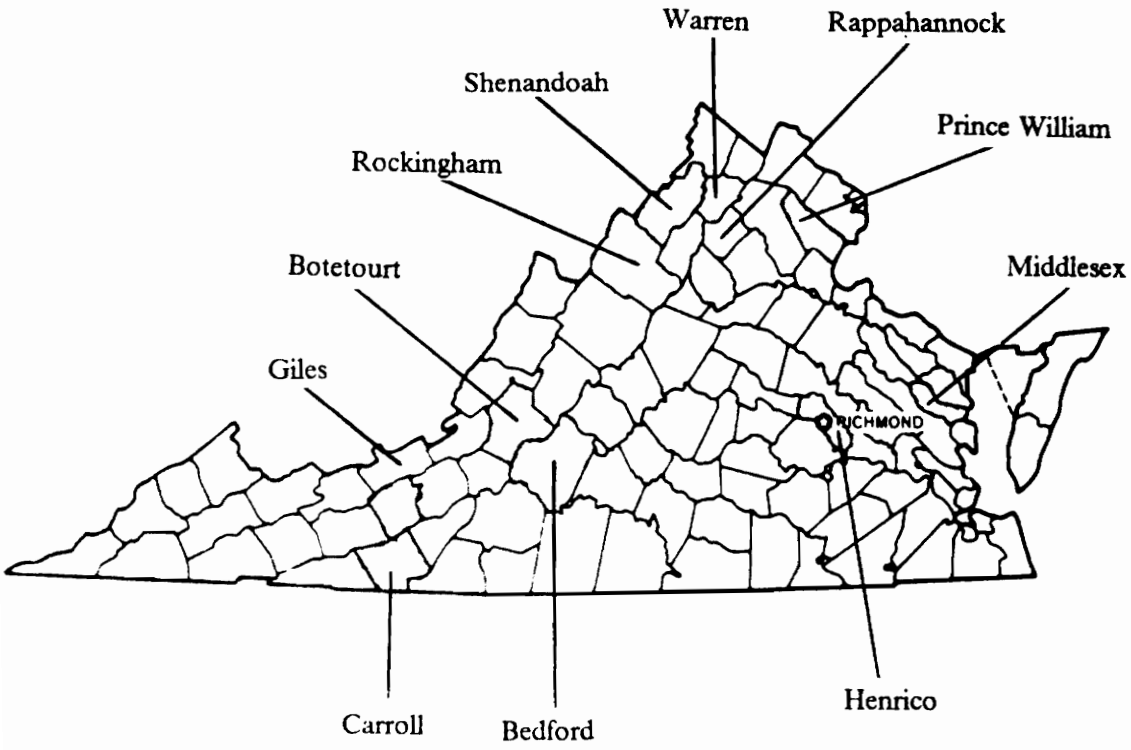
Study Methodology

This study focused on the usefulness and limitations of DRASTIC evaluations as demonstrated by the experience of local governments in Virginia counties for which DRASTIC assessments and maps had been completed. The counties included in the study were: Bedford, Botetourt, Carroll, Giles, Henrico, Middlesex, Prince William, Rappahannock, Rockingham, Shenandoah, and Warren.

In order to gain a working knowledge of the subject matter, the DRASTIC evaluation procedure and DRASTIC reports and maps for the study counties were reviewed. Two sets of interview questions were then developed. One set was directed toward county planners/officials, who use or have available the DRASTIC results. The other set was directed toward coordinators of DRASTIC mapping projects. The set of questions for project coordinators focused on two areas: (1) use of the results by counties/localities and (2) use of the DRASTIC procedure by analysts, including the reliability of the system. For a complete list of the interview questions, see Appendix 1.

Interviews were conducted with one county planner/official in each study county. Interviews were also conducted with the coordinators of DRASTIC mapping projects for the State Water Control Board and the Virginia Water Project. Findings and observations from these interviews were used in reaching conclusions concerning the use of DRASTIC results.

Figure 1. Location of Study Counties in Virginia.



The DRASTIC Evaluation System

The DRASTIC evaluation methodology was created through efforts coordinated by the National Water Well Association. The National Water Well Association assembled a committee of groundwater experts to develop a procedure for evaluating groundwater pollution potential. The DRASTIC methodology represents a synthesis of committee member ideas. Some of DRASTIC's basic concepts have origins in a waste disposal site evaluation procedure developed by Harry LeGrand. The geographic boundaries of the groundwater regions used in the DRASTIC methodology were defined by Ralph Heath.[10]

The DRASTIC evaluation system takes into consideration the most important physical characteristics which affect groundwater pollution potential and for which mapped data is available.[11] *DRASTIC* is an acronym which stands for the following factors:

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[10] Aller, et al., 1987. pp. xv-xvi. LeGrand's procedure is detailed in *A Standardized System for Evaluating Waste Disposal Sites*, published in 1983 by the National Water Well Association. Heath's concept of groundwater regions is explained in *Groundwater Regions of the United States*, published in 1984 by the U.S. Geological Survey.

[11] Ibid., p. 17.

D	depth to water table
R	net recharge
A	aquifer media
S	soil media
T	topography
I	impact of the vadose zone
C	hydraulic conductivity of the aquifer

Depth to water table is the depth at which an aquifer exists. Net recharge is the amount of precipitation per unit of land which infiltrates the ground and reaches the water table. Aquifer media are subsurface rocks that bear water and serve as aquifers. Soil media are the constituents that make up the upper level of the earth's surface. Topography refers to the slope of the land surface. Impact of the vadose zone refers to the degree to which the vadose zone affects filtration, dispersion, and other processes. The vadose zone is the unsaturated or discontinuously saturated zone above the water table and below the soil horizon. Hydraulic conductivity refers to the ability of an aquifer to transmit water.[12]

DRASTIC makes use of a classification system which divides the United States into 15 regions (see list and map in Appendix 2) based on groundwater system characteristics. For the purpose of creating mappable units, these groundwater regions are further divided into hydrogeologic settings. Each groundwater region has distinct hydrogeologic settings (see list in Appendix 2). When conducting a DRASTIC evaluation of a jurisdiction, a DRASTIC index value is calculated for each hydrogeologic setting. The hydrogeologic settings, therefore, define the distinguishable units on the resulting DRASTIC map.[13]

The groundwater regions of the state of Virginia are based on the state's physiographic provinces (see map in Appendix 2). The Coastal Plain province is in the Atlantic and Gulf Coastal Plain

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[12] Ibid., pp. 44-62.

[13] Ibid., pp. 13-14.

groundwater region. The Piedmont and Blue Ridge provinces make up the Piedmont and Blue Ridge groundwater region. The Valley and Ridge and Cumberland Plateau provinces are in the Nonglaciated Central groundwater region.[14]

The DRASTIC evaluation procedure was developed using the following assumptions[15]:

- **A contaminant is introduced at the ground surface.**
- **A contaminant is flushed into the groundwater by precipitation.**
- **A contaminant has the mobility of water.**
- **An area evaluated using DRASTIC is 100 acres or larger.**

The DRASTIC evaluation system involves the use of weights, ranges or significant media types, and ratings. Weights, which range from 1 to 5, have been assigned to each factor. Weights indicate a factor's importance relative to the other factors. The procedure uses one set of weights for normal applications and a second set for counties with intensive agriculture (see DRASTIC and pesticide DRASTIC weights in Appendix 3). Each factor has been divided into ranges or significant media types. For each range or significant media type, a rating has been assigned. Ratings range from 1 to 10. As an example, Table 2 gives the ranges, ratings, and weights for the depth to water table factor. The assigned weights, ranges, and ratings for each DRASTIC factor may be found in Appendix 3. The aquifer media and impact of the vadose zone factors have been assigned a typical rating and a variable rating (see Appendix 3). If detailed information is available, the variable rating allows the rating value to be adjusted based on the information.[16]

To determine the DRASTIC pollution potential index of an area, the weight and rating of each factor are multiplied and the resulting products are added together. An example of a DRASTIC index calculation is contained in Table 3. The numbers produced by this evaluation system provide

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[14] Wagner, Terry, State Water Control Board. Personal Communication. May 1990.

[15] Aller, Linda, et al., 1987. p. 42.

[16] Ibid., pp. 17-20.

relative measures for comparison, not absolute measures. The larger the DRASTIC index number, the greater the likelihood of groundwater pollution. The DRASTIC index number itself is no absolute indication of the potential for groundwater pollution. A DRASTIC index number only has meaning in comparison to other index numbers in the same map jurisdiction.[17]

Table 2.
Example of Ranges, Ratings, and Weights of a DRASTIC Factor

RANGES, RATINGS, AND WEIGHTS FOR DEPTH TO WATER TABLE

Range (in feet)	Rating
0 - 5	10
5 - 15	9
15 - 30	7
30 - 50	5
50 - 75	3
75 - 100	2
100 or more	1

Weight: 5 **Pesticide Weight: 5**

Source: Aller, et al, 1987.

[17] Ibid.

Table 3.
Example of a DRASTIC Index Calculation

DRASTIC CHART FOR HYDROGEOLOGIC SETTING 6Da --
ALTERNATING SANDSTONE, LIMESTONE AND SHALE -- THIN SOIL

Feature	Range	Weight	Rating	Number
Depth to water table	15 - 30	5	7	35
Net recharge	4 - 7	4	6	24
Aquifer media	Thin bedded SS, LS, SH sequences	3	6	18
Soil media	Loam	2	5	10
Topography	2 - 6%	1	9	9
Impact vadose zone	Bedded LS, SS, SH	5	6	30
Hydraulic conductivity	1 - 100	3	1	3
			DRASTIC index	**129**

Source: Aller, et al, 1987.

When using DRASTIC data to create a map of groundwater pollution potential, 7 1/2 minute USGS topographic quadrangle maps are usually used as base maps. Each DRASTIC factor is mapped on a separate acetate overlay. Sources of data are often found to be mapped at different scales. During the mapping process, an emphasis is placed on generalization and the tendency to be too specific or detailed is discouraged. This process recognizes generalities and combines "unimportant specifics." Areas with similar features are lumped together.[18]

[18] Ibid., pp. 86-88.

In the process of conducting a DRASTIC survey, it may be discovered that necessary data does not exist or is not available in a desirable quantity. In such cases, assumptions about features are made based on the opinions of experts and information about the features of nearby areas.

A final DRASTIC map is produced by aligning all the overlays and retracing the visible boundary lines onto a clean sheet of acetate. This final step can lead to further generalization because the boundaries of very small areas are not retraced.[19] This is why DRASTIC maps do not represent areas of less than 100 acres and are not intended for site-specific application.

The DRASTIC methodology establishes a standard color code and ranges of index scores to be used in representing areas on DRASTIC maps. The following colors have been assigned to the DRASTIC index ranges indicated[20]:

- Violet: below 80
- Indigo: 80 - 99
- Blue: 100 - 119
- Dark Green: 120 - 139
- Light Green: 140 - 159
- Yellow: 160 - 179
- Orange: 180 - 199
- Red: above 199

An example of a final DRASTIC map (in black and white) is contained in Figure 2. Each hydrogeologic setting delineated on the map contains two numbers. The top number indicates the type of hydrogeologic setting, while the bottom number is the DRASTIC index value for that hydrogeologic setting. The three DRASTIC index ranges represented on the map are 80-99, 100-119, and 120-139.

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[19] Ibid., p. 88.

[20] Ibid., p. 101.

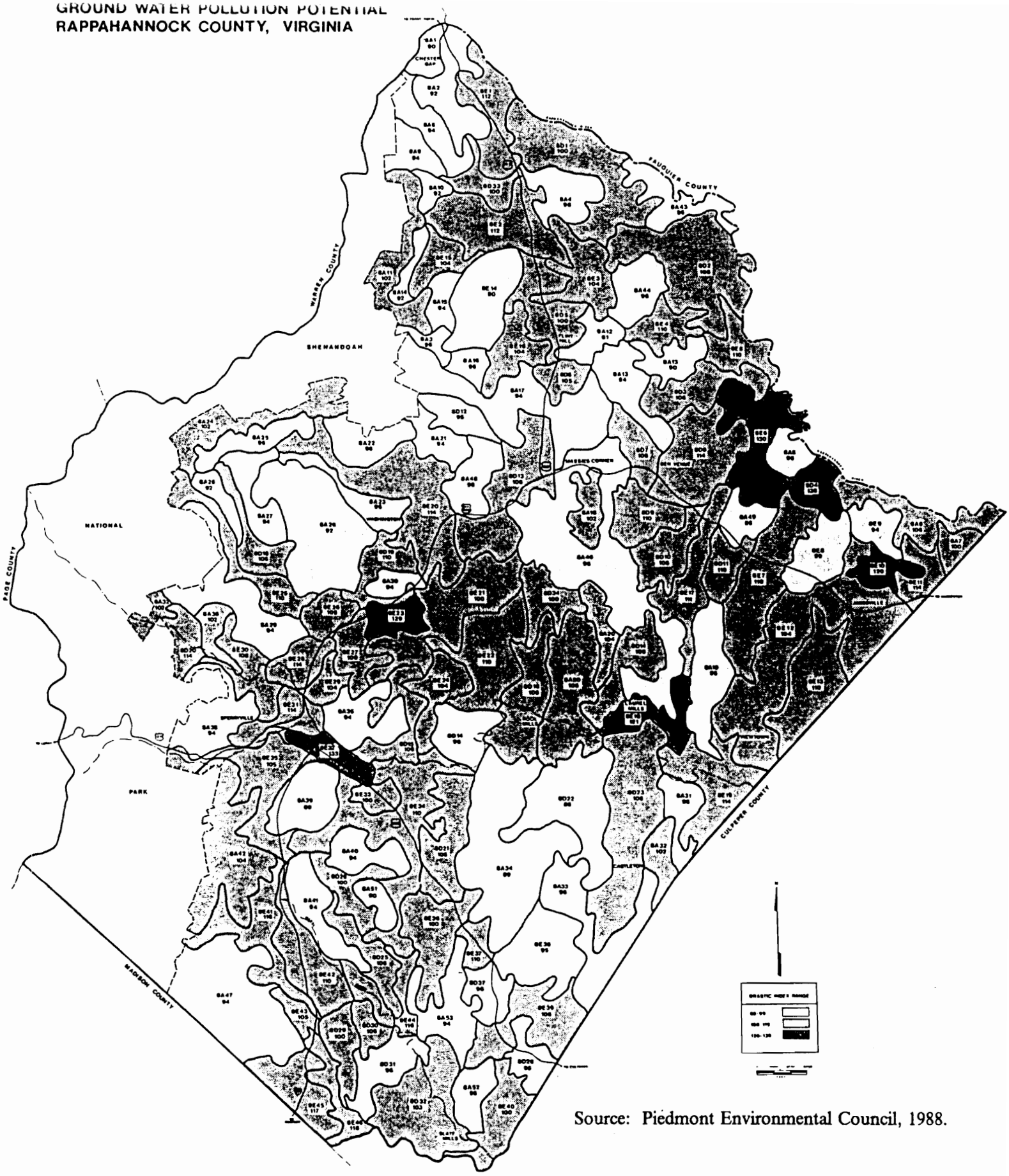

Figure 2. Example of a DRASTIC Map in Black and White.

Summary of County DRASTIC Reports

This section contains descriptions of Virginia's groundwater regions, followed by brief summaries of the DRASTIC evaluations of each of the study counties. These descriptions provide some idea of the subsurface diversity among the study counties and how this diversity is reflected in DRASTIC evaluations.

Each of the study counties lies in one or more of the following groundwater regions:

- **Nonglaciated central groundwater region.** In Virginia, this groundwater region is underlain by consolidated sedimentary rocks, consisting mostly of sandstone, shale, carbonate rocks (limestone and dolomite), and conglomerate. The Triassic Basin area of Virginia, which also lies in the nonglaciated central groundwater region, is underlain by beds of shale and sandstone which contain faults and bodies of igneous rock. Throughout the region, the rocks are covered by a thin layer of unconsolidated deposits (regolith). Small fractures in the bedrock serve as the water-bearing structures. In areas of limestone and dolomite, water moving through rock can enlarge the fractures over time.[21]

[21] Aller, Linda, et al., 1987. pp. 229-230.

- **Piedmont and blue ridge groundwater region.** This groundwater region is underlain by igneous, metamorphosed igneous, and sedimentary rocks. These consist of granite, gneiss, schist, quartzite, slate, marble, and phyllite. The rock formations are covered by a thick layer of unconsolidated material (saprolite). In many valleys, the flood plains of larger streams are underlain by a thin layer of alluvium. In the saprolite and alluvium layers, water is contained in pore spaces between rock particles. The rock formations contain water in "sheetlike" openings along fractures.[22]
- **Atlantic and gulf coastal plain groundwater region.** This groundwater region is underlain by unconsolidated sediments, which consist of sand, silt, and clay. Due to the depositions of streams and invasions by the sea, the sediments are interbedded. A small amount of limestone, some beds of mollusk shells, and some gravel (interbedded with sand) may also be found in the region. Groundwater in the region is found, for the most part, in aquifers consisting of unconsolidated sand.[23]

Counties involved in the State Water Control Board demonstration project:

Botetourt County

Botetourt County lies mainly in the Nonglaciated Central groundwater region. A small section, in the eastern part of the county, is in the Piedmont and Blue Ridge groundwater region.[24] Within these regions, the following hydrogeologic settings were identified and found to have the DRASTIC index values or ranges of index values indicated[25]:

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[22] Ibid., p. 252.

[23] Ibid., pp. 271-272.

[24] Wagner, Terry D., et al., *DRASTIC: A Demonstration Mapping Project.* Richmond, VA: Virginia Water Control Board, 1988. p. 16.

[25] Ibid., p. 17.

- 6A - Mountain Slope: 79 - 120.
- 6D - Alternating Sandstone, Limestone, Shale: 114 - 120.
- 6E - Solution Limestone: 174 - 188.
- 6Fa - River Alluvium with Overbank Deposits: 134 - 179.
- 8A - Mountain Slope: 70.

The presence of solution limestone in a large portion of the county increases the likelihood of groundwater pollution. Evaluations of the solution limestone setting in the county resulted in high individual scores for the following DRASTIC factors: aquifer media, impact of the vadose zone, and hydraulic conductivity. These three factors are largely responsible for the high DRASTIC index scores of the solution limestone setting. According to DRASTIC evaluations, a large area, in the center of the county with arms stretching to the northeast and southwest, is very susceptible to groundwater pollution.[26]

Carroll County

Carroll County is located in the Piedmont and Blue Ridge and the Nonglaciated Central groundwater regions.[27] Within these regions, the following hydrogeologic settings were identified and found to have the DRASTIC index values or ranges of index values indicated[28]:

- 6A - Mountain Slope: 107 - 129.
- 6B - Alluvial Mountain Valleys: 151.
- 6Fb - River Alluvium without Overbank Deposits: 186.
- 8A - Mountain Slope: 96 - 120.

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[26] Virginia Water Control Board, *Ground Water Pollution Potential Map of Botetourt County, Virginia* (and accompanying legend). 1988.

[27] Wagner, Terry D., et al., 1988. p. 20.

[28] Ibid., p. 21.

- 8B - Alluvial Mountain Valleys: 132 - 150.
- 8D - Regolith: 130 - 134.
- 8E - River Alluvium: 186.
- 8F - Mountain Crests: 87 - 93.

Most of the county has a relatively low potential for groundwater pollution, though an area in the southern part of the county does have a high potential in comparison. Areas with the highest groundwater pollution potential are located along the New River, which flows through the north-western corner of the county. Evaluation of the river alluvium setting in the county resulted in high individual scores for the following DRASTIC factors: depth to water table, aquifer media, soil media, impact of the vadose zone, and hydraulic conductivity. These factors are responsible for the high DRASTIC index score of the river alluvium setting.[29]

Henrico County

Henrico County is situated in two groundwater regions, which are separated by the fall line. West of the fall line, the county lies in the Piedmont and Blue Ridge groundwater region, while east of the fall line, the county lies in the Atlantic and Gulf Coastal Plain groundwater region.[30] Within these regions, the following hydrogeologic settings were identified and found to have the ranges of DRASTIC index values indicated[31]:

- 8D - Regolith: 126 - 160.
- 8E - River Alluvium: 160 - 182.
- 8H - Triassic Basin: 143 - 145.

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[29] Virginia Water Control Board, *Ground Water Pollution Potential Map of Carroll County, Virginia* (and accompanying legend). 1988.

[30] Wagner, Terry D., et al., 1988. p. 23.

[31] Ibid., p. 24.

- 10Ab - Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer: 129 - 171.
- 10Bb - River Alluvium without Overbank Deposits: 152 - 178.

Most of the county has a moderate to high potential for groundwater pollution, with an area in the western part of the county, along the James River, having the highest potential. Another area, also in the western end of the county, has a relatively low potential for groundwater pollution.[32]

Middlesex County

Middlesex County is located entirely within the Atlantic and Gulf Coastal Plain groundwater region.[33] Within this region, the following hydrogeologic settings were identified and found to have the ranges of DRASTIC index values indicated[34]:

- 10Ab - Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer: 150 - 196.
- 10c - Swamp: 182 - 188.

All areas of the county appear to have a fairly high potential for groundwater pollution, though some areas have a higher potential than others. The presence of shallow aquifers and permeable soils is largely responsible for the high DRASTIC index values in the county. Evaluations of the unconsolidated and semi-consolidated shallow surficial aquifer setting in the county resulted in high individual scores for the following DRASTIC factors: depth to water table, aquifer media, impact of the vadose zone, and hydraulic conductivity. These factors are largely responsible for the high DRASTIC index scores of the unconsolidated and semi-consolidated shallow surficial aquifer setting.[35]

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32 Virginia Water Control Board, *Ground Water Pollution Potential Map of Henrico County, Virginia.* 1988.

33 Wagner, Terry D., et al., 1988. p. 27.

34 Ibid.

35 Virginia Water Control Board, *Ground Water Pollution Potential Map of Middlesex County, Virginia* (and accompanying legend). 1988.

Prince William County

Prince William County lies in three groundwater regions: the Nonglaciated Central, the Piedmont and Blue Ridge, and the Atlantic and Gulf Coastal Plain.[36] Within these regions, the following hydrogeologic settings were identified and found to have the DRASTIC index values or ranges of index values indicated[37]:

- 8A - Mountain Slope: 60.
- 8C - Mountain Flank: 118 - 154.
- 8D - Regolith: 111 - 127.
- 8E - River Alluvium: 167 - 175.
- 8H - Triassic Basin: 141 - 152.
- 8I - Metamorphic/Igneous Domes and Fault Blocks: 77 - 92.
- 10Ab - Unconsolidated and Semi-consolidated Surficial Aquifers: 144 - 164.
- 10Ba - Alluvium with Overbank Deposits: 182.
- 10c - Swamp: 168.

A majority of the county has moderate to high potential for groundwater pollution. A large area with relatively low groundwater pollution potential is located in the mid-eastern section of the county. The far eastern section of the county has the highest DRASTIC index values.[38]

Rockingham County

Rockingham County is located in the Nonglaciated Central and the Piedmont and Blue Ridge

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[36] Wagner, Terry D., et al., 1988. p. 30.

[37] Ibid.

[38] Virginia Water Control Board, *Ground Water Pollution Potential Map of Prince William County, Virginia*. 1988.

groundwater regions.[39] Within these regions, the following hydrogeologic settings were identified and found to have the DRASTIC index values or ranges of index values indicated[40]:

- 6A - Mountain Slopes: 57 - 165.
- 6B - Alluvial Mountain Valleys: 160 - 173.
- 6Da - Alternating Sandstone/Limestone/Shale - Thin Soil: 119 - 125.
- 6E - Solution Limestone: 146 - 200.
- 6Fb - River Alluvium Without Overbank Deposits: 134 - 196.
- 6J - Igneous Domes: 67.
- 8A - Mountain Slopes: 56 - 97.

The mountainous eastern and western portions of the county have the lowest DRASTIC index values. The central valley section has the highest index values in the county and, therefore, possesses a higher risk of groundwater pollution. The valley is, for the most part, underlain by limestone, which provides avenues for the contamination of groundwater sources.[41]

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[39] Wagner, Terry D., et al., 1988. pp. 34-35.

[40] Ibid., p. 35.

[41] Virginia Water Control Board, *Ground Water Pollution Potential Map of Rockingham County, Virginia.* 1988.

Counties evaluated by the Virginia Water Project:

Giles County

Giles County lies entirely within the Nonglaciated Central groundwater region.[42] Within this region, the following hydrogeologic settings were identified and found to have the ranges of DRASTIC index values indicated[43]:

- 6A - Mountain Slopes: 48 - 96.
- 6B - Alluvial Mountain Valleys: 52 - 189.
- 6E - Solution Limestone: 150 - 174.
- 6Fa - River Alluvium with Overbank Deposits: 105 - 167.

The highest DRASTIC index values occur in the central portion of the county and in an area extending along the southern boundary. Areas to the northeast and southwest of the central portion of the county have relatively low DRASTIC index values. These areas, therefore, are less likely to experience groundwater pollution.[44]

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[42] Virginia Water Project, Inc., *Groundwater Pollution Potential Map of Giles County, Virginia.* 1989.

[43] Ibid.

[44] Ibid.

Shenandoah County

Shenandoah County is located in the Nonglaciated Central groundwater region.[45] Within this region, the following hydrogeologic settings were identified for the county and were found to have the ranges of DRASTIC index values indicated[46]:

- 6A - Mountain Slopes: 50 - 108.
- 6B - Alluvial Mountain Valleys: 68 - 152.
- 6C - Mountain Flanks: 82 - 106.
- 6Da - Alternating Sandstone, Limestone, and Shale: 116 - 120.
- 6E - Solution Limestone: 170 - 200.
- 6Fa - River Alluvium with Overbank Deposits: 91 - 187.
- 6K - Unconsolidated and Semi-consolidated Aquifers: 86 - 143.

Similar to Rockingham County, Shenandoah County's mountains, to the east and west, have the lowest DRASTIC index values in the county. The central valley portion of the county, underlain by limestone and dolomite, has the highest DRASTIC index values in the county. The central valley area is, therefore, more likely to experience groundwater pollution than other areas in the county.[47]

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[45] Virginia Water Project, Inc., *Mapping Groundwater Pollution Potential for Shenandoah County, Virginia.* 1988. p. 3.

[46] Ibid., appendix pp. 1-18.

[47] Virginia Water Project, Inc., *Groundwater Pollution Potential Map of Shenandoah County, Virginia.* 1988.

Warren County

Warren County is located in the Nonglaciated Central and the Piedmont and Blue Ridge groundwater regions.[48] Within these regions, the following hydrogeologic settings were identified for the county and were found to have the ranges of DRASTIC index values indicated[49]:

- 6A - Mountain Slopes: 83 - 104.
- 6C - Mountain Flanks: 98 - 175.
- 6Da - Alternating Sandstone, Limestone, and Shale: 100 - 154.
- 6E - Solution Limestone: 159 - 201.
- 6Fa - River Alluvium with Overbank Deposits: 106 - 193.
- 8A - Mountain Slopes: 69 - 109.
- 8B - Alluvial Mountain Valleys: 111 - 115.
- 8D - Regolith: 85 - 130.
- 8F - Mountain Crests: 60 - 70.

The central valley area has the highest DRASTIC index values in the county, due to underlying carbonate rocks. Mountainous areas to the east and west of the valley have relatively low DRASTIC index values.[50]

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[48] Virginia Water Project, Inc., *Mapping Groundwater Pollution Potential for Warren County, Virginia.* 1988. pp. 3-4.

[49] Ibid., appendix.

[50] Virginia Water Project, Inc., *Groundwater Pollution Potential Map of Warren County, Virginia.* 1988.

County evaluated by the Central Virginia Planning District Commission:

Bedford County

Bedford County is located in the Piedmont and Blue Ridge and the Nonglaciated Central groundwater regions.[51] Within these regions, the following hydrogeologic settings were identified and found to have the DRASTIC index values or ranges of index values indicated[52]:

- 6Da - Alternating Sandstone, Limestone, and Shale-Thin Soil: 165-179.
- 6Fa - River Alluvium with Overbank Deposits: 190.
- 8A - Mountain Slopes: 55-105.
- 8D - Regolith: 67-123.
- 8E - River Alluvium: 156.
- 8F - Mountain Crests: 67-71.

The Goose Creek drainage area, in the northwestern section of the county, is underlain by carbonate rock, which makes this area vulnerable to groundwater pollution. According to DRASTIC evaluations, this area has the highest groundwater pollution potential in the county.[53]

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[51] Central Virginia Planning District Commission, *Ground Water Pollution Potential in the City and County of Bedford, Virginia.* 1989. pp. 5-6.

[52] Ibid., p. 5.

[53] Central Virginia Planning District Commission, *Map of Ground Water Pollution Potential in the City and County of Bedford, Virginia.* 1989.

County evaluated by the Piedmont Environmental Council:

Rappahannock County

Rappahannock County is located in the Piedmont and Blue Ridge groundwater region.[54] Within this region, the following hydrogeologic settings were identified and found to have the DRASTIC index values or ranges of index values indicated[55]:

- 8A - Mountain Slopes: 81 - 106.
- 8D - Regolith: 86 - 136.
- 8E - River Alluvium: 94 - 136.

Some areas of the northeastern section of the county, the Laurel Mills area, and two areas near the center of the county have the highest DRASTIC index values in the county. The remainder of the county has relatively low to moderate DRASTIC index values. Western portions of the county, which are within the borders of Shenandoah National Park, were not included in the DRASTIC survey.[56]

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[54] Piedmont Environmental Council, *Mapping Groundwater Pollution Potential for Rappahannock County, Virginia.* 1988.

[55] Ibid.

[56] Ibid.

Summary

On the basis of the county DRASTIC studies, the solution limestone, river alluvium, and unconsolidated and semi- consolidated shallow surficial aquifer hydrogeologic settings appear to be the most vulnerable to groundwater pollution. The factors which affect DRASTIC index scores for the solution limestone setting are aquifer media, impact of the vadose zone, and hydraulic conductivity. The factors which affect DRASTIC index scores for the river alluvium setting are depth to water table, aquifer media, soil media, impact of the vadose zone, and hydraulic conductivity. The factors which affect DRASTIC index scores for the unconsolidated and semi-consolidated shallow surficial aquifer setting are depth to water table, aquifer media, impact of the vadose zone, and hydraulic conductivity.

County Use of DRASTIC Results

The effectiveness of DRASTIC, as an information source to protect groundwater, depends on the reliability of the results and on the actual use to which the information is put. The use of DRASTIC results by local governments can depend on several factors, including: degree of land use planning and control in the county, dependence on groundwater, existence of pollution problems, and confidence in the DRASTIC system. This section provides details on the use of DRASTIC information in each county in the study, derived from on-site interviews with county officials.

Botetourt County

Botetourt County was interested in a DRASTIC survey because a previous study had identified concerns and capital needs (i.e. public sewer system) in the Blue Ridge area of the county. The county was selected by the State Water Control Board to participate in the DRASTIC demonstration project. Botetourt County depends exclusively on groundwater, from wells and springs, as a source of drinking water.[57]

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[57] Hachey, Ron, County Planner/Zoning Administrator, Botetourt County. Personal Communication. April 1990.

Going into the DRASTIC project, the Botetourt County planner had expected the evaluation process to be more objective and site-specific than it was. Due to the subjective, nonsite-specific nature of DRASTIC, he is apprehensive about making land use decisions based solely on the DRASTIC results. He does feel, however, that as a general planning guide, DRASTIC effectively assesses groundwater pollution potential. A DRASTIC map, in his opinion, is well-suited for use as a general, large area planning tool.[58]

The DRASTIC map of Botetourt County, published in 1988, was completed one year after the county updated its comprehensive plan, so the county could not use the results in the plan. For the next comprehensive plan update, the Botetourt County planner anticipated that the DRASTIC evaluation results might be used to develop overlay districts for recommending the use of large lots and less dense development.[59]

The Botetourt County planner viewed the participation of local citizens/officials in the DRASTIC evaluation process as an important factor. The participation of local citizens/officials in a DRASTIC project is likely to lend more credibility to the results, within the county/locality, than the use of outside consultants.[60]

Carroll County

Carroll County was interested in a DRASTIC survey because the county is growing rapidly and depends on groundwater to supply both public and individual water systems. In addition, the availability of necessary information made the county attractive to the State Water Control Board as part of the demonstration project. Given the county's dependence on groundwater, a DRASTIC map could aid in directing development and guiding land use so as to protect the quality of

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[58] Ibid.

[59] Ibid.

[60] Ibid.

groundwater. There have been some contamination problems in the southern part of the county, due to petroleum leaking from underground storage tanks.[61]

Carroll County's comprehensive plan was last updated in 1986. Another update will be carried out over the next 12 to 18 months. The county administrator believes that the DRASTIC map could possibly be used in the development of recommended land uses. The DRASTIC map might also be used, over the next five years, in the preparation of zoning ordinances for selected growth areas of the county.[62]

Although Carroll County is not currently using the DRASTIC evaluation results, the county administrator reported that an engineering consulting firm, working for the county, found the DRASTIC map useful in conducting a long-term study of areas that need public sewer systems. In addition to the comprehensive plan functions mentioned previously, the county administrator viewed the county's DRASTIC map as potentially useful in siting a new landfill and in identifying suitable and unsuitable areas for development in high growth sections of the county. Through this latter use, the DRASTIC map could also be used to target areas for public water/sewer projects. The county administrator reported that the county building official is interested in using the DRASTIC map in the siting of underground storage tanks (USTs) in compliance with new UST regulations.[63]

The county administrator thought that the DRASTIC evaluation procedure effectively assesses groundwater pollution potential. He viewed the map's lack of an absolute scale as a limitation and would prefer that information be presented in a "black and white" manner, which would facilitate easier decision-making.[64]

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[61] Swain, Clinton, County Administrator, Carroll County. Personal Communication. April 1990.

[62] Ibid.

[63] Ibid.

[64] Ibid.

Henrico County

Henrico County became involved in a DRASTIC survey as a result of being selected by the State Water Control Board for participation in the demonstration project. A majority of Henrico County's population is served by a public water system, which depends mainly on a surface water source.[65]

Henrico County is currently working on an update of the land use plan component of its comprehensive plan. The county's comprehensive plan also includes a thoroughfare plan and a parks and recreation (open spaces) plan. The county planner who was interviewed anticipated that the county's DRASTIC map would be referred to as a resource document in the land use plan update. He foresaw no further use of the DRASTIC map by the county. The county is apprehensive about making land use decisions based on a general planning tool that is not site-specific.[66]

However, the same county planner believes that, as a general planning tool, DRASTIC effectively assesses groundwater pollution potential. He thought the fact that the DRASTIC map does not represent any areas of less than 100 acres in size is a limitation. As a participant in the DRASTIC mapping project, he was concerned about the quantity and quality of data used, the scale differences between sources of mapped data, and the quality assurance/quality control sessions conducted by the State Water Control Board. These sessions led to some changes in the Henrico County DRASTIC map which the planner did not think were necessary. The training sessions, conducted prior to the mapping project by the State Water Control Board, were viewed as effective and beneficial by the planner.[67]

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[65] Silber, Randall, Planner, Henrico County. Personal Communication. April 1990.

[66] Ibid.

[67] Ibid.

Middlesex County

Middlesex County became involved in a DRASTIC survey when it was approached by the State Water Control Board. The entire county depends on groundwater for public and private water systems.[68]

The county updated its comprehensive plan, conservation plan, and zoning plan in 1989. The county is currently working on plans for preservation areas in compliance with the Chesapeake Bay Preservation Act. The county official, who was interviewed for this report, indicated that the DRASTIC map might be used in designating "Chesapeake Bay Preservation Areas" in the county. The county official believed that DRASTIC effectively assesses groundwater pollution potential. He thought that the DRASTIC methodology accomplishes its objective of providing a general planning tool. DRASTIC maps show patterns and provide good information which did not exist previously.[69]

The county official was concerned about the assumptions of the DRASTIC methodology regarding pollutants and the fact that sources of information for producing the DRASTIC map are mapped at differing scales. He was also concerned about the fact that DRASTIC only assesses upper level aquifers, not deep aquifers. This is a significant concern in coastal areas, such as Middlesex County, where saltwater intrusion can be a problem.[70]

The county official pointed out that he thought the training workshops conducted by the State Water Control Board were good. He believed that more groundwater and geotechnical training for municipal employees would provide a great benefit for local governments.[71]

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[68] Selph, G. David, Code Compliance Officer, Middlesex County. Personal Communication. April 1990.

[69] Ibid.

[70] Ibid.

[71] Ibid.

Prince William County

Prince William County became involved in a DRASTIC survey as a result of being selected by the State Water Control Board to participate in the demonstration project. Approximately 20 sites in the county have been identified as having significant groundwater contamination. The eastern, most populous section of the county is, for the most part, served by a public water system which relies on a surface water source. The remainder of the county relies on individual, groundwater-supplied systems.[72]

The DRASTIC evaluation for the county is referenced in the recently adopted environmental element of the county's comprehensive plan. Along with the reference is a recommendation that the DRASTIC map should be used in the land use planning process. Aside from this, the county is not currently using the DRASTIC map. The county planner interviewed for this report did not foresee further use of the map in the future.[73]

The planner believed that DRASTIC, as a general planning tool, effectively assesses groundwater pollution potential. However, she cited the map's lack of an absolute scale as an inhibiting factor in its use. She also viewed the map's 100 acre limitation of resolution as further limiting its use to only broad and general applications. She would like to have, in addition to the DRASTIC map, a more site-specific level map. She was concerned about the credibility and accuracy of the process, as well as its defensibility.[74]

The Prince William planner would like to see the numbering/scoring system simplified in some manner. She would also like to have more explanation of the process, focusing on geotechnical

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[72] Phillips, Julie, Planner III - Community Facilities, Prince William County. Personal Communication. April 1990.

[73] Ibid.

[74] Ibid.

information. This could, perhaps, be accomplished through ongoing workshops, which update and educate. Such workshops might be conducted through the planning district commissions.[75]

Rockingham County

Rockingham County became involved in the DRASTIC demonstration project when it was approached by the State Water Control Board. There have been groundwater contamination problems throughout the county. In one small community, the county is developing a new groundwater source because of the large number of failing septic systems in the area. There was also a concern regarding the large amount of animal waste generated in the county.[76]

The county will be updating its comprehensive plan in 1990-1991. The county planning director anticipated that the DRASTIC map will be referenced in the plan as an information base. In the preliminary stages of evaluating a potential land use, the county planning director looks beyond the DRASTIC map to the hydrogeologic settings involved and critical factors within the settings.[77]

Protection of groundwater is a priority of the county government. The county wants to identify areas in rural and growing sections which need and would benefit from package sewage treatment systems. This is aimed at slowing the development of individual septic systems.[78]

Going into the DRASTIC project, the county planning director expected the product might be somewhat like a floodplain map, with "black and white" recommendations on where to develop and

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[75] Ibid.

[76] Veno, William, Director of Planning and Zoning, Rockingham County. Personal Communication. April 1990.

[77] Ibid.

[78] Ibid.

where not to develop. He believed that the inability of DRASTIC to be applied on a site-specific basis is a major limitation.[79]

The planning director questioned the effectiveness of DRASTIC assessments in karst areas. Because zones are not isolated and pollutants tend to migrate, he would also like to have information on the direction of aquifer flows.[80]

The planning director thought that DRASTIC maps could be useful in identifying areas in which site-specific groundwater studies should be undertaken. He was concerned, though, about any liability that might be involved in using DRASTIC maps as a basis for land use decision-making.[81]

The planning director was also concerned about fragmentation in the mapping of different jurisdictions. There are some differences in the representation of the valley floor between the DRASTIC maps of Rockingham and Shenandoah Counties. He was further concerned about the uniformity of base information scales, interpretation, and the mapping process itself.[82]

The Rockingham planning director would like to see some guidelines for using the DRASTIC map and report. These would guide the use of DRASTIC results in recommending site-specific testing and certain land uses for high vulnerability areas.[83]

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[79] Ibid.

[80] Ibid.

[81] Ibid.

[82] Ibid.

[83] Ibid.

Giles County

Giles County's interest in a DRASTIC survey lies in the fact that the county is very dependent on groundwater. There have been some groundwater contamination problems in the county. After reading about the DRASTIC methodology in an issue of *Virginia Review*, the county administrator approached the Virginia Water Project about conducting a DRASTIC evaluation of Giles County.[84]

Giles County will be updating its comprehensive plan during the second half of this year. The county administrator anticipated that the DRASTIC map will be used, to some extent, in updating the comprehensive plan and also in developing a land use plan.[85]

The county administrator thought the DRASTIC evaluation procedure effectively assesses groundwater pollution potential. He believed, however, that the general, nonsite-specific nature of the information presented by a DRASTIC map is a limitation. He was also concerned about the knowledge of geology that is required to understand what goes into the DRASTIC mapping process. The county administrator recommended that a note be placed on DRASTIC maps about their general nature and the fact that they are not site-specific planning tools. He also recommended better explanation of geological terms and concepts, along with the maps.[86]

Shenandoah County

Shenandoah County originally inquired through its planning district commission about a DRASTIC survey, and the Virginia Water Project eventually agreed to do a DRASTIC evaluation of the

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[84] Weaver, Ken, County Administrator, Giles County. Personal Communication. April 1990.

[85] Ibid.

[86] Ibid.

county. The county has experienced some groundwater contamination. Leaking underground storage tanks have led to contamination incidents and, in one community, a new municipal well was found to be contaminated by fecal coliform bacteria.[87]

The county is updating its comprehensive plan this year. There is no formal use of the DRASTIC map by the county at this time. The planning director believed that this is because the map is not site-specific enough. Going into the DRASTIC project, he expected the end product would be more suitable for site-specific application.[88]

The Lord Fairfax Planning District Commission prepared a water resources assessment of the county to be included in the county's comprehensive plan update. The assessment contains a summary of the DRASTIC findings and a groundwater vulnerability map which is based on the county's DRASTIC map.[89]

The planning director believed the DRASTIC evaluation procedure effectively assesses the potential for groundwater pollution. A DRASTIC map can also be effective in bringing about awareness of the vulnerability of groundwater to pollution. A DRASTIC map is a good first step in protecting groundwater quality.[90]

The planning director viewed DRASTIC's lack of site-specificity as a limitation. He believed, however, that DRASTIC maps are potentially useful in evaluating land uses and special use permits, recommending site-specific testing, and siting landfills and USTs.[91]

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[87] Poling, Vincent E., Director of Planning and Code Enforcement, Shenandoah County. Personal Communication. April 1990.

[88] Ibid.

[89] Raflo, Allen, Planner, Lord Fairfax Planning District Commission. Personal Communication. April 1990.

[90] Poling, Vincent E., April 1990.

[91] Ibid.

Warren County

Warren County became involved in a DRASTIC survey through its planning district commission, which notified the county that the Virginia Water Project was looking for candidate counties for a DRASTIC survey. The Virginia Water Project considered several counties and chose to conduct an evaluation of Warren County. The county does depend on groundwater and, due to the presence of a large number of sinkholes, there is potential for contamination. The Avtex superfund site is located within the county and also represents a threat to groundwater.[92]

The county reviewed its comprehensive plan last year and will be updating the plan in 1991. Currently, the county is revising its zoning ordinance. The county planning director anticipated that the DRASTIC evaluation results will be integrated into the comprehensive plan in some manner. The county planning director also indicated that the DRASTIC map would be one of the factors considered in producing a future land use map for the county.[93]

The planning director initially expected that the DRASTIC map might be used for recommending land uses. Though it is tempting to use the DRASTIC map for site-specific purposes, the planning director was aware of the fact that the map is very general in nature and not intended for site-specific application. She believed that the DRASTIC evaluation procedure effectively assesses groundwater pollution potential.[94]

The DRASTIC map was used by the county in the preliminary stages of siting a new landfill. Ten possible sites were selected based on the map. These sites were then tested before further evaluation was done and sites were eliminated from consideration.[95]

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[92] Lloyd, Lynne, Planning Director, Warren County. Personal Communication. April 1990.

[93] Ibid.

[94] Ibid.

[95] Ibid.

The planning director would like to see some mechanism in DRASTIC which allowed consideration of other factors, such as sinkholes. She noted that it would be helpful if there were subprograms of DRASTIC which allowed more detailed geologic information to be accessed. The planning director would also find it helpful if DRASTIC were available in the form of a computer program.[96]

Bedford County

Bedford County made a request to the Central Virginia Planning District Commission for a DRASTIC assessment of the county. The county's interest was stimulated somewhat by water quality studies of the Staunton/Roanoke River. The Central Virginia PDC applied for and received 205-J funding, administered through the Virginia Water Control Board. The DRASTIC assessment of Bedford County was conducted by the Central Virginia PDC.[97]

The completion of Bedford County's DRASTIC assessment in 1989 preceded the county's comprehensive plan update by one year. The county has already moved to incorporate DRASTIC results into the Growth Guidance Assessment of its Land Use Guidance System. This assessment takes 12 factors into consideration for a proposed site, one of which is the site's DRASTIC index value. The assessment assigns points based on the DRASTIC index value (see Table 4). Low index values receive a higher number of points, while high index values receive a lower number of points. The number of points is then multiplied by the appropriate weight factor (see Table 4), which produces an "earned points" figure for the groundwater vulnerability factor of the assessment.[98]

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[96] Ibid.

[97] Dillard, Bob, Planner, Central Virginia Planning District Commission. Personal Communication. April 1990.

[98] Burdett, Jeff, Community Development Planner and Planning Administrator, Bedford County. Personal Communication. April 1990.

Table 4.
Bedford County Growth Guidance Assessment - Assignment of Points

The Bedford County "Growth Guidance Assessment" assigns points to the DRASTIC factor based on the chart below.

DRASTIC Index Value	Points
0 - 79	10
80 - 99	8
100 - 119	6
120 - 139	4
140 - 159	2
160 +	0

The DRASTIC factor points for a proposed development are multiplied by a weight factor, which is determined by land use type.

Land Use Type	Weight Factor
Residential	2.1
Commercial	2.1
Industrial	2.4
Rural	2.1

Source: *Bedford County Land Use Guidance System*

The DRASTIC results were also used by the county in the preliminary stages of siting a new landfill.[99]

The Community Development Planner/Planning Administrator in Bedford County believed that the DRASTIC evaluation procedure effectively assesses groundwater pollution potential. He

[99] Ibid.

viewed DRASTIC as a very useful planning tool, because it provides a base of information that did not previously exist. The Bedford County planner was concerned about the lack of detail on DRASTIC maps, such as the absence of place names and physical features (i.e. roads and streams). Another concern of the Bedford County planner was that there needs to be more soils and geology information presented to those conducting a DRASTIC evaluation who do not have a background in these areas.[100]

Rappahannock County

Rappahannock County became interested in a DRASTIC survey after groundwater concerns were raised during the siting of a new landfill. The DRASTIC survey was conducted by the Piedmont Environmental Council. The county has experienced some problems with groundwater contamination. These problems were related to septic failures and animal waste. The county is largely dependent on groundwater as a source of water.[101]

The county updated its comprehensive plan in 1989. A reference was made to the DRASTIC evaluation in the plan. In April of 1991, the groundwater resources chapter of the comprehensive plan will be revised. The county administrator anticipated that in the future some sort of checklist will be developed by the county for recommending site-specific testing of certain areas.[102]

Going into the DRASTIC project, the county administrator expected the final product to identify areas of concern, which it did. He believed that the DRASTIC evaluation procedure effectively assesses groundwater pollution potential and that the DRASTIC map serves two functions: (1) it provides public officials with a quick thumbnail sketch of an area's groundwater situation and (2)

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[100] Ibid.

[101] McCarthy, John W., County Administrator, Rappahannock County. Personal Communication. April 1990.

[102] Ibid.

it heightens people's awareness of groundwater vulnerability, thereby providing a starting point for further work in protecting groundwater quality.[103]

The county administrator was concerned that there should be more variation in the DRASTIC factor weights to allow adjustment for local conditions. He was also concerned about the availability and quality of some data (i.e. water table data which comes from well logs) on which DRASTIC is based. The county administrator cautioned that local governments involved in DRASTIC evaluations should not try to push or rush the mapping process, which could lead to more lumping or generalizing of information than is necessary.[104]

Observations

Based on the experiences of the counties, the following observations can be made:

Use of DRASTIC results in comprehensive/land use plans

- The DRASTIC evaluation is referred to, or will be referred to, in the comprehensive plans of five counties (Henrico, Prince William, Rockingham, Shenandoah, Rappahannock).
- In two counties (Giles, Warren), the DRASTIC results will be used, or it is expected that they will be used, in some manner in updating the comprehensive plan.
- Officials in two counties (Giles, Warren) anticipated that their DRASTIC maps will be used in the development of a land use plan or map of future land uses.

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[103] Ibid.

[104] Ibid.

Use of DRASTIC results in land use decision-making

- One county official (Rappahannock) anticipated that the DRASTIC evaluation results will be used by his county in developing a checklist for recommending site-specific testing in certain areas. Officials in two other counties (Rockingham, Shenandoah) viewed DRASTIC maps as potentially useful in recommending site-specific testing.
- In one county (Botetourt), the official thought the DRASTIC map might possibly be used in developing overlay districts for recommending large lots and lower density development in the county.
- One official anticipated that his county (Carroll) will use its DRASTIC map in the development of recommended land uses.
- One county (Bedford) actually uses DRASTIC evaluation results in the land use decision-making process. Though the DRASTIC index value of a site is used as one of 12 factors in a growth assessment, this represents a site-specific application of DRASTIC.

Other uses of DRASTIC results

- Officials in two counties (Shenandoah, Rappahannock) viewed the DRASTIC evaluation results as useful in heightening awareness of groundwater vulnerability and in providing a first step toward protection of groundwater.
- Two counties (Bedford, Warren) used DRASTIC maps in the preliminary stages of siting a new landfill. Officials in two other counties (Carroll, Shenandoah) indicated that they thought DRASTIC maps would be useful for this purpose.
- One official indicated that his county's (Carroll) DRASTIC map might be used in the siting of underground storage tanks. One other county official (Shenandoah) viewed DRASTIC maps as potentially useful for this purpose.

- The DRASTIC map of one county (Carroll) was found to be useful by a consulting firm, which was doing contract work for the county.
- The county official in Middlesex County indicated that the DRASTIC map could possibly be used by his county in designating Chesapeake Bay Preservation Areas.

Perceived Effectiveness of the methodology/usefulness of the results

- Officials in ten counties (Bedford, Botetourt, Carroll, Giles, Henrico, Prince William, Middlesex, Shenandoah, Rappahannock, Warren) believed that the DRASTIC methodology effectively assesses groundwater pollution potential.
- Officials in the more urbanized counties of Henrico and Prince William viewed DRASTIC maps as less useful than did the officials in rural counties, such as Carroll, Giles, and Warren.
- Officials in two counties (Bedford, Middlesex) noted that DRASTIC evaluation results provided information that did not previously exist.

Expectations/limitations/concerns

- Officials in two counties (Botetourt, Shenandoah) initially expected their DRASTIC maps to be more site-specific than they are. Going into the mapping project, one county official (Rockingham) expected the DRASTIC map to present information in a more "black and white" manner, which would better facilitate decision-making.
- Four county officials (Giles, Henrico, Rockingham, Shenandoah) believed that the lack of site-specificity of DRASTIC is a limitation.
- Two county officials (Carroll, Prince William) viewed DRASTIC's lack of an absolute index scale as a limitation.
- Officials in two counties (Botetourt, Henrico) expressed apprehension about using DRASTIC evaluation results in land use decision-making.

- One county official (Rockingham) was concerned about any liability that might be involved in using DRASTIC maps as a basis for land use decision-making.
- Two county officials (Henrico, Rappahannock) were concerned about the quantity/availability and quality of data on which DRASTIC maps are based.
- One county official (Rockingham) was concerned about the uniformity of the DRASTIC mapping process. He noted differences in assumptions between the DRASTIC maps of two jurisdictions. He was also concerned about scale differences in base information. One other county official (Henrico) expressed concern about scale differences between sources of mapped data on which DRASTIC maps are based.
- One county official (Prince William) was concerned about the accuracy of the DRASTIC mapping process.
- One county official (Middlesex) was concerned about the fact that DRASTIC only assesses upper level aquifers and not deep aquifers. This is important in coastal areas where saltwater intrusion can be a problem.
- The Bedford County official was concerned about a lack of detail (i.e. place names and physical features) on DRASTIC maps.

Miscellaneous comments

- Officials in three counties (Bedford, Giles, Prince William) expressed a desire to have more information presented on geology and/or soils so that the DRASTIC evaluation process might be better understood.
- Two county officials (Henrico, Middlesex) thought the DRASTIC training sessions conducted by the State Water Control Board were effective.
- The Botetourt County official indicated that the participation of local citizens in the DRASTIC evaluation process is important.

- The Rockingham County official thought that a set of guidelines for use of the DRASTIC map and report would be helpful.
- One county official (Giles) thought a note should be included on DRASTIC maps which cautions that the maps are general in nature and not site-specific planning tools.

Summary

Use of DRASTIC evaluation results in the study counties has varied. The widest use of the results, so far, has been as a reference in comprehensive plans. Future use of DRASTIC results is anticipated in several counties. The DRASTIC methodology is perceived as effective by a large majority of the study counties. Rural (more groundwater dependent) counties viewed DRASTIC evaluation results as more useful or more beneficial than did the urban (less groundwater dependent) counties. The lack of site-specificity of DRASTIC maps is viewed by several county officials as a limitation. The expectations/limitations/concerns cited by county officials suggest a low level of confidence in the DRASTIC results in several counties. Table 5 contains a partial summary of interview responses. Table 5 provides a summary of the use of DRASTIC results by particular counties in the study and also partially summarizes the opinions of county officials regarding the DRASTIC methodology and DRASTIC results.

Table 5. Partial Summary of Responses

Study Counties	Response
Henrico, Rockingham, Prince William, Shenandoah, Rappahannock	refer or will refer to DRASTIC evaluation in comprehensive plan
Giles, Warren	expect that DRASTIC results will be used in some manner in updating the comprehensive plan
Giles, Warren	anticipate use of DRASTIC maps in development of land use plan or map of future land uses
Bedford, Warren	DRASTIC maps used in preliminary stages of siting new landfills
Bedford	DRASTIC index values of sites used in land use decision-making process; one of twelve factors in a growth assessment
Shenandoah, Rappahannock	DRASTIC evaluation results viewed as useful in heightening awareness of groundwater vulnerability
Bedford, Botetourt, Carroll, Giles, Henrico, Prince William, Middlesex, Warren, Shenandoah, Rappahannock	DRASTIC methodology effectively assesses groundwater pollution potential
Bedford, Middlesex	DRASTIC evaluation results provide information that did not previously exist
Botetourt, Shenandoah	initially expected DRASTIC maps to be more site-specific than they are
Giles, Henrico, Rockingham, Shenandoah	believe DRASTIC's lack of site-specificity is a limitation

Views of DRASTIC Project Coordinators

To gain further perspectives on the use and usefulness of DRASTIC, as well as information on the process of conducting a DRASTIC survey, interviews were conducted with Terry Wagner of the State Water Control Board and Jason Gray of the Virginia Water Project. They were responsible for supervising the DRASTIC evaluations of nine counties in this study. Virginia DeLuca of the Virginia Water Project, who has worked in and supervised the production of DRASTIC maps, was also present at the interview with Jason Gray. This section contains comments on and concerns about the DRASTIC mapping process.

State Water Control Board DRASTIC Coordinator

In discussing DRASTIC mapping efforts in the state, Terry Wagner brought out the following points[105]:

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[105] Wagner, Terry, State Water Control Board. Personal Communication. May 1990.

County evaluation experience

- Across the counties involved in the State Water Control Board mapping project, the participation of county personnel in mapping processes ranged from low to high. The participation of county personnel in the mapping process is a valuable component, for it allows those at the local level to understand the DRASTIC mapping process and the information on which it is based.
- There is a need for technical knowledge at the local level for working with and interpreting DRASTIC reports and maps. The participation of local personnel in the mapping process can help in building a base of such knowledge at the local level.

State Water Control Board demonstration project

- Some factor ratings were adjusted in the State Water Control Board's demonstration project. If a great deal of information is available for an area, then adjustment of factor ratings is more likely and more justifiable. If little information is available for an area, then the typical ratings set forth by the methodology are more likely to be used.
- In the State Water Control Board demonstration project, DRASTIC maps were produced by teams consisting of, usually, a geologist from the regional State Water Control Board office, a planning district commission staff person, and a county official or staff person.
- Virginia Department of Mineral Resources geologists and the Soil Conservation Service played an important role in the DRASTIC demonstration project. It is important for DRASTIC mappers to communicate with geologic mappers.

Base information

- There is not really a minimum information base necessary for conducting a DRASTIC survey. Even if very little is known about an area, a crude DRASTIC evaluation can still be carried out using soils and geology maps, typical factor ratings, and basic assumptions concerning the appropriate groundwater region.
- The fact that base information is often produced at different scales is not really a problem. It does present an inconvenience for the mappers.
- Information on subsurface conditions in Virginia is fairly adequate, as far as the needs of DRASTIC are concerned. Geologic mapping of the state could be improved and more hydrogeologic studies are needed, such as those concerning hydraulic conductivity. Field research is needed to confirm existing assumptions.

DRASTIC results and their use

- DRASTIC's lack of an absolute scale is somewhat of a limitation. The relative/comparative scale that DRASTIC does have is appropriate for use within a jurisdiction. At the state-wide level, however, this sort of scale is not so appropriate. There needs to be quality control to limit the differences in assumptions between DRASTIC maps of different jurisdictions.
- For what it is intended, DRASTIC is effective. DRASTIC maps accurately reflect groundwater vulnerability.
- There are two significant drawbacks associated with DRASTIC. These are:
    1. The perception of DRASTIC as a protection plan in itself. It is often thought that no further mechanisms are needed for protection of groundwater quality.
    2. Quality assurance/quality control is critical for use of DRASTIC maps at the state level. It is necessary to establish uniformity in the assumptions used in the mapping process.

- DRASTIC results are appropriate for use in preliminary evaluation of areas. When siting underground storage tanks, it should be kept in mind that the DRASTIC methodology assumes that a pollutant will have the consistency of water and that it will be introduced at the ground surface. Soils information should be reconsidered when siting underground storage tanks.
- DRASTIC maps have potential for use at the state government level. The lumping of county maps into a state or regional map could be useful in the following ways:
  - Identification of sensitive groundwater areas for the purpose of ambient monitoring.
  - Monitoring of pesticides by the Agriculture Department.
  - Identification of areas in need of HUD block grants for water systems.

Virginia Water Project DRASTIC Coordinator

In discussing the DRASTIC methodology and his experiences with it, Jason Gray made the following points[106]:

County evaluation experience

- Reaction to the DRASTIC information has been mixed in the counties for which evaluations were conducted by the Virginia Water Project. In one county (Shenandoah), the county government was initially very reluctant to accept and use the evaluation results, while in another county (Warren) the results were well-received.
- It should be kept in mind that the local planning process is very slow. DRASTIC findings are not likely to be acted upon quickly by local governments.

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[106] Gray, Jason, Virginia Water Project. Personal Communication. May 1990.

- Workshops on the DRASTIC mapping process are beneficial for counties. Local level knowledge of the DRASTIC mapping process is important. It is imperative that people are familiar with the limitations and assumptions inherent in the process.
- Based on the experiences of counties that have had DRASTIC surveys done, it is likely that other counties will become involved in DRASTIC mapping projects. Rockbridge County, for example, is currently involved in a DRASTIC evaluation.

Base information/collection of information

- The minimum information base necessary for a DRASTIC survey is a function of the sub-surface complexity of an area.
- The fact that base information is often produced at different scales is not a major problem.
- There is a need for more groundwater studies in Virginia. There needs to be better information on such items as depth to water table. DRASTIC is useful in identifying these information gaps.
- When gathering information, it is very important to seek expert opinions, even if those opinions are varied and different.
- Virginia DeLuca and interns with the Virginia Water Project collected information and produced the DRASTIC maps for the counties evaluated by the Virginia Water Project.

The DRASTIC methodology/use of DRASTIC results

- Uniformity in the DRASTIC mapping process is not that important, because overall differences between maps are very small. Demonstrating the sensitivity of the procedure is very important.
- Lack of data (i.e. hydraulic conductivity, depth to water table) and lack of local government support and integration are limitations of the DRASTIC evaluation procedure.

- DRASTIC is somewhat oversold as a procedure that can be done by a planner without a geotechnical background. Actually, a DRASTIC project should be overseen by an expert (i.e. hydrogeologist).
- Given the intentions and limitations of the DRASTIC methodology, it is viable and effective.
- DRASTIC maps are more appropriate for rural areas/jurisdictions. DRASTIC allows the use of groundwater vulnerability overlays in the land use planning and decision-making process.
- DRASTIC is a prioritization tool for planning. At the state level, DRASTIC could be used in prioritizing areas for management. DRASTIC could also be used in watershed-level management. DRASTIC, as a prioritization tool, could play a role in the allocation of resources. Such agencies as the Department of Waste Management, Department of Agriculture, and the Agriculture Extension Service could potentially make use of a state DRASTIC map.

Summary

DRASTIC results are appropriate for use in preliminary evaluation of areas. DRASTIC maps are more likely to benefit rural counties. It should be kept in mind that the local planning process is slow, so DRASTIC results are not likely to be acted upon quickly. At the state level, DRASTIC has potential as a prioritization tool in the management of areas and allocation of resources. Quality control is necessary at the state level to insure uniformity in the mapping process.

The participation of county personnel in the DRASTIC evaluation process is important in that it allows those at the local level to become familiar with the limitations and assumptions inherent in the process. It is also important that DRASTIC evaluation results are not perceived as complete groundwater protection programs.

Summary and Conclusions

The DRASTIC evaluation procedure aims to assess the vulnerability of groundwater, underlying specific land areas, to contamination. The DRASTIC methodology takes into consideration seven physical characteristics which affect groundwater quality. DRASTIC maps of 11 Virginia counties have been produced, with the State Water Control Board and the Virginia Water Project responsible for nine of these. Through the county DRASTIC maps and accompanying reports, three hydrogeologic settings have been found to have high potential for groundwater pollution: solution limestone, river alluvium, and shallow surficial aquifers.

Use of DRASTIC results at the local level has been limited. The counties view the DRASTIC methodology as effective, but rural counties perceive DRASTIC results as more useful than do urban counties. Planners and county officials would ideally like to see a detailed, site-specific map of groundwater vulnerability, because such a map is well-suited for evaluating proposed land uses. DRASTIC does not provide this. It is a general, large area planning tool, not intended for site-specific application.

Rural, groundwater-dependent counties are well-suited for DRASTIC evaluations. These counties usually lack the resources for detailed hydrogeologic studies. Compared to more detailed studies, DRASTIC evaluations are relatively inexpensive and can provide information that did not previ-

ously exist. Urban counties are usually not as groundwater-dependent and usually have the resources for more detailed studies.

Given the assumptions and intentions of the DRASTIC evaluation procedure, DRASTIC maps are appropriate for use in preliminary assessment of areas for proposed land uses. Emphasis is placed on **preliminary**. Development of groundwater protection overlay districts, identification of areas in which site-specific hydrogeologic testing is to be recommended, and preliminary evaluation of areas for the siting of landfills and underground storage tanks are appropriate uses of DRASTIC maps. Through these uses, DRASTIC maps and reports can be important sources of information for the preparation and updating of comprehensive plans. DRASTIC maps can also play a role in educating citizens and local officials on groundwater issues. A DRASTIC map, in providing a visual representation of groundwater vulnerability, serves to heighten awareness of the need for groundwater quality protection.

A DRASTIC map is not a complete groundwater protection plan. A DRASTIC map is merely the first step in a program for protection of groundwater quality. In identifying areas of concern, a DRASTIC map allows protection efforts to be focused where they are most needed.

Perhaps the greatest potential for use of DRASTIC results lies at the state level. As a prioritization tool for planning, DRASTIC could be used in the allocation of resources and prioritization of areas for management. A state DRASTIC map could be used to identify sensitive groundwater areas for ambient monitoring. A DRASTIC map could also be used in identification of areas needing public water systems. Quality control should be stressed at the state level. There should be uniformity in the mapping process, so as to reduce differences in assumptions between maps of different jurisdictions in the state.

Appendix 1 - Interview Questions

QUESTIONS FOR COUNTY PLANNERS/OFFICIALS

1. a. How did your county become involved in a DRASTIC survey?

   b. Why is your county interested in a DRASTIC survey?

   - Does your county have a groundwater problem?
   - Is groundwater used for water supply (individual or public systems)?

   c. Where is your county in the comprehensive planning process?

   d. Where, in the process, was the county at the beginning of the DRASTIC project?

2. Are the DRASTIC survey results being used by the county and/or by localities in the county? How are the results being used (e.g. comprehensive planning, siting landfills and USTs, development of overlay districts, location of community wells)?

3. If the results are not presently being used, do you anticipate that they will be used? How do you think they will be used?

4. What is the general reaction of local officials to the DRASTIC report?

5. a. What were your initial expectations for the DRASTIC report and its use?

   b. Have these expectations been realized? If not, do you think they will eventually be realized?

6. Do you expect any negative reaction to the use of DRASTIC information (e.g. from landowners, elected officials, planners, others -- due to use of DRASTIC as a basis for prohibiting certain land uses)?

7. Do you think you understand the DRASTIC evaluation procedure (i.e. how the maps were developed)?

   IF YES,

   - Do you think this procedure can effectively assess potential for groundwater pollution?
   - Does the lack of an absolute scale inhibit the usefulness of DRASTIC results?
   - Are you aware of and do you understand the 100-acre limitation of resolution?

- Do you think the DRASTIC evaluation procedure has any other limitations? If so, what are they?

QUESTIONS FOR COORDINATORS OF DRASTIC PROJECTS

Use of results by counties/localities

1. What has been the response of counties to DRASTIC information?
2. a. What sort of expectations did you have for use of DRASTIC survey results by localities?

   b. Have these expectations been realized? If not, do you think they will be?
3. Do you foresee other counties taking steps to conduct their own DRASTIC surveys as a result of the benefits realized by counties involved in the grant-funded surveys?
4. Is there a need for more technical knowledge at the local level for working with/interpreting DRASTIC data?
5. What do you think is the appropriate use of DRASTIC survey results (e.g. comprehensive planning, siting landfills and USTs, development of overlay districts, location of community wells)?

Use of procedure by analysts

1. How were your DRASTIC surveys funded?
2. a. How was data collected? What data was collected?

   b. Who collected the data?
3. a. Who determined the factor ratings for your DRASTIC surveys?

   b. How were these people selected?
4. a. What is the minimum information base necessary for a DRASTIC survey?

   b. What is the minimum scale for which DRASTIC is effective? (100 acres)

   c. Is there a problem with base information having been produced at different scales.

   d. Is information on subsurface conditions (e.g. geologic mapping) adequate for Virginia?
5. a. What role did the U.S. Geological Survey and the Virginia Division of Mineral Resources play?

   b. What role could they play?
6. What are the weaknesses/limitations of DRASTIC?
   - Are the factors and ratings used appropriate?
   - Does the lack of an absolute scale inhibit the usefulness of DRASTIC results?
7. How do you feel about the overall reliability/viability of DRASTIC?

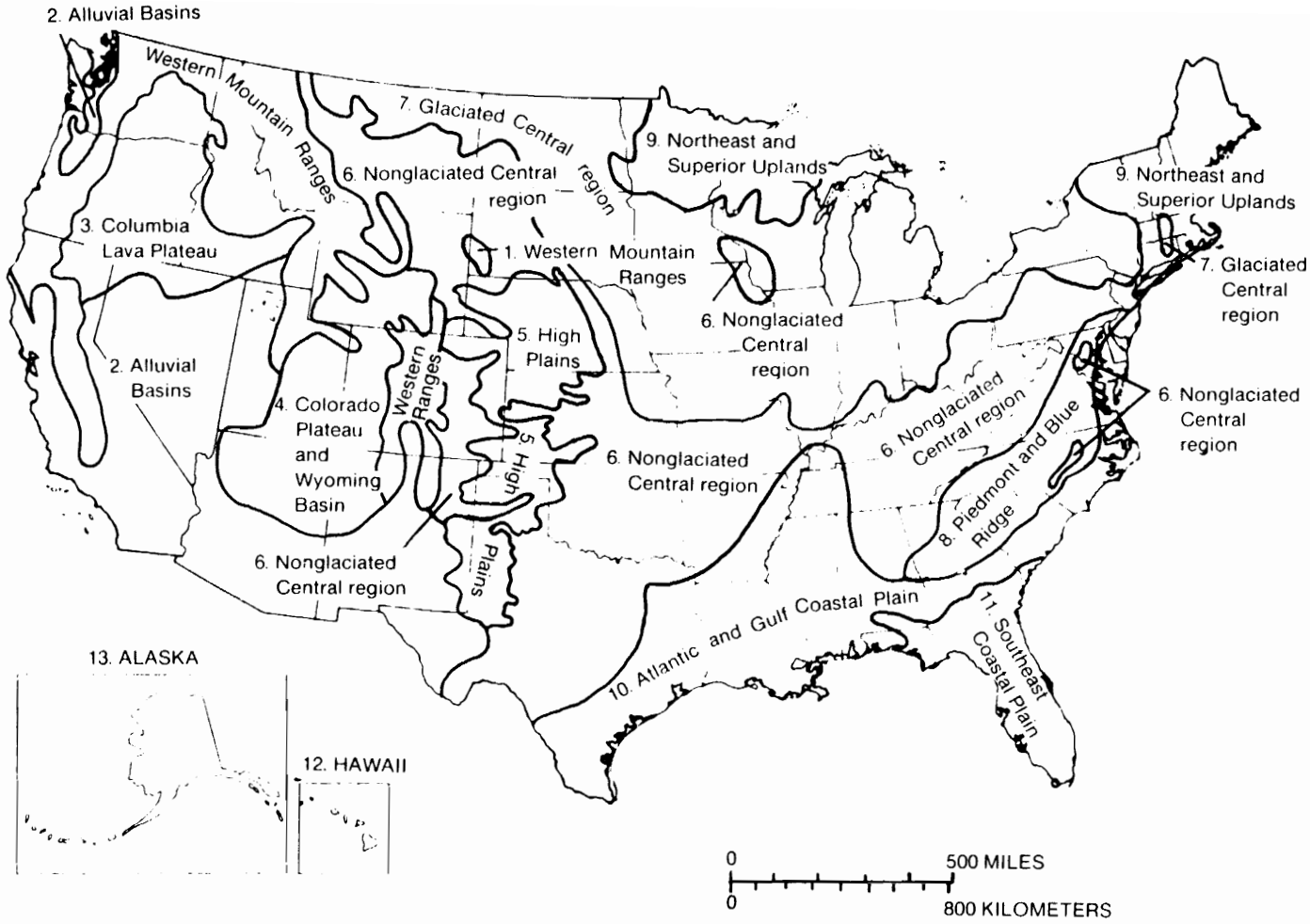
Appendix 2 - Groundwater Regions

Groundwater Regions of the U.S. 59
Map of Groundwater Regions of the U.S. 60
Hydrogeologic Settings 61
Physiographic Provinces of Virginia 62

GROUNDWATER REGIONS OF THE UNITED STATES

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

Source: Aller, et al, 1987.



Map of Groundwater Regions of the United States.

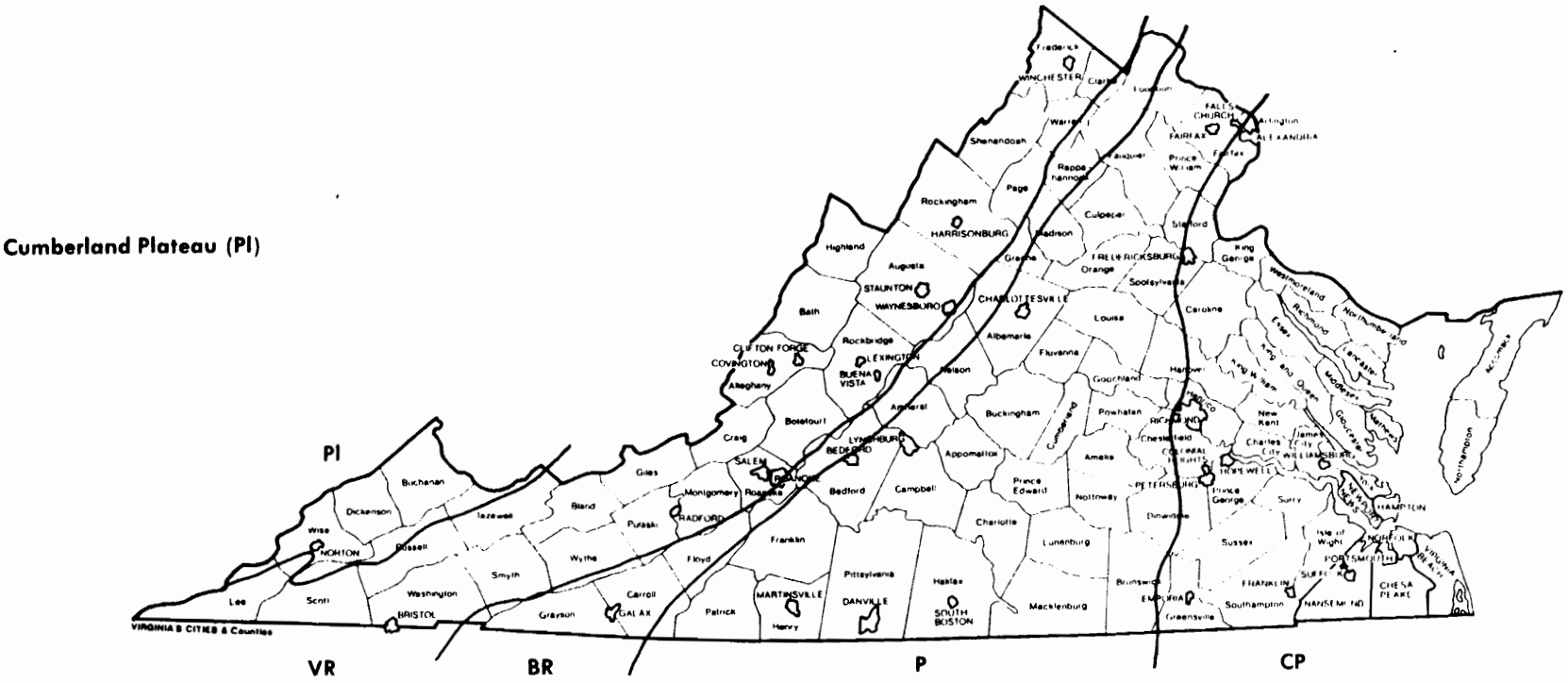
Source: Aller, et al., 1987.

HYDROGEOLOGIC SETTINGS OF THE UNITED STATES SORTED BY GROUNDWATER REGIONS

SETTINGS	DESCRIPTIONS
1Aa East	Mountain Slopes
1Ab West	Mountain Slopes
1Ba East	Alluvial Mountain Valleys
1Bb West	Alluvial Mountain Valleys
1Ca East	Mountain Flanks
1CB West	Mountain Flanks
1D	Glacial Mountain Valleys
1Ea East	Wide Alluvial Valleys (External Drainage)
1Eb West	Wide Alluvial Valleys (External Drainage)
1F	Coastal Beaches
1G	Swamp/Marsh
1H	Mud Flows
2A	Mountain Slopes
2B	Alluvial Mountain Valleys
2C	Alluvial Fans
2D	Alluvial Basins (Internal Drainage)
2E	Playa Lakes
2F	Swamp/Marsh
2G	Coastal Lowlands
2Ha	River Alluvium with Overbank Deposits
2Hb	River Alluvium without Overbank Deposits
2I	Mud Flows
2J	Alternating Sandstones and Shale Sequences
2K	Continental Deposits
3A	Mountain Slopes
3B	Alluvial Mountain Valleys
3C	Hydraulically Connected Lava Flows
3D	Lava Flows Not Connected Hydraulically
3E	Alluvial Fans
3F	Swamp/Marsh
3G	River Alluvium
4A	Resistant Ridges
4B	Consolidated Sedimentary Rock
4C	River Alluvium
4D	Alluvium and Dune Sand
4E	Swamp/Marsh
5A	Ogallata
5B	Alluvium
5C	Sand Dunes
5D	Playa Lakes
5E	Braided River Deposits
5F	Swamp/Marsh
5Ga	River Alluvium with Overbank Deposits
5Gb	River Alluvium without Overbank Deposits
5H	Alternating Sandstone, Limestone and Shale Sequences
6A	Mountain Flanks
6B	Alluvial Mountain Valleys
6C	Mountain Flanks
6Da	Alternating Sandstone, Limestone and Shale -- Thin Soil
6Dd	Alternating Sand, Limestone and Shale -- Deep Regolith
6E	Solution Limestone
6Fa	River Alluvium with Overbank Deposits
6Fb	River Alluvium without Overbank Deposits
6G	Braided River Deposits
6H	Triassic Basins
6I	Swamp/Marsh
6J	Metamorphic/Igneous Domes and Fault Blocks
6K	Unconsolidated and Semiconsolidated Aquifers
7Aa	Glacial Till Over Bedded Sedimentary Rock
7Ab	Glacial Till Over Outwash
7Ac	Glacial Till Over Solution Limestone
7Ad	Glacial Till Over Sandstone
7Ae	Glacial Till Over Shale
7Ba	Outwash
7Bb	Outwash Over Bedded Sedimentary Rock
7Bc	Outwash Over Solution Limestone
7C	Moraine
7D	Buried Valley
7Ea	River Alluvium with Overbank Deposits
7Eb	River Alluvium without Overbank Deposits
7F	Glacial Lake Deposits
7G	Thin Till Over Bedded Sedimentary Rock
7H	Beaches, Beach Ridges and Sand Dunes
7I	Swamp/Marsh
8A	Mountain Slopes
8B	Alluvial Mountain Valleys
8C	Mountain Flanks
8D	Regolith
8E	River Alluvium
8F	Mountain Crests
8G	Swamp/Marsh
9A	Mountain Slopes
9B	Alluvial Mountain Valley
9C	Mountain Flanks
9Da	Glacial Till Over Crystalline Bedrock
9Db	Glacial Till Over Outwash
9E	Outwash
9F	Moraine
9Ga	River Alluvium with Overbank Deposits
9Gb	River Alluvium without Overbank Deposits
9H	Swamp/Marsh
9I	Bedrock Uplands
9J	Glacial Lake/Glacial Marine Deposits
9K	Beaches, Beach Ridges and Sand Dunes
10Aa	Regional Aquifers
10Ab	Unconsolidated and Semiconsolidated Shallow Surficial Aquifer
10Ba	River Alluvium with Overbank Deposits
10Bb	River Alluvium without Overbank Deposits
10C	Swamp
11A	Solution Limestone and Shallow Surficial Aquifers
11B	Coastal Deposits
11C	Swamp
11D	Beaches and Bars
12A	Mountain Slopes
12B	Alluvial Mountain Valleys
12C	Volcanic Uplands
12D	Coastal Beaches
13A	Alluvium
13B	Glacial and Glaciolacustrine Deposits of the Interior Valleys
13C	Coastal Lowland Deposits
13D	Bedrock of the Uplands and Mountains

Source: Aller, et al., 1987

Physiographic Provinces of Virginia.



Source: Groundwater Protection Steering Committee, 1987.

Appendix 3 - Weights, Ranges, and Ratings of DRASTIC Factors

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

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

Source: Aller, et al, 1987.

RANGES AND RATINGS FOR DEPTH TO WATER

Range (feet)	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**

RANGES AND RATINGS FOR NET RECHARGE

Range (inches)	Rating
0-2	1
2-4	3
4-7	6
7-10	8
10+	9

Weight: 4 **Pesticide Weight: 4**

Source: Aller, et al, 1987.

RANGES AND RATINGS FOR 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 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**

RANGES AND RATINGS FOR 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 Laom	4
Clay Loam	3
Muck	2
Nonshrinking and Nonaggregated Clay	1

Weight: 2 **Pesticide Weight: 5**

Source: Aller, et al, 1987.

RANGES AND RATINGS FOR TOPOGRAPHY

Range (percent slope)	Rating
0-2	10
2-6	9
6-12	5
12-18	3
18+	1

Weight: 1 **Pesticide Weight: 3**

RANGES AND RATINGS FOR 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**

Source: Aller, et al, 1987.

RANGES AND RATINGS FOR HYDRAULIC CONDUCTIVITY

Range (*GPD/Ft.²*)	Rating
1-100	1
100-300	2
300-700	4
700-1000	6
1000-2000	8
2000+	10
Weight: 3	**Pesticide Weight: 2**

Source: Aller, et al, 1987.

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