Baltimore
Integrated Environmental Management Project

Phase II Report

Underground Storage Tanks Study

Regulatory Integration Division
Office of Policy Analysis
Office of Policy, Planning, and Evaluation
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Phase II Report:
Underground Storage Tanks Study

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PREFACE

This report was prepared under the auspices of the Baltimore Integrated Environmental Management Project (IEMP). The Baltimore IEMP is a collaborative effort of the State of Maryland, Anne Arundel and Baltimore Counties, the City of Baltimore and the U.S. Environmental Protection Agency. The Environmental Protection Agency (EPA) initiated the project as part of its pursuit of new approaches to environmental management and policy. The purpose of the IEMP is to use an integrated approach to identify and assess environmental issues that concern managers, to set priorities for action among these issues, and to analyze appropriate approaches to manage these problems.

The Baltimore IEMP represents the second of four geographic projects that EPA initiated across the country. The Baltimore area was chosen, not because it has a significant toxics problem, but because EPA and local officials wanted to explore better ways to identify, assess, and manage the human health risks of environmental pollutants in the area. Other IEMPs include Philadelphia, Santa Clara County, and Denver.

The decision-making structure of the Baltimore IEMP consisted of two committees, which also served as the means for State and local participation: the Management Committee and the Technical Advisory Committee. The Management Committee, with members representing Baltimore City, Baltimore County, Anne Arundel County, and the State, managed the IEMP and set its overall policy directions. The Technical Advisory Committee, composed of technical managers from the City of Baltimore, the two counties, the State, as well as representatives from the Regional Planning Council and the academic community, recommended issues to study, advised the Management Committee on the technical and scientific aspects of the project, and oversaw and commented on all EPA and consultant work. EPA provide administrative, technical, and analytical support.

The Baltimore IEMP examined five environmental issues: air toxics, Baltimore Harbor, indoor air pollution, lead paint abatement, and potential contamination of groundwater from underground tanks. For further information on these reports or other IEMP studies contact the Regulatory Integration Division, the Office of Policy Analysis (PM-220) in the Office of Policy, Planning, and Evaluation, U.S. Environmental Protection Agency, Washington, D.C. 20460.

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EXECUTIVE SUMMARY

This report presents the results of the Underground Storage Tanks (UST) Study undertaken as part of EPA's Baltimore Integrated Environmental Management Project (IEMP). The UST study represents one of five Phase II studies of the Baltimore area conducted to address environmental issues of particular concern. As a result of Maryland requirements that UST owners test their tanks and report leaks, 8,500 tanks were tested and 720 were found to be leaking. This 720 was part of 1,100 UST leaks reported in fiscal year (FY) 1987, a 78 percent increase in leak reports from FY 1986. The UST screening methodology developed in this project enables environmental planners and oil pollution enforcement officials to assess the relative vulnerability of areas within the study area to groundwater contamination from leaking USTs; it does not attempt to assess human health risks from exposures. Participants in the IEMP UST study recommend that environmental officials at state, regional, and local levels target their resources to evaluate and combat leaking USTs more efficiently.

The UST screening methodology measures three separate factors that taken together determine the relative vulnerability of an area: hydrogeologic setting, groundwater use, and UST density.

- o Hydrogeologic vulnerability is assessed using DRASTIC, a standardized system developed by the National Water Well Association with EPA support to evaluate groundwater pollution potential using hydrogeologic settings.

- o Groundwater use is assessed by determining the density of populations using groundwater as a source of drinking water per square mile within zip code areas.

- o UST density is measured as the number of USTs per square mile within specific zip code areas.

Each measure is geographically displayed on computer-generated maps at a scale of 1:62,500 as well as the smaller size included in this report. These maps are printed on transparent mylar, so that they can be laid over each other to highlight interactions between the three indicators of vulnerability.

As applied to the Baltimore IEMP study area, the methodology reveals a number of areas exhibiting relatively high vulnerability. <u>Anne Arundel County is shown to be more vulnerable than Baltimore County</u>. Two factors contribute to this. First, in Anne Arundel County, most people rely on public or privately owned wells as their source of drinking water, whereas in Baltimore County, most people obtain their drinking water from the Baltimore City water system, which is derived from surface water. Second, the hydrogeology of Anne Arundel County is relatively more susceptible to contamination. Much of the northern portion of Anne Arundel County overlies vulnerable groundwater and exhibits both high groundwater use and UST density. Within Baltimore County, areas overlying the Cockeysville Marble formation exhibited the highest vulnerability due to the pollution potential of the formation.

The UST screening methodology allows officials to analyze the three individual factors contributing to the vulnerability of a region, and evaluate the interaction of these factors on maps. The State of Maryland plans to apply the methodology to each of its counties. The IEMP participants plan to use the UST screening methodology to set priorities for UST leak investigation and cleanup, to review proposed development, to educate UST users and developers, and to supplement related studies. The availability and accuracy of data will strongly influence the time and effort involved and the accuracy of the analysis. Jurisdictions may wish to evaluate and revise their UST and groundwater data reporting to facilitate updates of the screening products.

I. INTRODUCTION

I.A. Integrated Environmental Management Projects

This report describes a study of underground storage tanks (USTs) in the greater Baltimore area. In this study, we developed a methodology that can help state and local officials set priorities for UST management. We applied this methodology in the study area and identified those areas most vulnerable to groundwater contamination from leaking USTs.

The study was conducted as part of the Baltimore Integrated Environmental Management Project (IEMP). The Environmental Protection Agency (EPA) initiated the project as part of its pursuit of new approaches to environmental management and policy. The purpose of the IEMP is to use an integrated approach to identify and assess environmental issues that concern managers, to set priorities for action among these issues, and to analyze appropriate approaches to manage these problems.

EPA adopted the concept of integrated environmental management as a potential solution to the shortcomings of the traditional approaches for pollution control. The traditional approach of focusing on one pollutant or class of pollutants within each medium at a time may result in environmental programs and regulations characterized by inefficient use of resources. Grounded in the concepts of risk assessment and risk management, the IEMP uses estimates of risk, that is, the probability of adverse effects, as a common measure for comparing and setting priorities among environmental issues that involve different pollutants, sources, and exposure pathways and that may affect human health, ecosystems, and resources. The need for setting priorities is prompted by the realization in the past ten years that hundreds of chemicals present in our environment pose some risk of causing cancer or other adverse health effects. Comparing the risks to help set priorities allows environmental managers to focus limited resources in a manner that will achieve the greatest public benefit -- the greatest reduction in risk for a given cost of control. The projects are also intended to involve all local responsible parties and agencies in actually managing and coordinating the projects, ensuring that issues of greatest local concern are adequately addressed. The Baltimore IEMP was particularly successful in this regard.

The IEMP projects are divided into two phases. In the first, project managers establish the decision-making structures of the project, identify key environmental issues and set priorities among them. Risk is but one of the criteria used in ranking issues; the others include analytical feasibility, relevance to EPA, state and local program objectives, and the potential for effective response. In the second, the IEMP studies the priority issues in greater detail and analyses strategies for their control or resolution.

I.B. The Baltimore IEMP Study

The Baltimore IEMP is a cooperative effort involving the governments of the State of Maryland, the City of Baltimore, Baltimore County, Anne Arundel County, and EPA. The Baltimore area was chosen, not because it has a significant toxics problem, but because EPA and local officials wanted to explore better ways to identify, assess, and manage the human health risks of environmental pollutants in the area. It represents the second of four, full-scale geographic projects that EPA has initiated to date across the country.

The Baltimore IEMP study area covers Baltimore City, which includes the Port of Baltimore, and Baltimore and Anne Arundel counties (see Exhibit I.1). It extends from the Pennsylvania border on the north, to south of Washington, DC, and borders on the Chesapeake Bay on the southeast.

The decision-making structure of the IEMP consisted of two committees, which also represented the vehicles for State and local participation: the Management Committee (MC) and the Technical Advisory Committee (TAC). The MC, with members representing Baltimore City, Baltimore County, Anne Arundel County, and the State, managed the IEMP and set its overall policy directions. The TAC, composed of technical managers from the City of Baltimore, the two counties, the State, as well as representatives from the Maryland Regional Planning Council and the academic community, recommended issues to study, advised the MC on the technical and scientific aspects of the project, and oversaw and commented on all EPA and consultant work. EPA provided administrative, technical, and analytical support. In phase II, special work groups with members from both the TAC and representatives from industry, public interest groups, government, and academia were organized around each priority issue. They provided greater specialized expertise in examining the issues. The Underground Storage Tank work group members are listed in Appendix A.

Five topics were chosen for further examination in phase II of the Baltimore IEMP. They were:

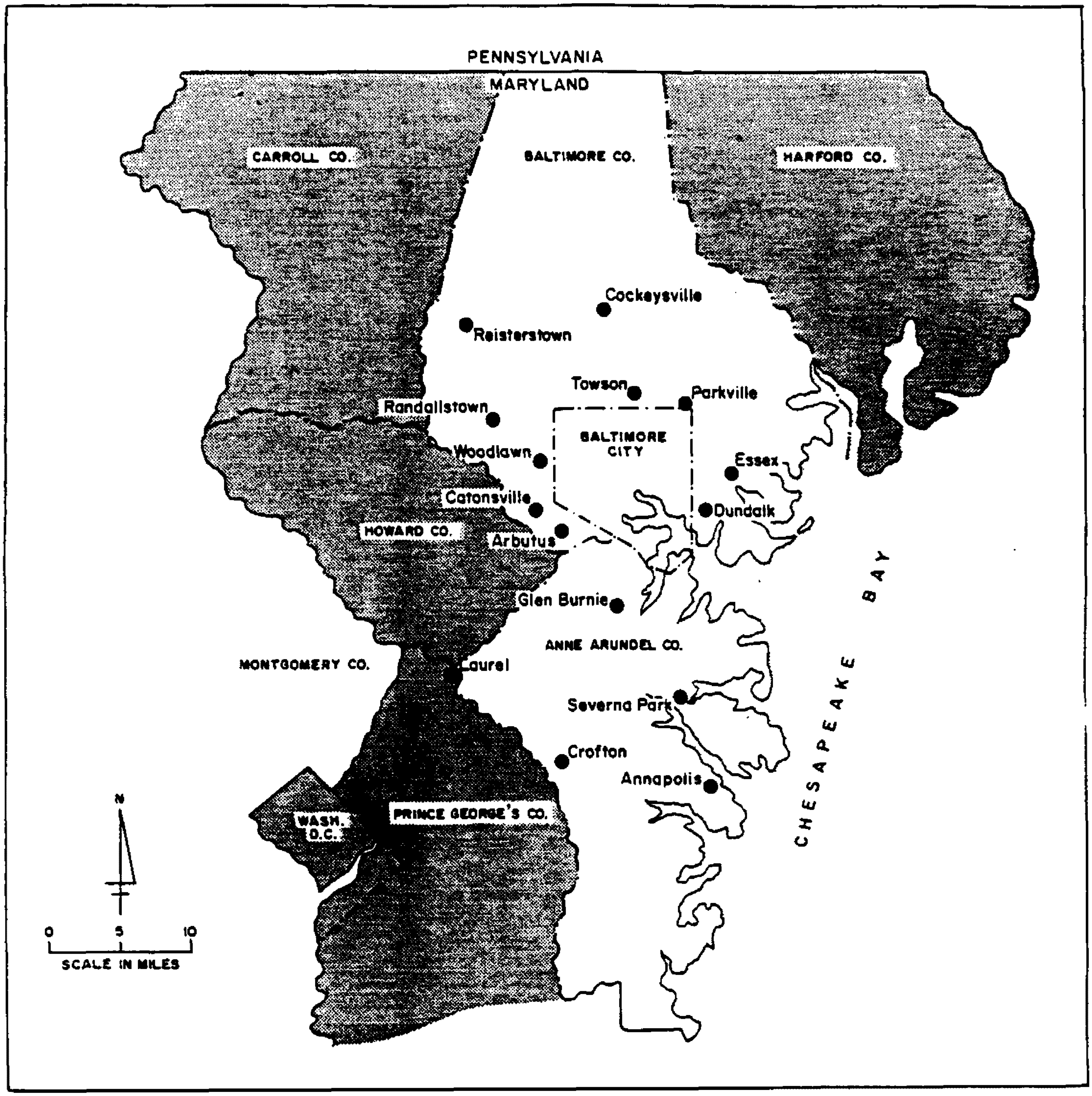
1) Multimedia metals. The goal was to develop cost-effective techniques for lead paint removal and dust abatement.

2) Indoor air pollution. The goal was to develop the information necessary to support possible programs to reduce exposures to indoor air pollution and to support the expansion of local government capability to respond to inquiries concerning indoor air pollution.

3) Air toxics. The goal was to estimate ambient air concentrations of selected air toxics, analyze associated risks, and develop control strategies for reducing these risks.

4) Baltimore Harbor. The goal was to define current and future uses of the Harbor's waters and identify actions, additional research, and institutional arrangements necessary to help environmental decision-makers improve water quality and habitat in the Harbor to achieve the desired uses.

EXHIBIT I.1: Baltimore IEMP Study Area



5) Underground storage tanks. The goal was to develop a strategy for identifying which groundwater resources are at greatest potential risk if underground tanks leak.

In addition, the risk analysis conducted in Phase I on trihalomethanes, which result from the disinfection of drinking water through chlorination, was to provide the reference point for risk identified in the air toxics study.

I.C. Results of the Phase I Priority-Setting Process

The major task in phase I was to identify environmental issues of concern in the study area and to set priorities among them for further study and development of control strategies in phase II. The Baltimore IEMP set priorities on the basis of available information, supplemented by data from a brief ambient monitoring effort conducted by EPA. [Please see Chapter IV of Baltimore Integrated Environmental Management Project: Phase I Report, May 1987 (hereafter referred to as the Phase I report) for a detailed account of the priority-setting process in the first phase of the IEMP.]

The selection of Underground Storage Tanks as an issue for Phase II study resulted from an extended environmental decision-making process by the TAC and MC of the Baltimore IEMP. (See Phase I Report, expecially Chapters IV, VI, and VIII.) This process is summarized below.

First, the TAC members defined the geographic boundaries of the study. Second, the TAC identified thirty-two potentially important environmental issues, drawing heavily upon the members' experience and knowledge of potential problems. Third, the committee agreed on the use of three separate measures of environmental degradation to evaluate the severity or significance of the thirty-two issues. These measures -- human health risk, ecological impact, and groundwater resource impact -- also would define a set of three categories into which each of the thirty-two issues would be placed.

The TAC established the Groundwater Resources Subcommittee to formulate a methodology for setting priorities among groundwater issues. This Subcommittee was chaired by a representative of the Maryland Geological Survey, and included one representative from Anne Arundel County, one from Baltimore County, and one from EPA. The Subcommittee was asked to identify and rank the environmental issues that posed the greatest potential impact on groundwater resources, and to recommend no more than three issues for further study.

The Subcommittee developed an index consisting of two components, pollution impact and economic impact. They used the index to evaluate and rank different sources of groundwater contamination. This ranking is shown in Exhibit I.2. (See Phase I Report, Chapter VI, for a complete description of the indexing process.)

The Subcommittee eventually decided to recommend only two issues for study in Phase II -- underground storage tanks and multimedia metals. There was agreement among all Subcommittee members that they were among the most important issues in each geographic region of the study area.

EXHIBIT I.2: Relative Ranking* of Potential Sources of Groundwater Contamination

Underground storage tanks
Multi-media metals
Benzene
Pesticides/herbicides
Pollution from farming
Landfills
Septic tanks
Chromium in Harbor
Surface Impoundments
Acid rain
Sanitary sewers
Road salting
Feedlots

* The highest ranked issue is listed first, and the lowest is listed last.

Source: Baltimore Integrated Environmental Management Project: Phase I Report, May 1, 1987.

USTs were thought to be particularly important by the Subcommittee members for these reasons:

- the large number of underground storage tanks;
- the existence of known contamination incidents;
- the potential for future incidents;
- the size of the population using groundwater near the units; and
- expected high values for the three types of cost that could be incurred: prevention of contamination, treatment of contamination, and provision of an alternate water supply.

In addition, the State of Maryland's recent regulations (Code of Maryland Regulations, 08.05.04) required testing of underground storage tanks for leaks. This led Subcommittee members to believe that there would be substantial increase in the number of reports of leaking USTs, and response to these reports could strain inspection and oil pollution enforcement resources.

The TAC developed a set of secondary criteria to evaluate all of the proposed Phase II issues and to choose those issues for further study. The TAC recommended underground storage tanks for detailed Phase II study. The MC approved this recommendation.

The goals of the work plan developed for underground storage tanks were:

- o Set priorities for UST inspection and enforcement in the study area. Identify those areas where underground storage tank leaks which are most likely to damage groundwater resources.

- o Provide a methodology, or tool, that can be readily applied by State and local officials, both in the study area and elsewhere, to help set priorities for managing underground storage tanks.

The UST Phase II study would evaluate the potential risks to groundwater resources from USTs in different parts of the study area, and thus enable officials to target their resources more effectively. The study does not attempt to assess human health risks from exposures. The methodology developed can be used by other jurisdictions to set priorities for their own UST management.

I.D. Priority-Setting for Improved UST Management

The UST screening methodology was developed to assist environmental enforcement officials set priorities for responding to potential leaks from USTs. The need for a priority-setting methodology in the Baltimore area is highlighted by several factors:

1. State and/or local officials respond to and investigate every report of an UST leak to protect the groundwater resource and well water quality;

2. as a result of recent Maryland regulations, the number of reports of UST leaks has increased significantly in the last year; and

3. the personnel and resources available to enforcement agencies for response have not increased proportionately.

State and local officials thought that it was important to develop a decision tool to enable them to respond to the potentially most serious UST leaks first.

The State of Maryland regulations for controlling oil pollution from USTs (Code of Maryland Regulations, 08.05.04) set standards for UST construction, installation, corrosion protection, monitoring, tightness testing, and reporting of leaks.

The regulations require tightness testing on:

1. all tanks which have been buried 15 years or longer, or are of unknown age, by January 28, 1987, and these must be retested every five years thereafter;

2. all tanks which show inventory variations of more than 1/2 of 1 percent of inventory over 30 days time; and

3. all new tank installations.

All tanks found to be leaking (defined as more than or equal to .05 gallons/hour loss) must be reported. Of the estimated 8,500 USTs tested in Maryland, 720 were found to be leaking. This was part of a total of 1,100 UST leak reports in fiscal year (FY) 1987, a 78 percent increase over FY 1986 (The Maryland Oil Disaster Containment, Clean-up and Contingency Fund 15th Annual Report, Fiscal Year 1987, Maryland Department of Natural Resources, Water Resources Administration, Oil Control Division).

The Maryland Waste Management Administration currently has seven inspectors responding to leak reports in the State (an increase of one inspector since FY 86). Baltimore County and Anne Arundel Country each has two to three individuals who respond to possible UST contamination of drinking water wells as a part of their jobs. The resources available to respond to leak reports will limit the ability of State, county, and local officials to address all leaks expeditiously, as well as perform their other permitting, inspection, and enforcement activities.

The development of the UST screening methodology allows officials at all levels of government to focus their inspection and response resources on those incidents most likely to result in serious damages. This may involve focusing State resources on the most vulnerable counties, or it may involve county and regional governments allocating their resources to those areas at greatest risk from leaking USTs. The methodology developed here is intended to support these resource allocation decisions.

In this analysis, we only considered gasoline USTs, and did not attempt to assess the potential impacts of USTs containing other chemicals. We also did not consider USTs located on farms.

II. THE UST SCREENING METHODOLOGY

This chapter describes the UST screening methodology developed for ranking the vulnerability of areas to leaking USTs. First, we present an overview of the problem. Next, we present an overview of the general approach and the development of UST screening analysis maps using a computerized geographic information management system. Then we present the three measures of vulnerability -- hydrogeologic settings, UST density, and groundwater use -- as well as alternatives considered. Next we discuss issues concerning the identification and collection of data for quantifying these three measures of vulnerability. We conclude the chapter with a description of how map overlays are created.

II.A. Overview of the Problem

Groundwater in the Baltimore Region supplies agricultural, industrial, commercial, and residential uses, and its discharge to streams and rivers is crucial to sustaining surface water ecosystems. Most of Anne Arundel County depends upon groundwater, and significant parts of suburban Baltimore County depend on groundwater supplies. Contamination of groundwater, and its prevention, has become a vital environmental issue nationwide, and is a focus of State and local concern.

In order to evaluate the problem of groundwater vulnerability to contamination, it is necessary to recognize that the resource is not uniformly distributed throughout the study area. Some rocks and sediments are good water-bearing strata, and others are not. Various physical and chemical factors affect both the availability and the vulnerability to pollution of the groundwater, a few of which include type of sediment (sand or clay), mineralogy of clay minerals, and porosity and permeability of the sediment or rock. Despite a large body of theory and research on hydrogeology, the fate and transport of contaminants traveling in groundwater is often unclear. We used a system called DRASTIC to evaluate the vulnerability of an hydrogeologic system to groundwater contamination.

Sources of pollution are numerous - examples include landfills, road salting, septic tanks, and non-point sources. We chose the number of USTs present as a surrogate for the degree of pollution threat. Because pollution affects people using the resource, we chose the number of persons dependent on water wells as a surrogate for population impacts.

Our study focuses on a methodology for evaluating resource impact rather that human health effects. We have assumed that once water is identified as contaminated, it will either be avoided or treated.

II.B. Overview of the Approach

The Baltimore IEMP UST screening approach identifies areas vulnerable to leaking USTs by quantifying and integrating three factors: hydrogeologic setting, UST density, and population served by groundwater. Using a computerized mapping system, we developed maps of an area that depict the relative potential for impact from each factor and plotted them on transparent materials. We then evaluated the overall vulnerability of areas within the study area by overlaying the UST and groundwater use maps on the hydrogeologic setting map.

A computerized geographic information management system allows maps to be drawn at various scales. For the Baltimore IEMP study, full-scale (1:62,500) maps were created for use by the Maryland, Anne Arundel County, Baltimore County, and Baltimore City governments. These maps provide environmental officials with a useful tool for setting priorities within their jurisdictions. In addition to the full-scale maps, a computerized system allows report-sized maps to be produced which depict the same information as the large maps. These maps can be reproduced easily and used by numerous analysts and officials. Report-sized maps are provided in the map pockets at the end of this report.

A benefit of developing separate component maps is that they can be used and updated individually as well as together. This approach provides a great deal of flexibility in determining which component (i.e., UST density, groundwater usage, or hydrogeologic vulnerability) plays the predominant role in defining the vulnerability of an area and also allows component maps to be used for different types of analysis. In some cases, environmental officials may be concerned with all areas exhibiting a high hydrogeologic vulnerability, while in other cases, the density of USTs within a location may be the factor of greatest interest. Furthermore, this approach will allow other components, not previously considered, to be easily incorported into an analysis.

The UST screening approach focuses on potential impacts on the groundwater resource; it does not attempt to assess human health risks from exposures.

We considered a number of geographic information management mapping packages for use in this study. Some required a mainframe computer due to the software's large memory demands. However, other software packages are available for personal computer use; we selected a commercially available software package designed to run on a personal computer for this study. Appendix B discusses hardware and software options more fully.

II.C. Individual Measures of Vulnerability

This section presents our methodology for evaluating our three component measures of vulnerability: hydrogeologic setting, UST density, and population served by groundwater. Each measure is described separately along with a discussion of possible alternatives.

II.C.1. Hydrogeologic Settings

Many factors may affect the way in which contaminants released from an UST move in groundwater to a well. The hydrogeology of an area is a primary factor in determining the potential impact of leaking USTs upon wells. In developing the screening methodology, we characterized hydrogeologic potential for groundwater contamination as indicated by natural variability inherent in the land.

We selected a method developed by the National Water Well Association (NWWA) under the sponsorship of the U.S. EPA Robert S. Kerr Laboratory in Ada, Oklahoma, called DRASTIC[1], to systematically evaluate the pollution potential of hydrogeologic settings within regional groundwater systems.

DRASTIC was developed with the guidance of groundwater experts representing federal and state agencies, the Canadian government, and private consultants to help environmental managers make screening level evaluations of the relative vulnerability of a hydrogeologic setting to contamination. DRASTIC allows users with a basic understanding of hydrogeology to score a region for pollution potential. Depending upon the availability of hydrogeologic information and the expertise of the user, it may take less than one week to develop DRASTIC scores for one or two counties. We selected DRASTIC for this study because its intended use is consistent with the objectives of our UST screening analysis.

The approach quantifies the relative pollution potential of a hydrogeologic setting by analyzing seven hydrogeologic parameters that form the acronym, DRASTIC: Depth to groundwater, net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone, and hydraulic Conductivity. A hydrogeologic setting is defined as a mappable unit with common hydrogeologic characteristics and, therefore, common vulnerability to contamination. A hydrogeologic setting in DRASTIC must be greater than 100 acres in areal extent, as the method is considered inappropriate for smaller areas. DRASTIC is designed to be used as a screening tool and should not used to replace on-site inspections, or as a site assessment methodology. It provides a basis for comparative evaluation of pollution potential of areas within a larger region, but does not provide an absolute assessment of groundwater vulnerability.

DRASTIC is a numerical ranking system that enables one to rank the vulnerability of different settings through its system of weights, ranges, and ratings for each of the seven parameters. Each parameter has a weight ranging from 1 to 5 that designates its relative importance to the overall vulnerability of a setting. The weights are set by DRASTIC, and should not be changed, with 1 as the least important and 5 as the most important. For example, Depth to Water Table is a relatively important parameter with a weight of 5, while Topography is least important with a weight of 1. Each DRASTIC parameter is divided into either ranges or significant media types that have an impact on pollution potential. For example, Hydraulic Conductivity has six ranges from 1 gallon/day/ft^2 to over 2000 gallons/day/ft^2. A numerical rating is then assigned to each range by the user; the rating determines the relative importance of each range with respect to pollution potential. The ratings are assigned based on the assessment of the user as to which classification or range an area falls into, and the ratings for those classifications or ranges as provided by DRASTIC. Higher ratings indicate higher vulnerability. For example, the Soil Media range corresponding to "gravel" receives a rating of 10, while the range corresponding to "clay loam" receives a rating of 3. Exhibit II.1 displays the weights, ranges, and ratings associated with each of the seven DRASTIC parameters.

Exhibit II.1 DRASTIC Parameter Weights, Ranges, and Ratings

Ranges and Ratings for Depth to Water

Depth to Water (feet)

Range	Rating
0-5	10
5-10	9
18-30	7
30-50	5
50-75	3
75-100	2
100+	1

Weight: 5 Agricultural Weight: 5

Ranges and Ratings for Net Recharge

Net Recharge (inches)

Range	Rating
0-2	1
2-4	3
4-7	5
7-10	8
10+	9

Weight: 4 Agricultural Weight: 4

Ranges and Ratings for Topography

Topography (percent slope)

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

Weight: 1 Agricultural Weight: 3

Ranges and Ratings for Hydraulic Conductivity

Hydraulic Conductivity (GPD/ft^2)

Range	Rating
1-300	1
100-300	2
300-700	4
700-1,000	6
1,000-2,000	8
2,000+	10

Weight: 3 Agricultural Weight: 2

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	5
Massive Sandstone	4-9	5
Massive Limestone	4-9	5
Sand and Gravel (Till)	4-9	8
Basalt	2-10	9
Karst Limestone	9-10	10

Weight: 3 Agricultural Weight: 3

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	5
Loam	5
Silty Loam	4
Clay Loam	3
Muck	2
Nonshrinking and Nonaggregated Clay	1

Weight: 2 Agricultural Weight: 5

Ranges and Ratings for 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

Weight: 5 Agricultural Weight: 4

In order to develop a DRASTIC index for a given setting, the user determines the proper rating for each of the seven DRASTIC parameters, and multiplies each rating by its corresponding weight; all weighted ratings are summed to get a score representative of the relative pollution potential:

$$D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w = \text{Pollution Potential}$$

where: r = rating
w = weight

DRASTIC maps of the Baltimore study area were developed by calculating DRASTIC indices for each of the major hydrogeologic settings in the area.

II.C.2. Selecting Zip Codes as Basic Geographic Units

The UST methodology uses zip code areas as the smallest geographic unit for defining UST and groundwater-dependent population density distributions. The hydrogeologic vulnerability ranking follows the natural boundaries of hydrogeologic settings within the study area. Zip codes and hydrogeologic settings both vary greatly in size. In areas of great variability, the size of geographic areas may have a significant impact on the results and utility of the screening analysis; smaller units will allow finer distinctions to be made. The unit selected depends upon the scale of the study, the availability of data for different units, and the costs of data collection. Generally, the UST screening analysis will provide more detailed results with smaller units, as finer distinctions can be drawn across the entire study. However, it may be difficult or expensive to obtain data at a fine scale. In this study, we chose zip codes as the basic geographic unit as a compromise between the usefulness and feasibility of the options considered.

Zip code boundaries are useful for several reasons. First, location information on documents such as State permits or well records often include zip codes, making it relatively easy to obtain and collate data for the analysis. Zip codes are relatively small, and their boundaries often follow county boundaries making it easy to integrate zip code maps and other geographic maps of an area. Exhibits II.2 and II.3 show the zip codes in the study area.

Drawbacks associated with using zip code boundaries include the fact that some hydrogeologic units are considerably smaller than a zip code area and others are considerably larger, and zip code sizes may vary greatly. In particular, zip code sizes tend to be larger in rural areas, where groundwater use may be higher. This may provide less detail in the areas of most concern. Differences in UST and well distributions within these areas cannot be readily discerned. Wells and USTs may be evenly distributed in a zip code, or the wells may be concentrated in one portion of a zip code, and USTs in another. In addition, zip code boundaries may be changed by the Postal Service from time to time, compromising the accuracy of the boundaries used as well as the data.

One alternative would be to map the actual locations of wells and USTs in the geographic information management system. If this were done, precise interactions between wells and USTs could theoretically be analyzed, although

EXHIBIT II.2: Zip Code Map of Anne Arundel County

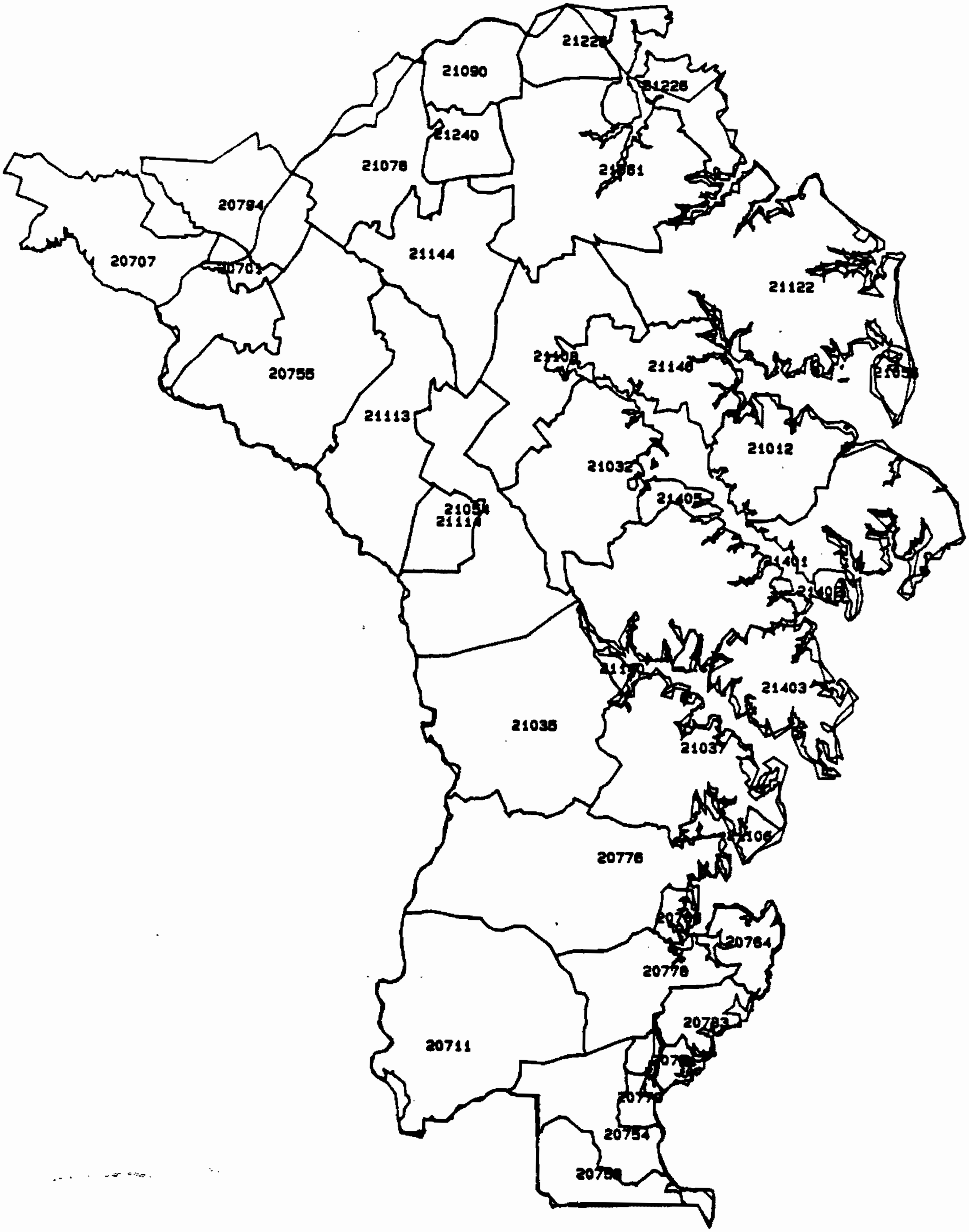
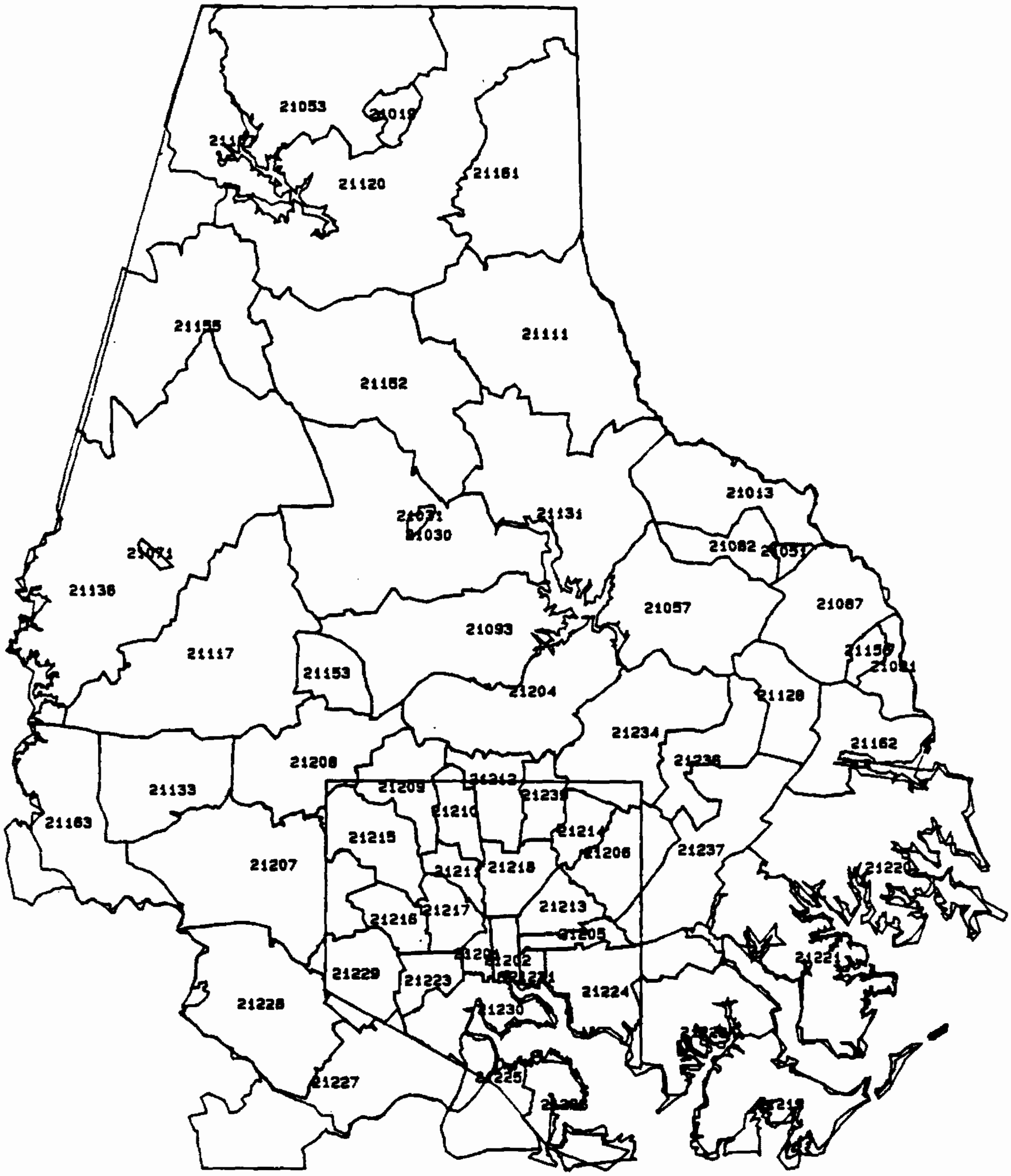


EXHIBIT II.3: Zip Code Map of Baltimore County and Baltimore City



it might be difficult to effectively display the data on maps. The primary drawback to such an approach would be the additional time and expense of data collection, since it might be difficult to obtain latitude and longitude information for many USTs and wells. States and regional authorities might have adequate well inventory and location data, and UST locations could be generated by a physical inventory, but the time and cost may prohibit such a mapping effort. It must also be considered that DRASTIC may not provide a comparable level of detail.

II.C.3. UST Location and Density

The UST screening methodology indicates the potential for groundwater contamination by depicting the potential interactions between USTs, wells, and hydrogeologic settings in specific areas. The density of USTs (number of USTs per square mile) within each zip code is one of the three basic measures of vulnerability used.

To calculate the density of USTs within each zip code, we divided the number of USTs by the surface area of the zip code. In cases where zip code areas are extremely small (such as the case where a single large building has been assigned a separate zip code), we assigned USTs to an adjacent zip code. This sacrificed some detail, but allowed us to present UST density more easily on maps.

After we calculated UST densities within each zip code, we divided the zip codes within each county into three categories corresponding to high, medium, and low UST density. This facilitated making relatively broad distinctions concerning the potential for impacts in specific zip codes. With the UST density distribution grouped into three categories, we can more readily correlate UST densities with groundwater use and hydrogeologic settings in order to highlight areas vulnerable to leaking USTs. The approach followed in the UST screening methodology involved creating distributions such that equal numbers of zip codes within the counties are placed in each of the three categories (i.e., low, medium, and high). The data were arrayed into categories for each county individually; thus, the range of data in each category is different for Baltimore and Anne Arundel county. After considering some alternatives, we chose this method of displaying the data because we thought that this array would be most useful to the jurisdictions in the study area. Other configurations of the data are possible, such as division of the data into high, medium and low categories on a state-wide basis. A complete listing of the UST density used for each zip code in the study area, as well as the groundwater-dependent population density for each zip code, is provided in Appendix B.

II.C.4. Population Density of Groundwater Users

The screening methodology utilizes well locations and information on groundwater use as a surrogate for the groundwater-dependent populations that may be affected by leaking USTs. From data on the number of private and public wells within the study area and estimates of the number of persons per household and pumpage data, we calculated the population that is dependent on groundwater.

For private wells, the analysis relies on Bureau of Census and State of

Maryland estimates of the average number of persons per household in order to determine the average number of persons (users) per private well. For public wells, we determined the numbers of users at each well based upon State well permit records. We summed the number of users of private and public well water to calculate the total number of groundwater users per zip code. We calculated the population density of groundwater users per square mile within each zip code by dividing the estimated population served by the area of the zip code.

In assigning users to specific zip codes, we assigned users to the zip code in which the well is located, rather than the zip code in which the users may be located. This ensures that the importance of the groundwater provided by a well is fully reflected on the maps.

We assigned the distribution of groundwater use by zip code in each county to the high, medium, or low category, following the same approach used in calculating UST densities by zip code. Again, we placed equal numbers of zip codes within each county in each of the three categories. If we had divided the zip codes into three categories across the entire study area, more of Baltimore County's zip codes would exhibit low well use density, while Anne Arundel County would have a higher proportion in the high category.

Alternatives to this approach again focused on using geographic boundaries other than zip codes as the basis of the screening approach, which is discussed in Section II.C.2.

II.D. Identifying and Collecting Data

Conducting an UST screening analysis requires the collection of significant amounts of data on the hydrogeology, groundwater use, and number of USTs in the region. Since the quality of data will determine the accuracy and usefulness of the results, the identification and collection of data play major roles in the application of this methodology.

The availability of hydrogeologic data will vary across states and to some extent within states. Many states have geologic surveys that map the groundwater resources, mineral resources, and geology of portions or all of the state. These sources provide detailed information for development of DRASTIC ratings. U.S. Geological Survey and state geological studies and reports provide fundamental information needed in developing a DRASTIC rating. If hydrogeologic reports specific to a study area do not exist, the DRASTIC report provides general ratings for over one hundred hydrogeologic settings across the United States which can be applied to the appropriate areas. Because these ratings are quite general, they should be evaluated by experienced professional geologists or hydrogeologists familiar with the specific features of the area being studied.

While a number of data sources can be identified providing both well and UST information, this information will not always be of high quality, and the data may not exist in terms of zip codes. Major sources of available data include the U.S. Census Bureau, and other Federal, State and local government agencies. In some cases, data can be purchased from firms that specialize in collecting and categorizing census data and household and business statistics.

The Bureau of the Census estimates the number of households served by public and private groundwater wells by Standard Metropolitan Statistical Areas (SMSAs) and by census tracts. We found in this study that these data do not necessarily provide sufficient accuracy because of the large variation in the size of the census tracts in the Baltimore study area. (Census tracts exhibited much more size variation than zip codes.) The data available from State and local government agencies (such as the state environmental agency or the state public works department) may have more detailed and more geographically specific UST and well information. However, many State and local governments do not have permitting and notification data computerized.

Data for this study on the number of wells were obtained from well permit records that had been compiled by the State Department of Health and Mental Hygiene. These data required much additional manipulation to be put into a useable format.

Data collection for USTs was relatively straightforward due to the availability of data from the EPA Region III UST Notification Survey. The Hazardous and Solid Waste Amendments (HSWA) of 1984 required States to collect this UST data, and most states have complied. The data were collected by EPA Regional Offices for those states like Maryland, which did not participate. EPA Region III is now providing the data to Maryland. The only difficulty was that the data were formatted by a proprietary software package which was not initially available to the project. Once arrangements were made for reformatting the UST data, it took about two days to sort the data by zip code and to calculate UST densities.

The Bureau of the Census also collects information on the number of business establishments by Standard Industrial Classification (SIC) code located in each SMSA and in each census tract. Service stations have a unique four-digit SIC code, and therefore can be identified using Census data. By making an assumption regarding the average number of USTs at service stations in the study area, it is possible to estimate the number of service station USTs in a region using available Census data. However, if UST location information is estimated using Census data, the user must keep in mind that business establishments other than service stations may maintain USTs (e.g., rental car agencies, airports, delivery agencies, and auto dealerships). In considering other business establishments, an estimate must be made regarding the average number of USTs at each type of establishment and the proportion of all establishments that actually have USTs.

Another major consideration concerns the format and quality of the data. The data should be in a format that can be easily integrated onto the computerized mapping system. Often, data compiled by state agencies will be stored on mainframe computers, and will be available on tape or as computer printouts. The large number of wells in many parts of the country, such as in the Baltimore study area, make it necessary to obtain the information on computer tape. In many cases, it will be necessary to arrange to have the tape outputs transferred onto a floppy disk in order to use the data on a personal computer system.

In most cases, the user will not receive the data already aggregated into the geographic units being analyzed in the study. It may be necessary to use a statistical package to sort the information by this unit (e.g., zip code) in order to tabulate the number of USTs or wells in each unit within the study area.

II.E. UST Screening Analysis Map Overlays

The UST screening methodology uses a computerized mapping system to develop maps that display the density of groundwater use, UST density, and hydrogeologic vulnerability within the study area. By producing these maps on mylar and overlaying them upon the county base map, potential interactions between groundwater use patterns and the presence of USTs in areas with differing hydrogeologic vulnerability can be observed.

In integrating the measures of vulnerability, the separate maps must first be developed. In this study, we used a personal computer-based data management and geographic information system to generate and display relevant boundaries and to visually display the relative ranking of the various measures of vulnerability. Appendix C outlines the basic hardware and software requirements for a personal or desktop computer management system. It provides an overview of possible systems that are available at relatively low costs, but does not provide an exhaustive list of system possibilities or recommend a particular system. The best system for any particular agency depends on the resources available, including any currently owned computer resources, and the priority the agency wishes to attribute to an UST or groundwater vulnerability screening analysis.

We used purchased files displaying zip code boundaries within the study area to develop the UST and groundwater use density maps. After generating distributions of high, medium, and low for each county, we assigned a value to each zip code to enable the computer system to draw the proper patterns. For example, the high-density areas have the most lines per inch, while the low-density areas have the least. Zip codes for which data were unavailable were left blank. The UST density map lines run from northeast to southwest, while the groundwater use map lines run from northwest to southeast. When overlayed, the density of cross-hatching, together with the underlying DRASTIC rating, indicates the vulnerability of the zip code. Alternatively, each part of the distribution can be shaded using different patterns, depending upon the needs of the user.

Given access to digitizing software, the computer management system can be used to define new boundaries for the analysis. Digitizing software allows geographic boundaries to be entered into a computer data base as strings of coordinates. In this study, we used a digitizer to computerize the hydrogeologic setting boundaries of Anne Arundel and Baltimore Counties and Baltimore City, which were developed for quantifying hydrogeologic pollution potential. One of the benefits of using digitizing equipment is the capability it provides for defining new geographic units within which analysis can be conducted.

One of the primary benefits of using a computerized data base and geographic analysis system is that maps can be printed at various scales. With the proper hardware, full-scale maps (e.g., 1:62,500 scale) can be printed for use by environmental officials. Large maps provide officials with benefits associated with their scale, such as allowing individual locations of greater concern to be indicated on the map. In addition, full-scale maps can be overlayed onto full-scale county maps that highlight roads and other important cultural features, allowing the user to consider other potential impacts with the screening analysis.

The computer-based system also enables each individual vulnerability measure to be updated, revised, and printed out separately at little additional cost. Once the system has been developed, the costs associated with printing additional maps will be based primarily on the costs of the materials and the time to print them.

Once the individual maps have been created, the high to low vulnerability areas within the region can be identified. The relative importance of each of the three maps on this final estimate of vulnerability will depend upon the user's orientation. If the primary issue involves the identification of problem USTs in regions with a low UST density and high groundwater use, the user may wish to focus enforcement resources on these few USTs; given high groundwater use patterns, the potential for a leaking UST to affect a well would be high. Conversely, in areas with a high density of USTs and a low density of well use, enforcement authorities may not be as concerned given the lower likelihood that a single UST will actually affect a well. Clearly, areas with high well and UST densities will pose the greatest potential problems in all but the least hydrogeologically vulnerable areas.

If an agency is primarily concerned with protecting wells, it may wish to highlight wells for inspection in areas with a high population density of groundwater users and a high density of USTs, since they will exhibit a high potential for contamination. Additionally, the overall pollution potential of the aquifer as defined with DRASTIC will greatly influence groundwater vulnerability. The extent to which officials evaluate the significance of wells and USTs located in regions of high groundwater vulnerability versus those located in regions of low groundwater vulnerability will vary with the priorities of the user.

III. APPLICATION OF THE UST SCREENING METHODOLOGY TO THE BALTIMORE IEMP STUDY AREA AND GUIDANCE FOR ITS APPLICATION ELSEWHERE

In this chapter, the UST screening methodology is applied to the Baltimore IEMP study area. First is an overview of the geography, climate, and hydrogeology of the area. Next, we describe how we assessed the potential for groundwater pollution by applying DRASTIC to create pollution potential maps of Baltimore County (including Baltimore City) and Anne Arundel County. We then discuss data collection for USTs and populations dependent on groundwater. In the final section, we discuss integration of individual map overlays. For each section, we provide resource estimates (equipment, personnel, time, and costs) and discuss potential problems that may confront future users of this screening methodology.

III.A. Overview of the Baltimore Study Area

III.A.1. Geography

The Baltimore IEMP study area covers Baltimore County, Anne Arundel County, and Baltimore City (see Exhibit I.1, page 3). Baltimore City, with a population of about 700,000 people, is located in the center of the study area.

Anne Arundel County includes an area of 417 square miles of land and 41 square miles of water, extending from the City of Baltimore in the north, to within 15 miles of Washington, D.C. in the south.[2] Annapolis, the capital of Maryland, is located in the east central part of the county. Major rivers in Anne Arundel include the Patuxent River (forming the County's western boundary) and the Patapsco (forming parts of its northern boundary). The county also borders on the Chesapeake Bay to the east.

Baltimore County has a land area of 610 square miles, extending from Baltimore City in the south to the Pennsylvania border in the north. The county borders to the southeast on the Chesapeake Bay, the nation's largest estuary.

III.A.2. Climate

The climate in the Baltimore IEMP study area is humid and temperate with a mean annual temperature of 56°F and an average annual precipitation of about 44 inches.[3] The net recharge to aquifers in the region represents approximately 25% of the average precipitation, or about 8-11 inches per year.

III.A.3. Hydrogeology

The study area is characterized by two major physiographic provinces: the Piedmont and the Atlantic Coastal Plain provinces. The dividing line between these two provinces, known as the Fall Line, divides Baltimore in half, running from the southwest corner of the city through its northeast corner. Anne Arundel County lies entirely within the Atlantic Coastal Plain province, and Baltimore County lies in both provinces.

The Piedmont province is composed of crystalline rocks of Precambrian or early Paleozoic age, chiefly schist, gneiss, phyllite, gabbro, quartzite, and marble.[4] A mantle of weathered material, known as regolith or saprolite, overlies the crystalline rock. The saprolite serves as a storage zone for the water in the crystalline rock, which supplies groundwater primarily through fractures and joints.

The Atlantic Coastal Plain region underlying Anne Arundel and parts of Baltimore County is composed of a wedge-shaped mass of unconsolidated sediments of Cretaceous, Tertiary, and Quaternary age, approximately 50 feet thick in the northwestern part of the Anne Arundel County and increasing to about 2,000 feet thick in the southeastern part of the county.[5] This region contains some of the most productive aquifers in the state.

III.B. Development of Groundwater Pollution Potential Maps

Groundwater pollution potential maps are the key element in the screening methodology. These maps portray the variability of groundwater pollution potential of the water table aquifer as it exists on the landscape.

We applied the DRASTIC approach for mapping hydrogeologic vulnerability to both Anne Arundel and Baltimore Counties (Baltimore City is included in the Baltimore County DRASTIC map). The key element of DRASTIC centers on identifying and defining hydrogeologic settings. As described in Chapter II.C.1, DRASTIC assigns ratings to seven hydrogeologic parameters for each setting, and weights them according to their relative contribution to pollution potential.

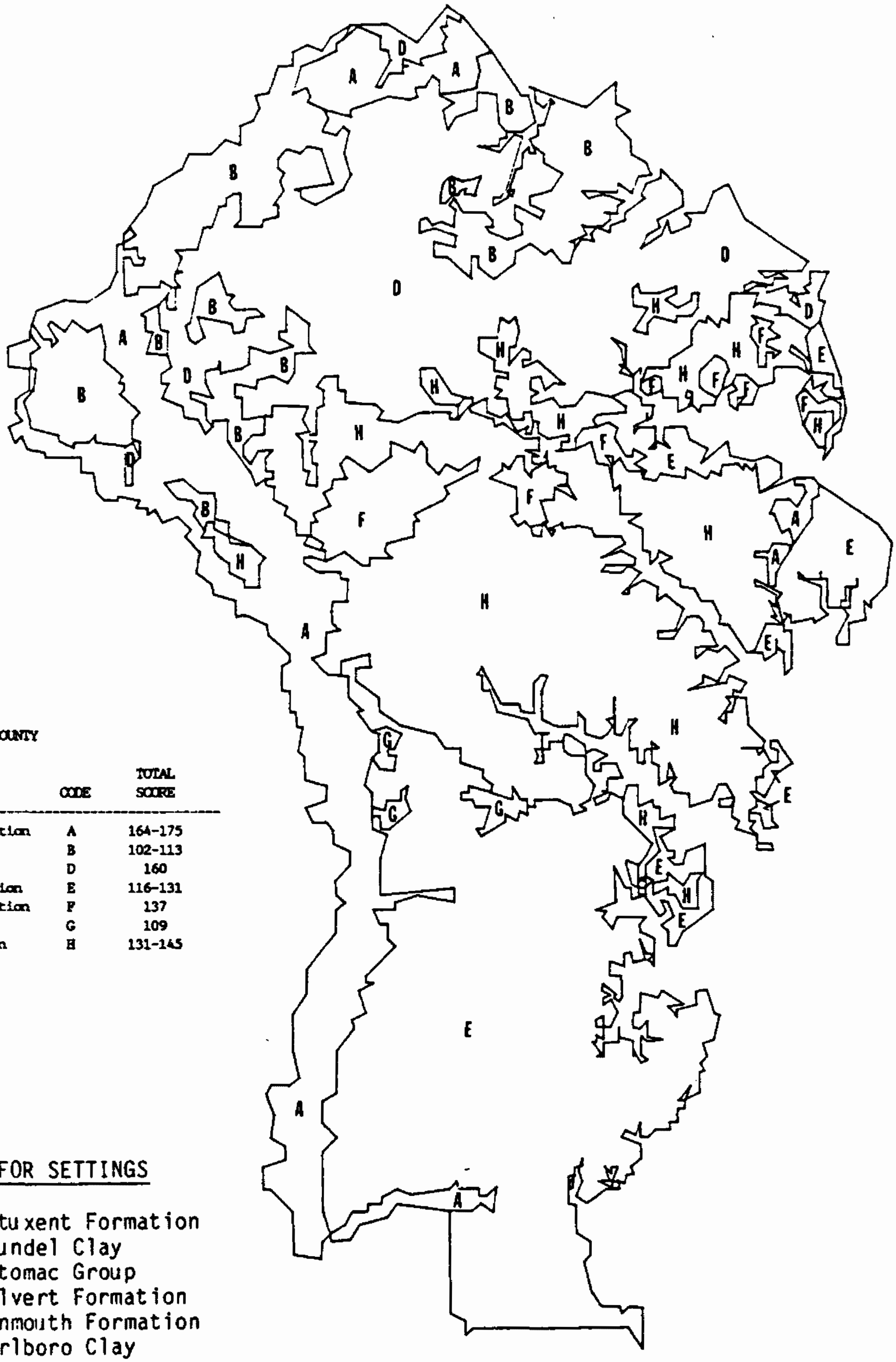
A definition of each hydrogeologic setting and a description of the DRASTIC rating assigned to each of the seven parameters in both counties follows below. To illustrate the DRASTIC approach, base maps for each separate parameter, along with the final DRASTIC pollution potential map of each county are shown.

III.B.1. Hydrogeologic Settings in Anne Arundel County

Anne Arundel County, located in the Atlantic Coastal Plain physiographic province, is underlain by unconsolidated coastal plain sediments with a thickness of 50 feet in the northwest section of the county, increasing to about 2,000 feet in the southeastern part of the county. The sediments contain three major aquifer units: the Potomac Group, Magothy, and Aquia formations, which dip gently to the southeast at a rate of 30-80 ft/mile.[6] Altogether, 12 geologic formations are shown on the Anne Arundel County Geologic Map;[7] however, some units have similar hydrogeologic characteristics and were combined into a single hydrogeologic setting for this study. The unconsolidated deposits are stratified layers of sand, gravel, silt, and clay; the sand and gravel strata constitute the major water-bearing rocks.[8]

We defined and mapped seven hydrogeologic settings comprised of unconsolidated sediments in Anne Arundel County. (See Exhibit III.1, Units A, B, D, E, F, G, H.) We produced this exhibit, and the other maps presented in this chapter, by editing and printing the data files created when we digitized the hydrogeologic units in each county. An additional sedimentary unit is found in Baltimore (Unit C). For convenience, all eight are defined in the following paragraphs. Each setting is named after the most areally extensive

EXHIBIT III.1: Hydrogeologic Settings in Anne Arundel County



ANNE ARUNDEL COUNTY

HYDROGEOLOGIC SETTING	CODE	TOTAL SCORE
Patuxent Formation	A	164-175
Arundel Clay	B	102-113
Potomac Group	D	160
Calvert Formation	E	116-131
Monmouth Formation	F	137
Marlboro Clay	G	109
Aquia Formation	H	131-145

LEGEND FOR SETTINGS

- A Patuxent Formation
- B Arundel Clay
- D Potomac Group
- E Calvert Formation
- F Monmouth Formation
- G Marlboro Clay
- H Aquia Formation

geologic unit which occurs within its boundary, and is identified with a letter code.

Patuxent Setting (A): Named for the Patuxent formation in Baltimore County, where it is a prolific source of groundwater, this setting consists predominantly of sand and gravel, with subordinate silt and clay. In Baltimore County/City it includes: Patuxent formation (sand facies); upland gravels; alluvial terrace gravels; artificial fill. In Anne Arundel County it includes: Brandywine formation; Patuxent River Terraces; Terrace Deposits; artificial fill.

Arundel Clay Setting (B): Named for the Arundel Clay in Baltimore County, this setting includes the clay facies of each of the following formations: Arundel formation, Patuxent formation, Patapsco Formation and Talbot formation in Baltimore County, and Potomac Groups silt-clay facies in Anne Arundel County. The formations are made up of clay-silt and subordinate fine to medium-grained muddy sand; the silt-clay materials are generally massive and thick-bedded, compact and tough.

Patapsco Setting (C): This setting consists mostly of well-bedded medium- to fine-grained sands. This setting includes the sand facies of the Patapsco formation, the Talbot formation and the alluvium. It occurs in Baltimore County/City but not in Anne Arundel County.

Potomac Setting (D): The sand-gravel facies component of the Potomac group is a productive aquifer. It is characterized by interbedded quartz sand, pebbly sand, gravel, and subordinate silt-clay; the sand is fine to coarse-grained, poorly-sorted to well-sorted, and clean to very muddy. This setting serves as a major source of drinking water in Anne Arundel County.

Calvert Setting (E): Named for the Calvert formation, the setting combines the Calvert, Nanjemoy and Talbot formations because of their hydrogeologic similarities, which are generally characterized as clayey sands. The Calvert formation consists chiefly of fine-grained sand, silt, and diatomaceous silt; the Nanjemoy consists of glauconitic fine to medium-grained sand, silt, and silty clay. The Talbot formation is a very fine to fine-grained sand aquifer.

Monmouth Setting (F): In this setting two similar formations, the Monmouth and Matawan formations, are combined. The setting consists of very fine to fine-grained sand which is poorly to moderately well-sorted with micaceous clayey silt. This setting is generally not considered a productive aquifer.

Marlboro Clay Setting (G): The Marlboro clay occurs in three relatively small areas within Anne Arundel County, and is characterized as a plastic clay. Despite is small areal extent, it has been included as a separate setting for this study in order to illustrate the vulnerability associated with a true clay unit.

Aquia Setting (H): This setting groups two highly productive aquifer formations, the Magothy and Aquia formations. The Aquia formation supplies groundwater for most of the area in Anne Arundel County south of Annapolis, outcropping extensively in the central portion of the county. The Aquia formation consists of glauconitic sand, and clean to moderately-clayey and calcareous sandstone; the sands are well-sorted with medium grained sands dominating, but fine and coarse-grained sands also appearing in places. The sands of the Magothy formation form a productive aquifer serving as the primary source of groundwater for the City of Annapolis. The aquifer is characterized by fine to coarse-grained sand interstratified with silt and clay, with subordinate pebbly sand or gravel.

III.B.2. DRASTIC Parameters for Anne Arundel County

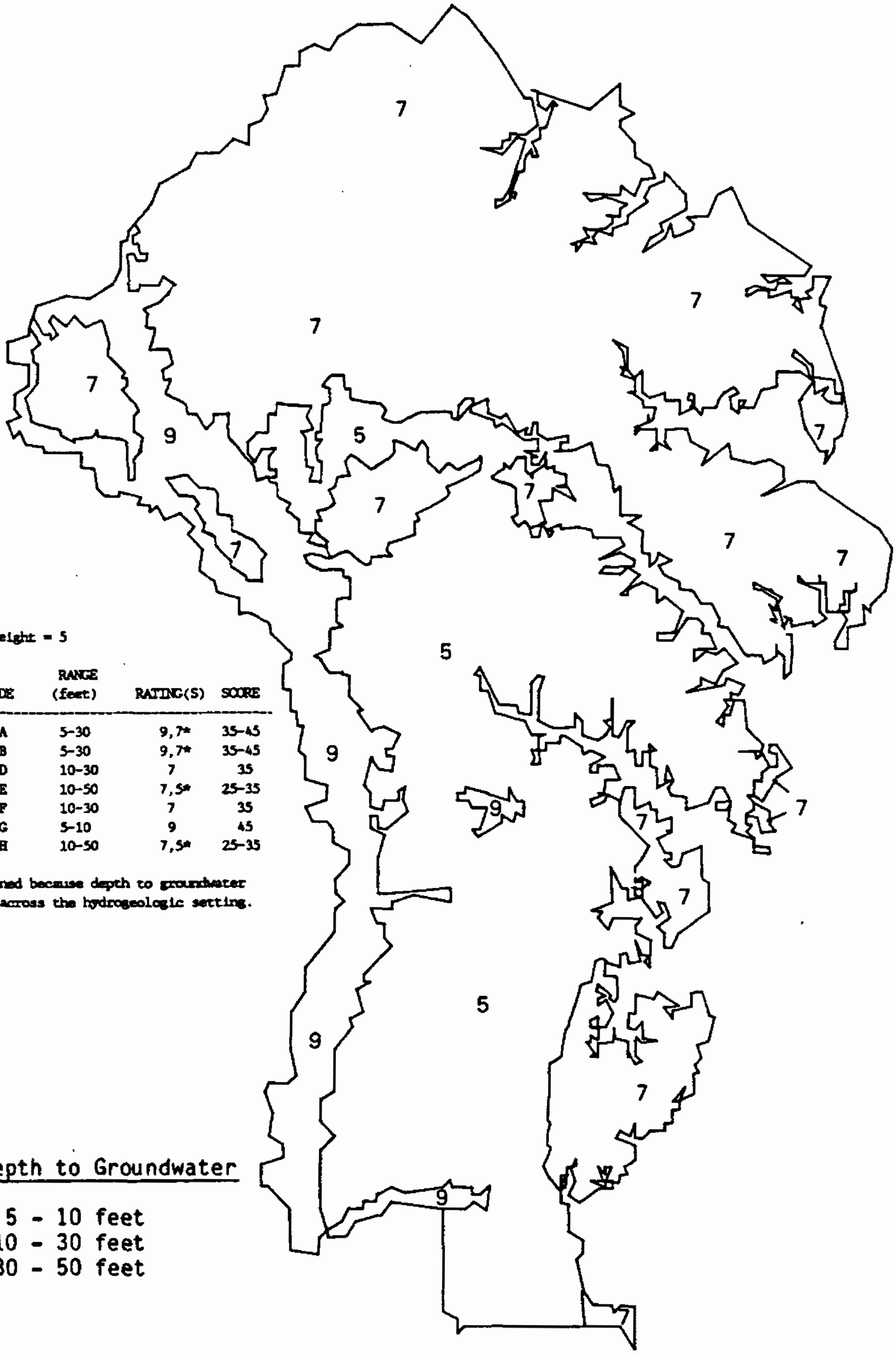
This section describes the seven DRASTIC parameters and the ratings we assigned to them for each of the hydrogeologic settings in Anne Arundel County. Section III.B.5 describes the parameters and their ratings for Baltimore County. A separate parameter map accompanies each discussion in order to display the variability of each parameter across the county. The letter associated with the acronym "DRASTIC" follows each parameter name in parenthesis for additional clarity. We assigned these ratings based on the assessments of a senior geologist familiar with the hydrogeology of Maryland, a mid-level environmental engineer, and a junior geologist.

Depth to Groundwater (D): As described earlier, the Coastal sediments in Anne Arundel County form a multi-layered system of aquifers, with the lowest aquifer units outcropping further north in the county. Although wells may often penetrate the surficial aquifer in order to pump from one of the lower, confined units, we assumed that the pollution potential of a geographic location will be based upon the characteristics of the surficial aquifer. Although well users may not always drink from the aquifer outcropping in their area, contamination occurring in the surficial aquifer could contaminate a drinking water supply through a well bore-hole or by a pinching out of the aquitard between members. Depth to the water table varied in the county from a minimum of about 5 feet to a maximum of about 50 feet. The DRASTIC rating thus varied from 5 to 9 within the county (Exhibit III.2)

Net Recharge (R): Of the approximately 44 inches of annual precipitation in Anne Arundel County, about one quarter represents groundwater recharge.[9] This value was applied to Anne Arundel County based upon review by members of the Maryland Geologic Survey. A revised DRASTIC rating of 9 was assigned to Anne Arundel County, corresponding to the value for greater than 10" per year net recharge (Exhibit III.3).

Aquifer Media (A): The aquifer media in Anne Arundel County are characterized by unconsolidated sediments, ranging from sand and gravel to silty clays. Because a number of the various unconsolidated sediments found in Anne Arundel County are not represented in the DRASTIC system, a revised table of Aquifer Media ratings has been prepared for use in this study (personal communication, E.T. Cleaves, Maryland Geological Survey).

EXHIBIT III.2: Depth to Groundwater in Anne Arundel County

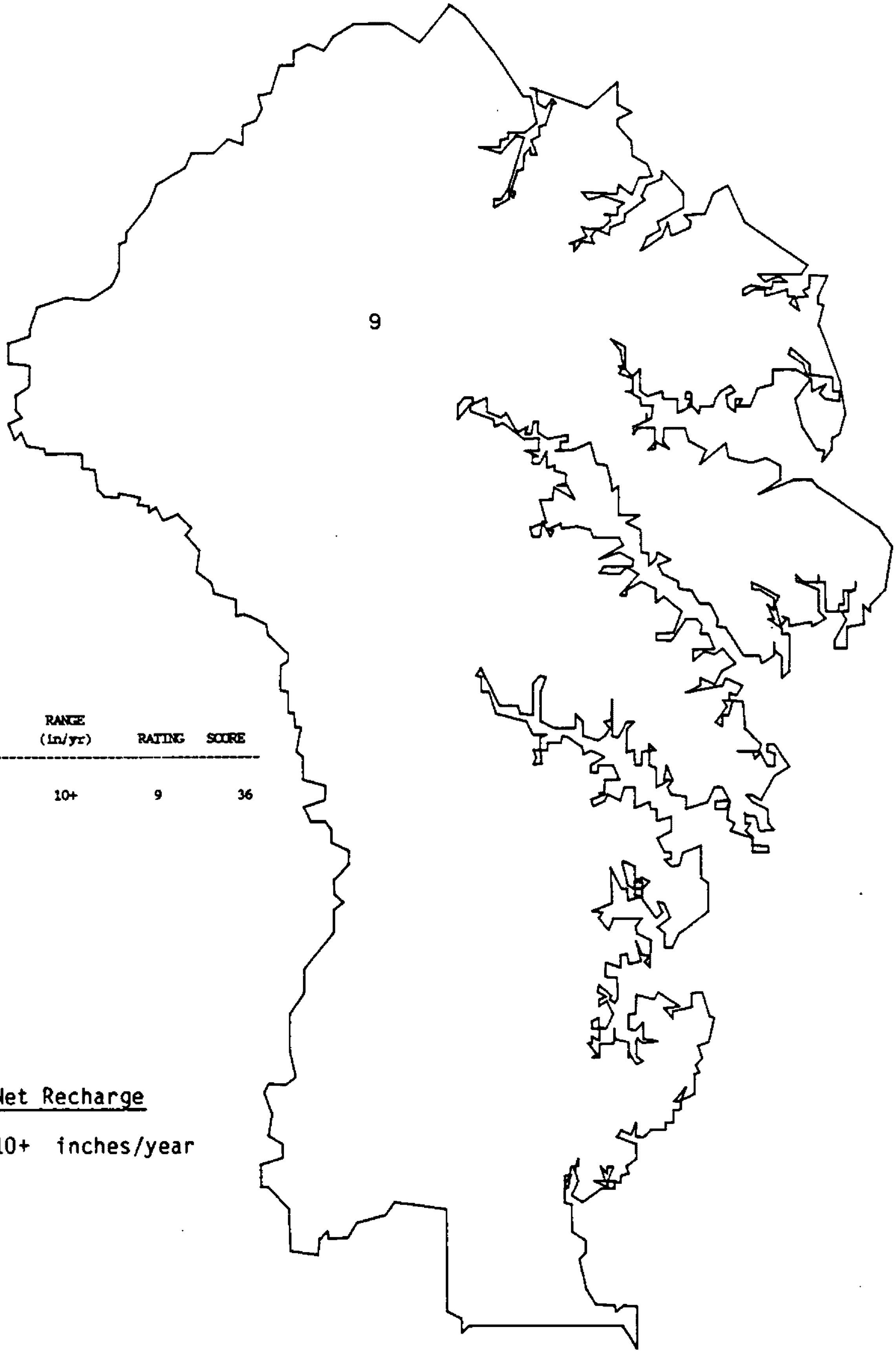


ANNE ARUNDEL COUNTY
DEPTH TO GROUNDWATER: Weight = 5

HYDROGEOLOGIC SETTING	CODE	RANGE (feet)	RATING(S)	SCORE
Patuxent Formation	A	5-30	9,7*	35-45
Arundel Clay	B	5-30	9,7*	35-45
Potomac Group	D	10-30	7	35
Calvert Formation	E	10-50	7,5*	25-35
Monmouth Formation	F	10-30	7	35
Marlboro Clay	G	5-10	9	45
Aquia Formation	H	10-50	7,5*	25-35

* Two ratings are assigned because depth to groundwater varies significantly across the hydrogeologic setting.

EXHIBIT III.3: Net Recharge in Anne Arundel County



ANNE ARUNDEL COUNTY
NET RECHARGE: Weight = 4

HYDROGEOLOGIC SETTING	RANGE (in/yr)	RATING	SCORE
ALL UNITS	10+	9	36

LEGEND

Rating	Net Recharge
9	10+ inches/year

Aquifer Media in the Coastal Plain Settings

Unconsolidated Sediment Type	Rating
Gravel	9
Sand	6
Clayey/silty sand	4
Silt	3
Clay/silt	2
Clay	1

This type of fine tuning is recommended by the DRASTIC authors in situations where local conditions differ from these described in the DRASTIC report. The scores for each setting are depicted in Exhibit III.4.

Soil Media (S): Values for this factor are based on the Soil Survey of Anne Arundel county (1973).[10] The settings with silty clay subsoil were assigned a DRASTIC rating of 3. Silty clay loam subsoils were assigned a rating of 4 and the settings with sandy loam were given a rating of 6 (Exhibit III.5). The table below describes the soil associations and textures corresponding to each setting in Anne Arundel County.

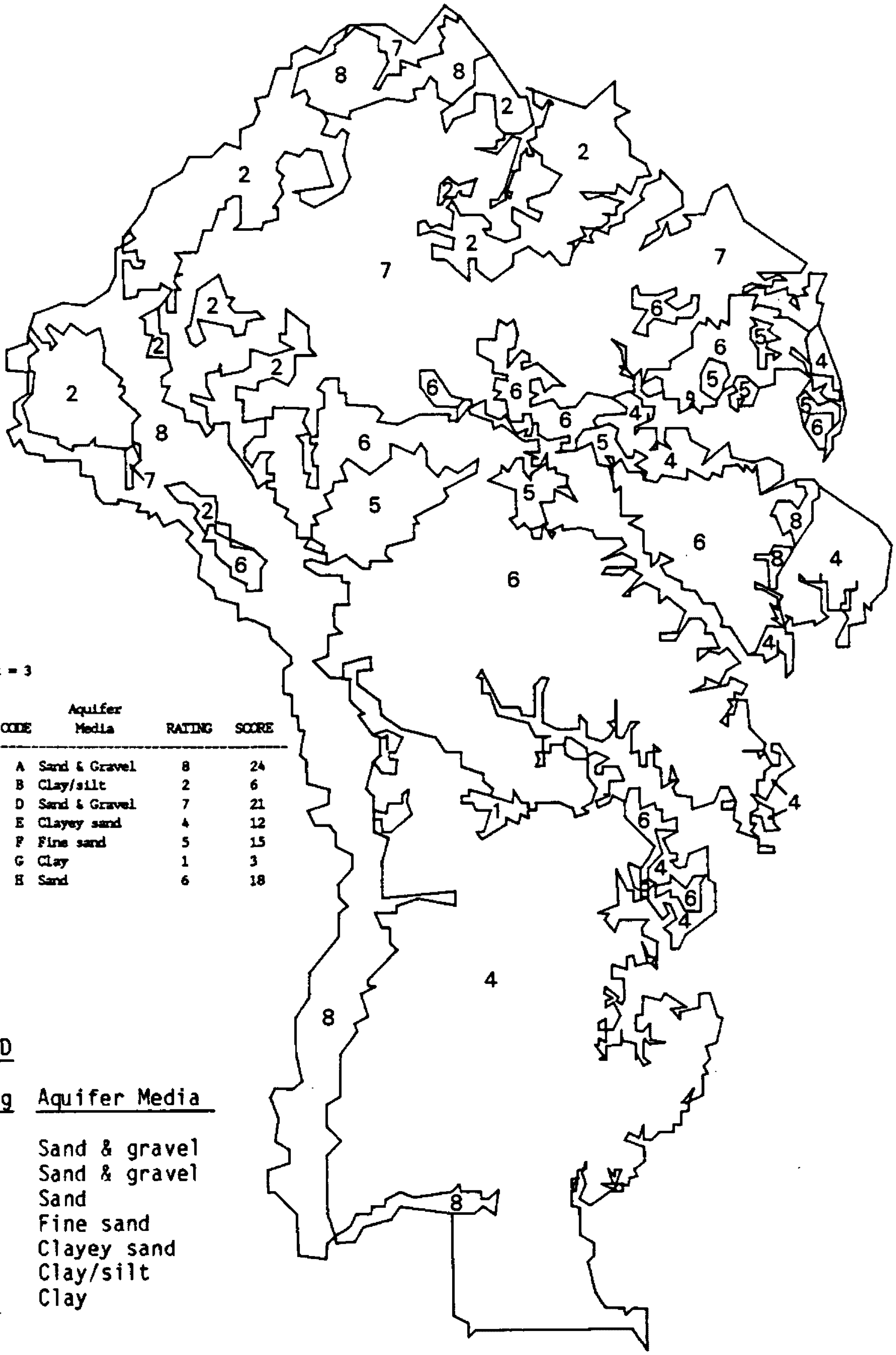
Soil Media in Anne Arundel County

Setting	Soil Association (and Texture)	Rating
A	Beltsville-Chillum-Sassafras: (silt (loam to sandy clay loam subsoil)	4
B	Lenoir-Beltsville: (silt loam subsoil) Mattapox-Barclay-Othello: (silty clay loam subsoil)	4
C	Sassafras-Woodstown-Fallingston: (sandy clay loam) Mattapox-Barclay-Othello: (silt-silty clay)	3
D	Evesboro-Rumford-Sassafras: (sandy loam)	6
E	Marr-Westphalia-Sassafras: (sandy loam subsoil)	6
F,H	Monmouth-Collington: (sandy clay loam subsoil)	3

Topography (T): The topography of Anne Arundel County is relatively flat and uniform except along the coves and embayments along Chesapeake Bay, and where tributaries join major streams. Most of the county has land surface slope of about 2 to 6 percent corresponding to a DRASTIC rating of 9. Part of the county, however, has land surface slopes of 6 to 12 percent, corresponding to a DRASTIC rating of 5 (Exhibit III.6).

Impact of the Vadose Zone (I): The Impact of the Vadose Zone category parallels the Aquifer Media category, as many of the materials forming the saturated zone of the aquifer also compose major portions of the unsaturated zone. Again, ratings for the surficial aquifer in each area were developed.

EXHIBIT III.4: Aquifer Media in Anne Arundel County



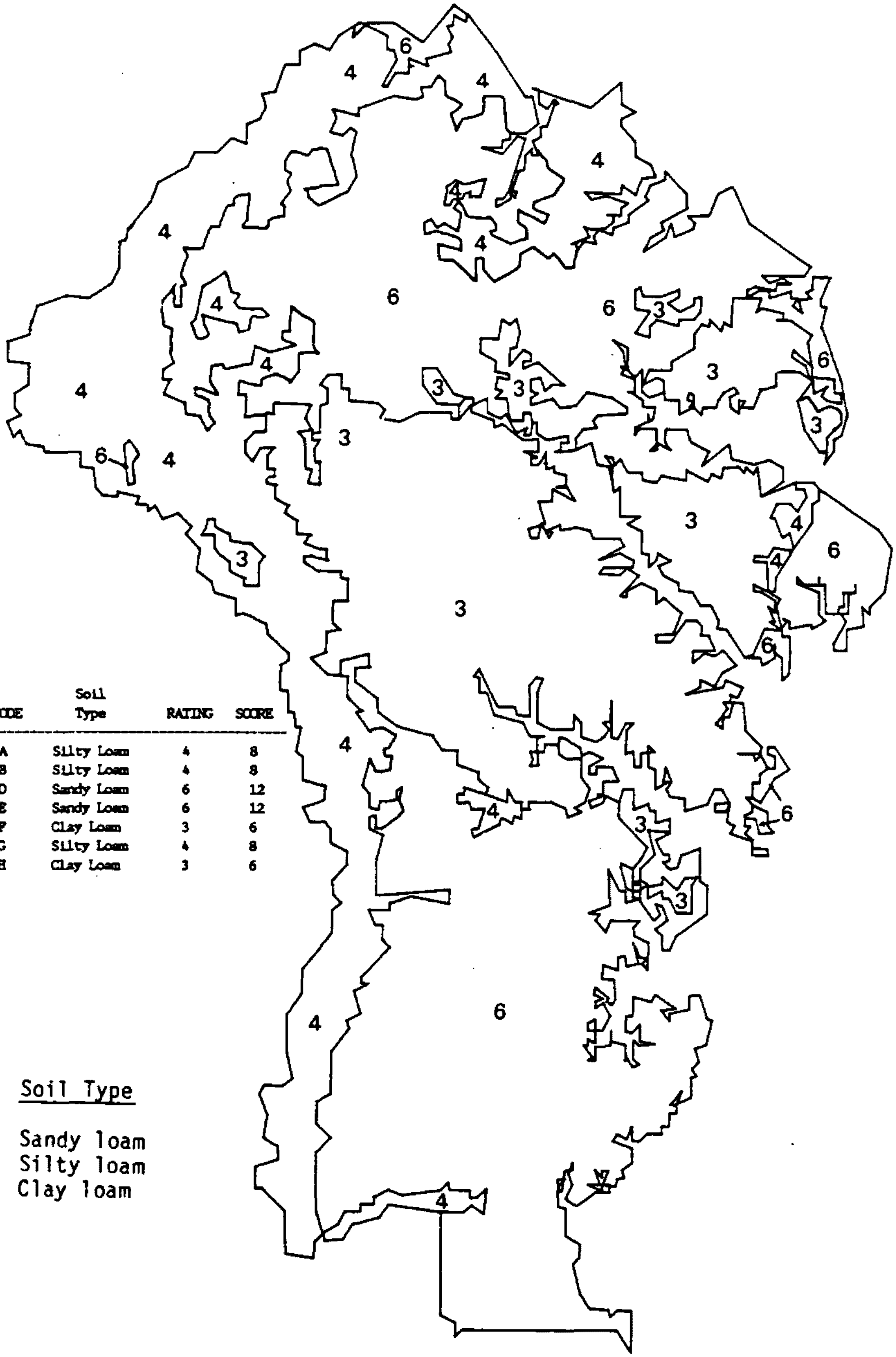
ANNE ARUNDEL COUNTY
AQUIFER MEDIA: Weight = 3

HYDROGEOLOGIC SETTING	CODE	Aquifer Media	RATING	SCORE
Patuxent Formation	A	Sand & Gravel	8	24
Arundel Clay	B	Clay/silt	2	6
Potomac Group	D	Sand & Gravel	7	21
Calvert Formation	E	Clayey sand	4	12
Monmouth Formation	F	Fine sand	5	15
Marlboro Clay	G	Clay	1	3
Aquia Formation	H	Sand	6	18

LEGEND

Rating	Aquifer Media
8	Sand & gravel
7	Sand & gravel
6	Sand
5	Fine sand
4	Clayey sand
2	Clay/silt
1	Clay

EXHIBIT III.5: Soil Media in Anne Arundel County



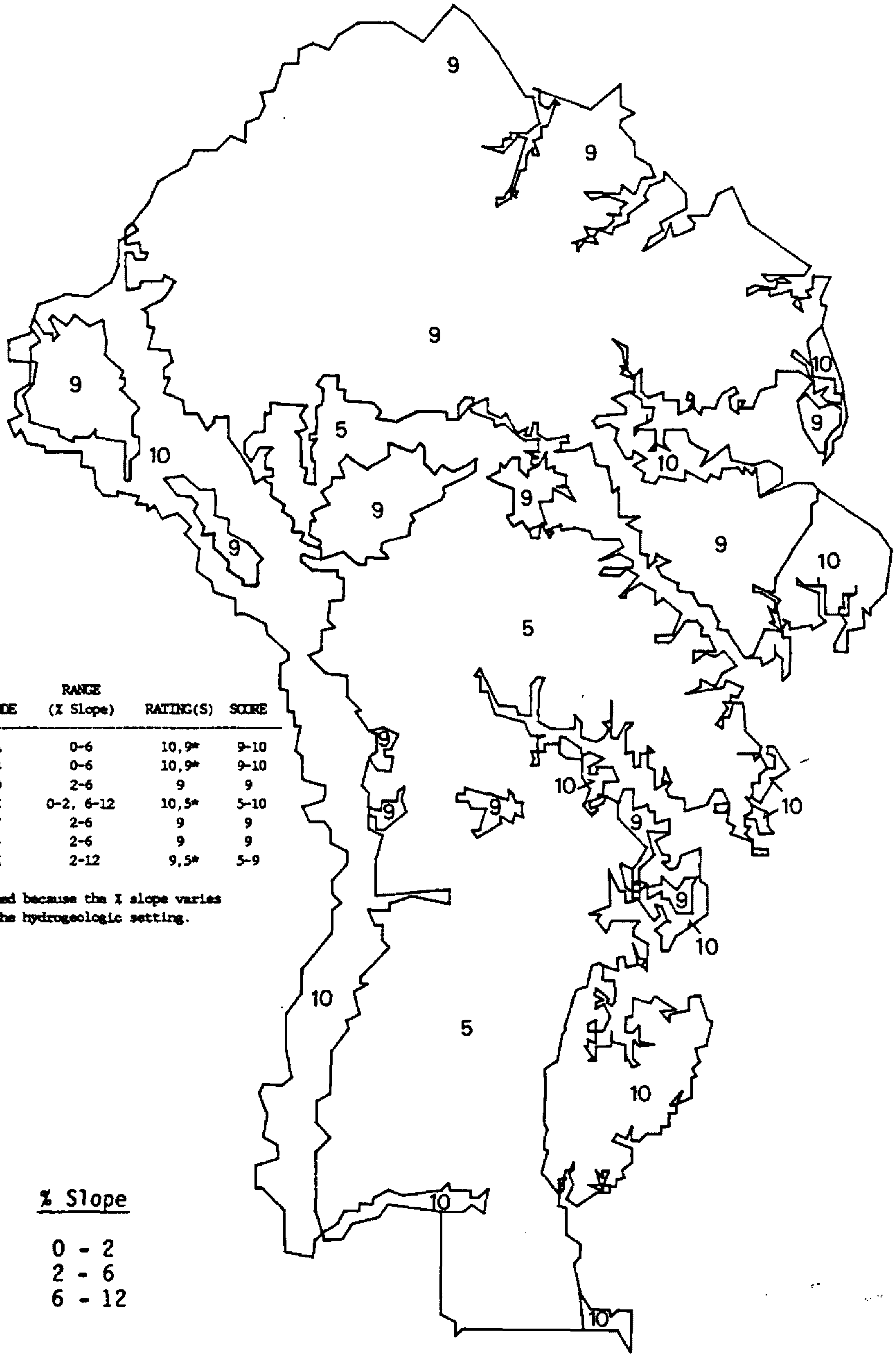
ANNE ARUNDEL COUNTY
SOIL: Weight = 2

HYDROGEOLOGIC SETTING	CODE	Soil Type	RATING	SCORE
Patuxent Formation	A	Silty Loam	4	8
Arundel Clay	B	Silty Loam	4	8
Potomac Group	D	Sandy Loam	6	12
Calvert Formation	E	Sandy Loam	6	12
Monmouth Formation	F	Clay Loam	3	6
Marlboro Clay	G	Silty Loam	4	8
Aquia Formation	H	Clay Loam	3	6

LEGEND

Rating	Soil Type
6	Sandy loam
4	Silty loam
3	Clay loam

EXHIBIT III.6: Topography in Anne Arundel County



ANNE ARUNDEL COUNTY
TOPOGRAPHY: Weight = 1

HYDROGEOLOGIC SETTING	CODE	RANGE (% Slope)	RATING(S)	SCORE
Patuxent Formation	A	0-6	10,9*	9-10
Arundel Clay	B	0-6	10,9*	9-10
Potomac Group	D	2-6	9	9
Calvert Formation	E	0-2, 6-12	10,5*	5-10
Monmouth Formation	F	2-6	9	9
Marlboro Clay	G	2-6	9	9
Aquia Formation	H	2-12	9,5*	5-9

* Two ratings are assigned because the % slope varies significantly across the hydrogeologic setting.

LEGEND

Rating	% Slope
10	0 - 2
9	2 - 6
5	6 - 12

Ratings for the Coastal Plain deposits may be expected to vary from 1 (clay) to 9 (sand and gravel). The rating for each setting is shown on Exhibit III.7.

Hydraulic Conductivity (C): The hydraulic conductivity of each formation in Anne Arundel County was estimated using the DRASTIC report or data from Mack.[11] The ratings for the Coastal Plain unconsolidated settings ranged from a low of 1 for clay to a high of 4 for sands (Exhibit III.8).

III.B.3. Map of Groundwater Pollution Potential in Anne Arundel County

A DRASTIC score for each hydrogeologic setting in Anne Arundel County was compiled from the seven DRASTIC parameters (Exhibit III.9). This exhibit provides both the individual scores for each parameter and the overall DRASTIC rating for each setting. These scores, combined with the map of hydrogeologic settings, create a map of "Groundwater Pollution Potential, Anne Arundel County" (this map has been placed in the Anne Arundel map overlay pocket at the end of the report along with the UST and well use maps). The setting with the highest groundwater pollution potential is the Patuxent setting with a score of 164-175; the lowest pollution potential is in the Arundel and Marlboro Clay settings with scores of 102-113 and 109 respectively.

III.B.4. Hydrogeologic Settings of Baltimore County (and Baltimore City)

The hydrogeology of Baltimore County is more varied than Anne Arundel County, as both crystalline rocks and unconsolidated sediments are present. Baltimore County straddles two physiographic provinces: the Piedmont Province and the Atlantic Coastal Plain Province. The geologic map of Baltimore County maps over 25 separate geologic units within the region.[12] Many of these units, although of geologic consequence, are similar in hydrogeologic characteristics and for purposes of this study have been lumped together.

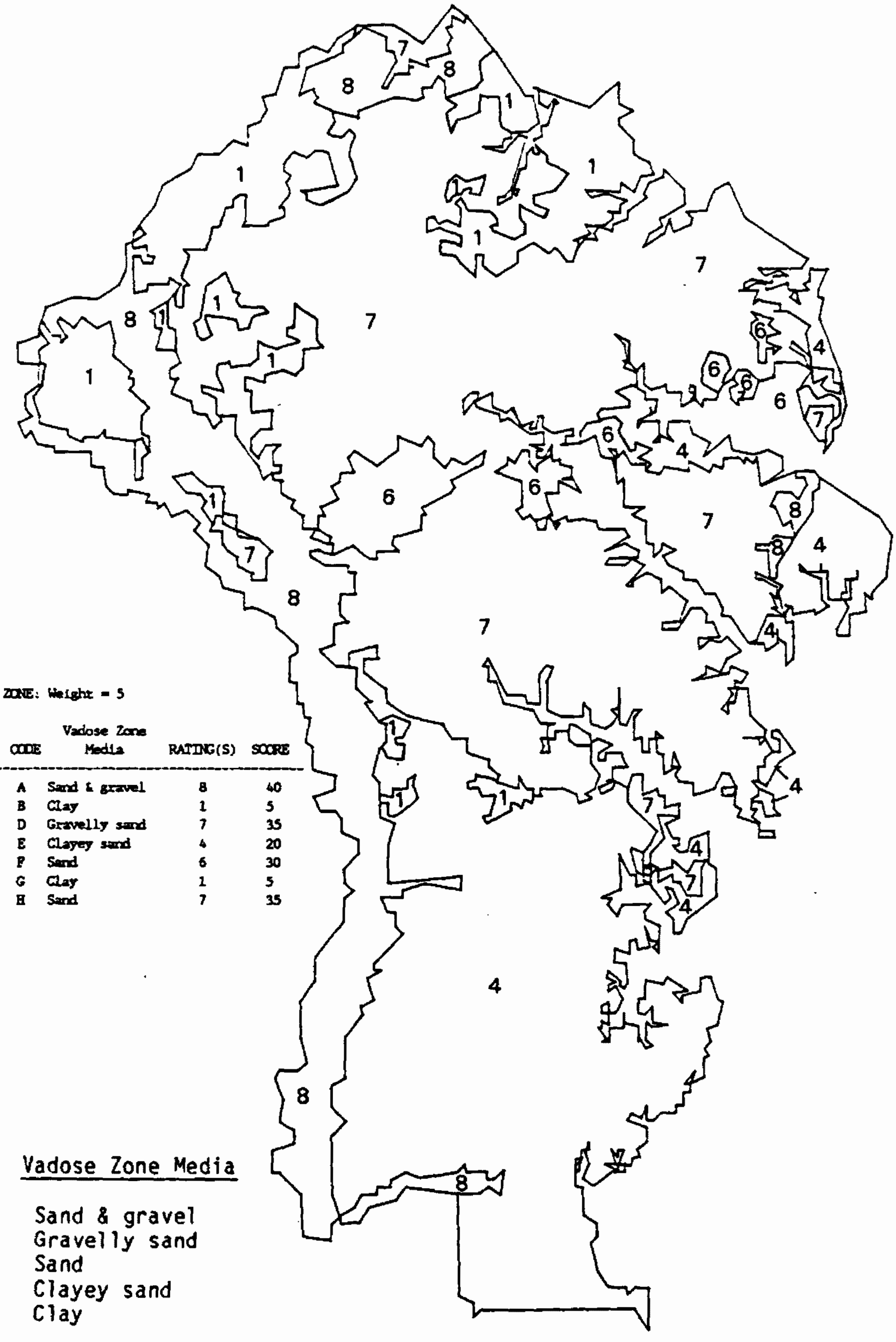
Altogether nine hydrogeologic settings have been mapped in Baltimore County (Exhibit III.10). Three hydrogeologic settings consisting of unconsolidated sediments occur in Baltimore County: Patuxent, Arundel Clay, and Patapsco (which were described above for Anne Arundel County). The other six hydrogeologic settings are crystalline rock settings, which are numbered with Roman numerals in order to distinguish them from the sedimentary units.

Cockeysville Marble Setting (I): This setting includes the Cockeysville Marble formation and the Hydes Marble member. The Cockeysville Marble is a crystalline marble ranging from coarsely crystalline calcite to a fine-grained dense dolomite. It is the best source of groundwater in the Piedmont part of the county.

Mount Washington Amphibolite Setting (II): This setting includes the Mount Washington Amphibolite, the Holofield Layered Ultra-Mafite, the Sweathouse Amphibolite member of the Oella formation, the Raspeburg Amphibolite, the Bradshaw Amphibolite, the Perry Hall Gneiss, and serpentinite at Bare Hills.

Baltimore Gneiss Setting (III): This setting includes the Baltimore Gneiss, the Setters Quartzite, the Franklinville Gneiss, the Slaughterhouse Gneiss, the Woodstock Granite, the Ellicott City Granite, the Sykesville

EXHIBIT III.7: Impact of the Vadose Zone in Anne Arundel County



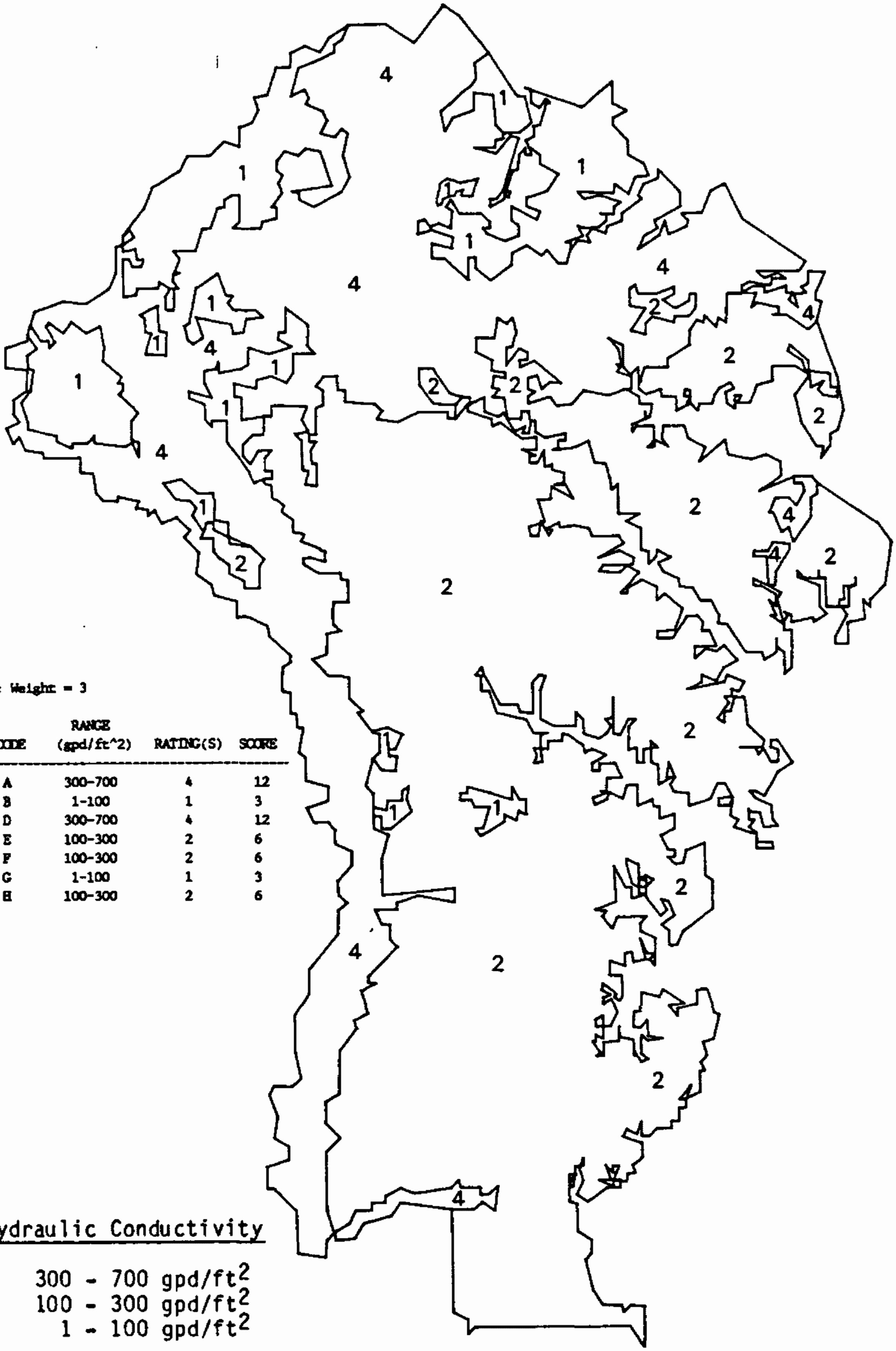
ANNE ARUNDEL COUNTY
IMPACT OF THE VADOSE ZONE: Weight = 5

HYDROGEOLOGIC SETTING	CODE	Vadose Zone Media	RATING(S)	SCORE
Patuxent Formation	A	Sand & gravel	8	40
Arundel Clay	B	Clay	1	5
Potomac Group	D	Gravelly sand	7	35
Calvert Formation	E	Clayey sand	4	20
Monmouth Formation	F	Sand	6	30
Marlboro Clay	G	Clay	1	5
Aquia Formation	H	Sand	7	35

LEGEND

Rating	Vadose Zone Media
8	Sand & gravel
7	Gravelly sand
6	Sand
4	Clayey sand
1	Clay

EXHIBIT III.8: Hydraulic Conductivity in Anne Arundel County



ANNE ARUNDEL COUNTY
HYDRAULIC CONDUCTIVITY: Weight = 3

HYDROGEOLOGIC SETTING	CODE	RANGE (gpd/ft^2)	RATING(S)	SCORE
Patuxent Formation	A	300-700	4	12
Arundel Clay	B	1-100	1	3
Potomac Group	D	300-700	4	12
Calvert Formation	E	100-300	2	6
Monmouth Formation	F	100-300	2	6
Marlboro Clay	G	1-100	1	3
Aquia Formation	H	100-300	2	6

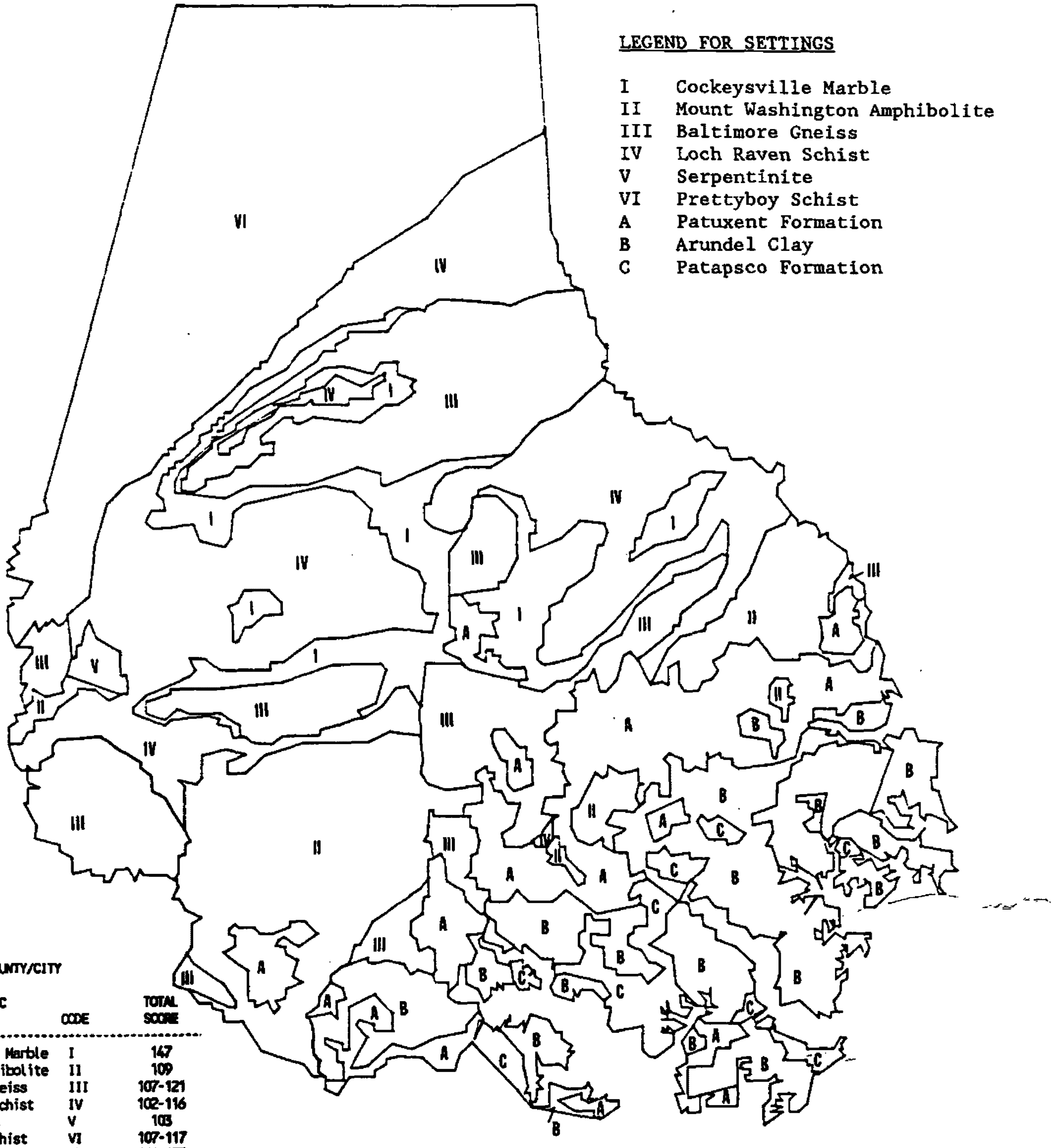
LEGEND

Rating	Hydraulic Conductivity
4	300 - 700 gpd/ft^2
2	100 - 300 gpd/ft^2
1	1 - 100 gpd/ft^2

EXHIBIT III.9 DRASTIC SCORES FOR SEDIMENTARY ROCK SETTINGS

Setting	Total Score	Depth to Groundwater	Net Recharge	Aquifer Media	Soil Media	Topography	Impact of Vadose Zone	Hydraulic Conductivity
A. Patuxent	162-175	35-45	36	24	8	7-10	40	12
B. Arundel	102-113	35-45	36	6	8	9-10	5	3
C. Patapsco	146-157	35-45	36	18	6	9-10	30	12
D. Potomac	160	35	36	21	12	9	35	12
E. Calvert	116-131	25	36	12	12	5-10	20	6
F. Monmouth	137	35	36	15	6	9	30	6
G. Marlboro Clay	109	45	36	3	8	9	5	3
H. Aquia	131, 145	25	36	18	6	5-9	35	6

EXHIBIT III.10: Hydrogeologic Settings in Baltimore County



BALTIMORE COUNTY/CITY

HYDROGEOLOGIC SETTING	CODE	TOTAL SCORE
Cockeysville Marble	I	147
Mt Wash Amphibolite	II	109
Baltimore Gneiss	III	107-121
Loch Raven Schist	IV	102-116
Serpentinite	V	103
Prettyboy Schist	VI	107-117
Patuxent Formation	A	164-175
Arundel Clay	B	102-113
Patapsco Formation	C	146-157

formation (Gneiss member), and the James Run formation (Relay Gneiss member and Carroll Gneiss member). The unit includes rocks ranging from heavily banded granitoid biotite gneiss to a thinly banded "ribbon" gneiss to a fine to medium-grained biotite muscovite-plagioclase quartz schist to a fine-grained felspathic gneiss. These units are not as productive a source of groundwater as either the marble or the Loch Raven Schist.

Loch Raven Schist Setting (IV): This setting includes the Loch Raven Schist and the Oella formation. These formations are located in the central portion of Baltimore County. They are relatively poor sources of groundwater, with uniformly low transmissivities. Schists of this setting are medium- to coarse-grained.

Serpentinite Setting (V): This setting comprises a rock called "serpentinite". The rock occurs in two main masses in Baltimore County, one at Soldiers Delight and the other at Bare Hills. The setting is unusual because of its lack of saprolite, thin soil cover, and low permeability. Only the Soldiers Delight area on the western side of the County is areally large enough to be evaluated with DRASTIC.

Prettyboy Schist Setting (VI): In this formation we have lumped together several similar formations: the Prettyboy Schist, the Sykesville formations, the Pleasant Grove Schist, and the Piney Run formation. Schists of this group are fine grained, low metamorphic grade minerals and have low water renovation characteristics.

III.B.5. DRASTIC Parameters for Baltimore County

Depth to Groundwater (D): Exhibit III.11 shows the distribution of groundwater depths in Baltimore County. As can be seen on the map, the DRASTIC rating ranges from 5 to 9, corresponding to groundwater table depths from 5 to 50 feet.

Net Recharge (R): The sediments outcropping in Baltimore County are assigned the same value of 10+ inches per year of net recharge as those units in Anne Arundel County (resulting in a DRASTIC rating of 10). Net recharge in the Piedmont sections of the county has been estimated at 8-10 inches per year.[13] This corresponds to a DRASTIC rating of 8. The distribution of DRASTIC ratings for net recharge is illustrated in Exhibit III.12. This is an arbitrary decision based on contrasting information available from groundwater reports about the area.

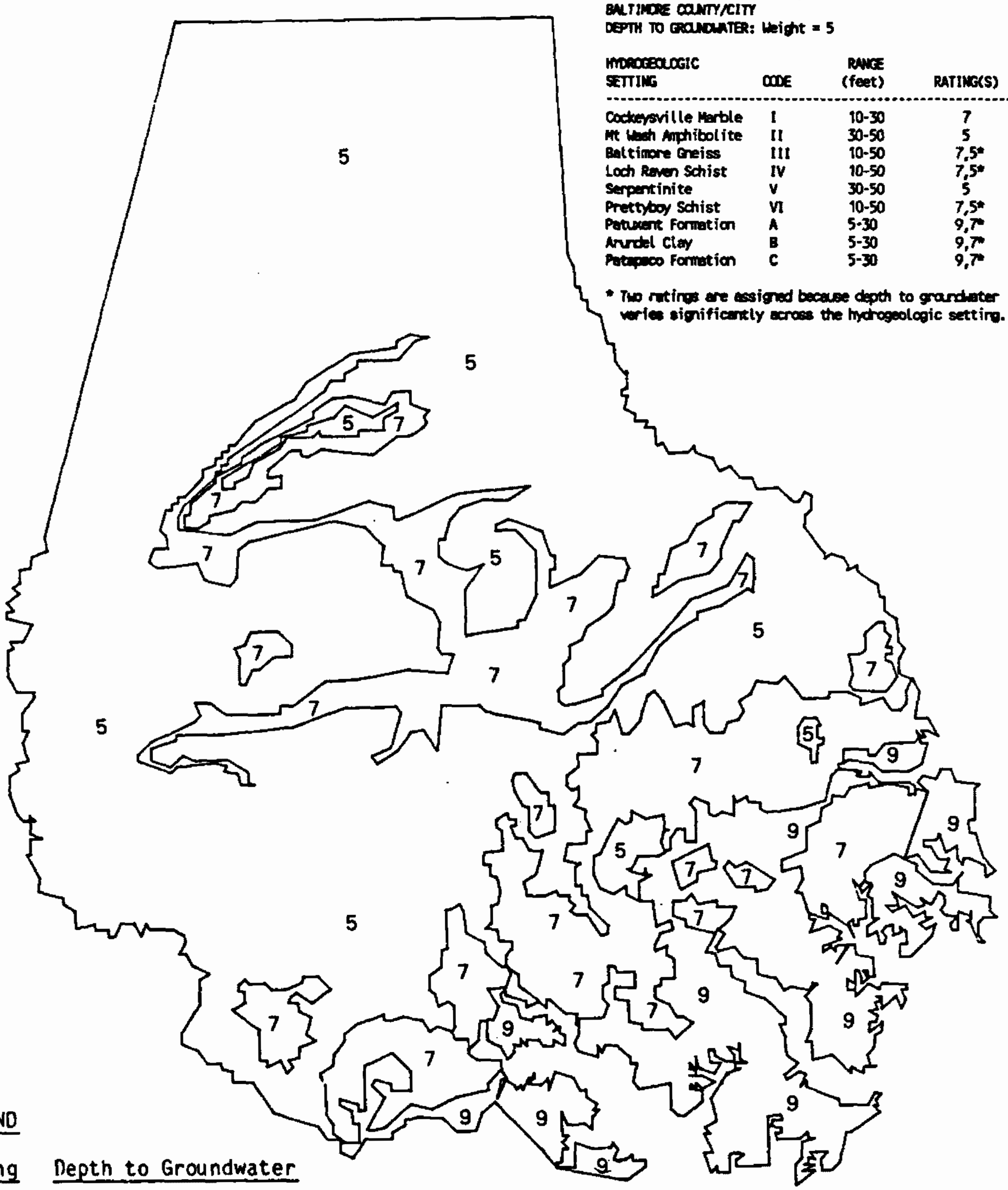
Aquifer Media (A): Baltimore County is characterized by both crystalline rock and sedimentary hydrogeologic settings. The sediment settings consist of sand and gravel aquifers, with varying amounts of interspersed silt and clay. The Piedmont settings consist primarily of metamorphic and igneous rock overlain by weathered rock and saprolite. Groundwater is available through fractures within the crystalline bedrock, while the saprolite serves as a storage zone. Because the DRASTIC ratings for Aquifer Media do not adequately represent the hydrogeologic settings in Anne Arundel and Baltimore Counties, a revised table has been prepared for this study. The revised ratings for the unconsolidated formations are shown on page 27; the crystalline rock ratings are given below.

EXHIBIT III.11: Depth to Groundwater in Baltimore County

BALTIMORE COUNTY/CITY
DEPTH TO GROUNDWATER: Weight = 5

HYDROGEOLOGIC SETTING	CODE	RANGE (feet)	RATING(S)	SCORE
Cockeysville Marble	I	10-30	7	35
Mt Wash Amphibolite	II	30-50	5	25
Baltimore Gneiss	III	10-50	7,5*	25-35
Loch Raven Schist	IV	10-50	7,5*	25-35
Serpentinite	V	30-50	5	25
Prettyboy Schist	VI	10-50	7,5*	25-35
Patuxent Formation	A	5-30	9,7*	35-45
Arundel Clay	B	5-30	9,7*	35-45
Patapsco Formation	C	5-30	9,7*	35-45

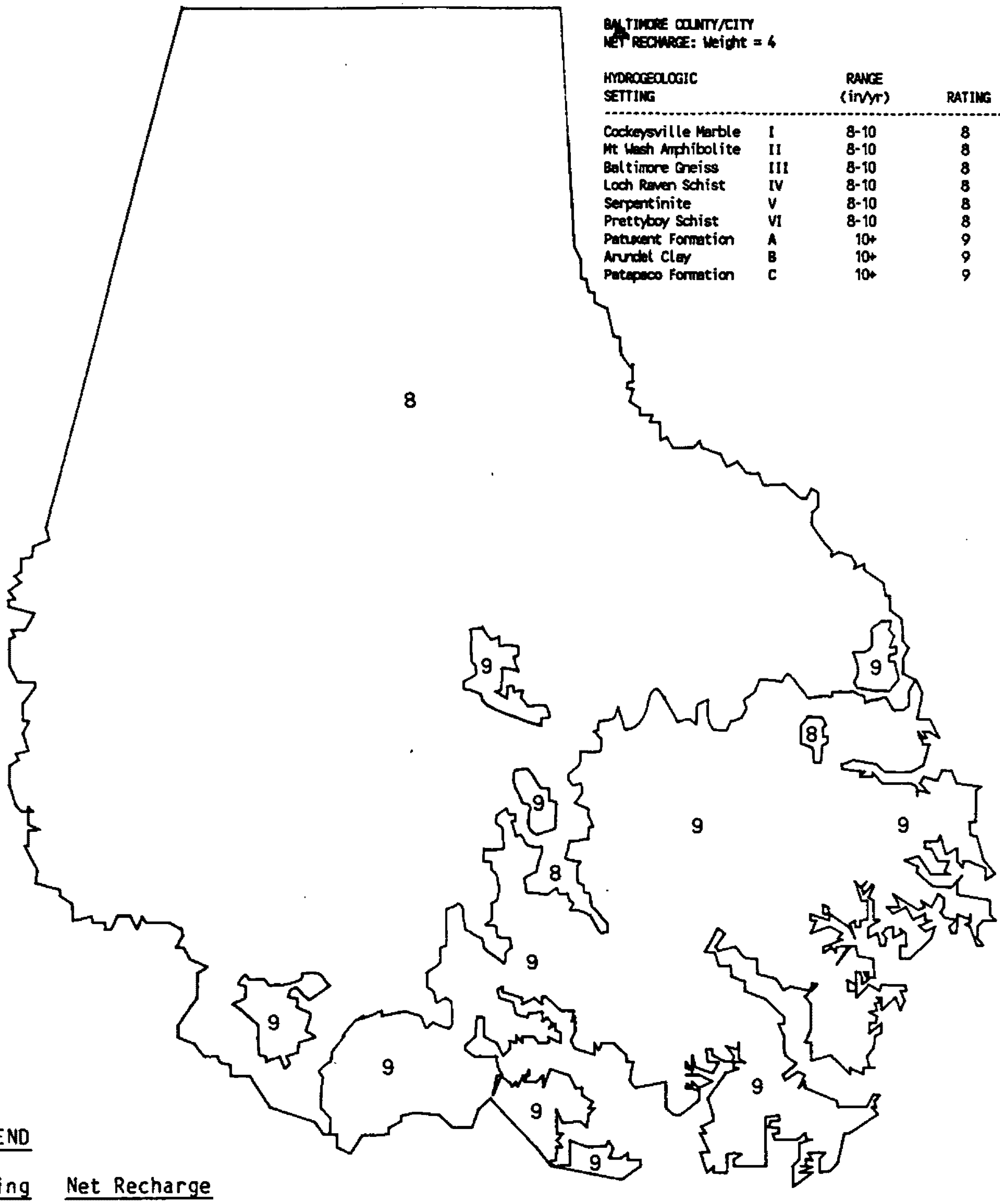
* Two ratings are assigned because depth to groundwater varies significantly across the hydrogeologic setting.



LEGEND

Rating	Depth to Groundwater
9	5 - 10 feet
7	10 - 30 feet
5	30 - 50 feet

EXHIBIT III.12: Net Recharge in Baltimore County



BALTIMORE COUNTY/CITY
NET RECHARGE: Weight = 4

HYDROGEOLOGIC SETTING		RANGE (in/yr)	RATING	SCORE
Cockeysville Marble	I	8-10	8	32
Mt Wash Amphibolite	II	8-10	8	32
Baltimore Gneiss	III	8-10	8	32
Loch Raven Schist	IV	8-10	8	32
Serpentinite	V	8-10	8	32
Prettyboy Schist	VI	8-10	8	32
Patuxent Formation	A	10+	9	36
Arundel Clay	B	10+	9	36
Patapsco Formation	C	10+	9	36

LEGEND

Rating	Net Recharge
9	10+ inches/year
8	8-10 inches/year

AQUIFER MEDIA IN THE PIEDMONT PROVINCE OF BALTIMORE COUNTY

Setting		Crystalline Rock Type	Rating
I.	Cockeysville	Saprolite, silty sand to sand	6
II.	Mt. Washington	Amphibolite: saprolite, clay to silty clay, including various amphibolites and mafic gneiss	2
III.	Baltimore Gneiss	Saprolite, silty clayey sands	4
IV.	Loch Raven Schist	Saprolite and medium to coarse-grained crystalline	4
V.	Serpentinite	Fractured crystalline rock	1
VI.	Prettyboy Schist	Saprolite, clayey silt, and fine-grained schists	3

Exhibit III.13 illustrates the aquifer media ratings of the hydrogeologic settings within the county.

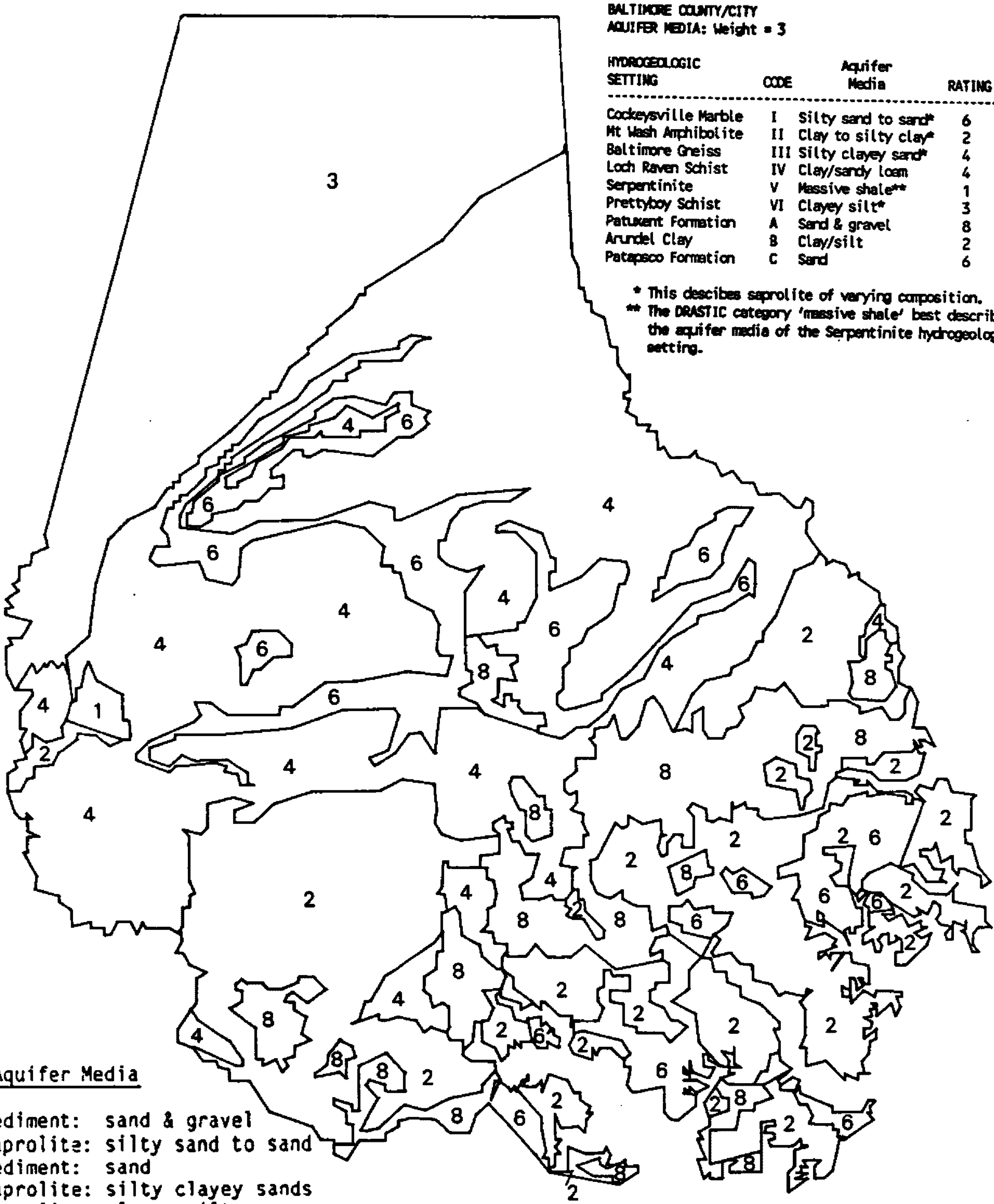
Soil Media (S): Ratings for soil media are based on the Soil Survey of Baltimore county (1976).[14] The soil in Baltimore county ranges from heavy clay found in the sediment areas (DRASTIC rating of 3) to aggregated clay with a DRASTIC rating of 7 found in the crystalline rock areas. In general, the soils found in Baltimore county are highly varied, as can be seen by examining Exhibit III.14, which illustrates the DRASTIC Soil Media Map for Baltimore County. The hydrogeologic settings and their associated soil types are given below.

SOIL MEDIA IN THE PIEDMONT PROVINCE OF BALTIMORE COUNTY

Setting		Soil Association and Textures	Rating
I.	Cockeysville Marble	Baltimore-Conestoga-Hagerstown (clay loam to clay)	3
II.	Mt. Washington Amphibolite	Chrome-Watcheeng (silty clay; montmorillonite a major clay mineral)	7
III.	Baltimore Gneiss	Chester-Glenelg; Manor-Glenelg (loam)	5
IV.	Lock Raven Schist	Chester-Glenelg; Manor-Glenelg (loam)	5
V.	Serpentinite	Thin or absent	10
VI.	Prettyboy Schist	Manor-Glenelg; Chester-Glenelg (silty-clay loam)	4

Topography (T): A topographic map of Baltimore County was overlayed with the Geologic map of Baltimore County in order to make generalizations about the topography of the county and related to the settings. In general, the county was within a 2-6% slope range corresponding to a DRASTIC rating of 9. Some areas were more hilly and had a slope of 6-12% and therefore a DRASTIC rating of 5. Locally, slopes exceeded 12% along major streams, but they have been subsumed within the 6-12% slope category for this exercise (Exhibit III.15).

EXHIBIT III.13: Aquifer Media in Baltimore County



BALTIMORE COUNTY/CITY
AQUIFER MEDIA: Weight = 3

HYDROGEOLOGIC SETTING	CODE	Aquifer Media	RATING	SCORE
Cockeysville Marble	I	Silty sand to sand*	6	18
Mt Wash Amphibolite	II	Clay to silty clay*	2	6
Baltimore Gneiss	III	Silty clayey sand*	4	12
Loch Raven Schist	IV	Clay/sandy loam	4	12
Serpentinite	V	Massive shale**	1	3
Prettyboy Schist	VI	Clayey silt*	3	9
Patuxent Formation	A	Sand & gravel	8	24
Arundel Clay	B	Clay/silt	2	6
Patapsco Formation	C	Sand	6	18

* This descibes saprolite of varying composition.
** The DRASTIC category 'massive shale' best describes the aquifer media of the Serpentinite hydrogeologic setting.

LEGEND

Rating	Aquifer Media
8	Sediment: sand & gravel
6	Saprolite: silty sand to sand Sediment: sand
4	Saprolite: silty clayey sands
3	Saprolite: clayey silt
2	Saprolite: clay to silty clay Sediment: clay/silt
1	Massive shale**

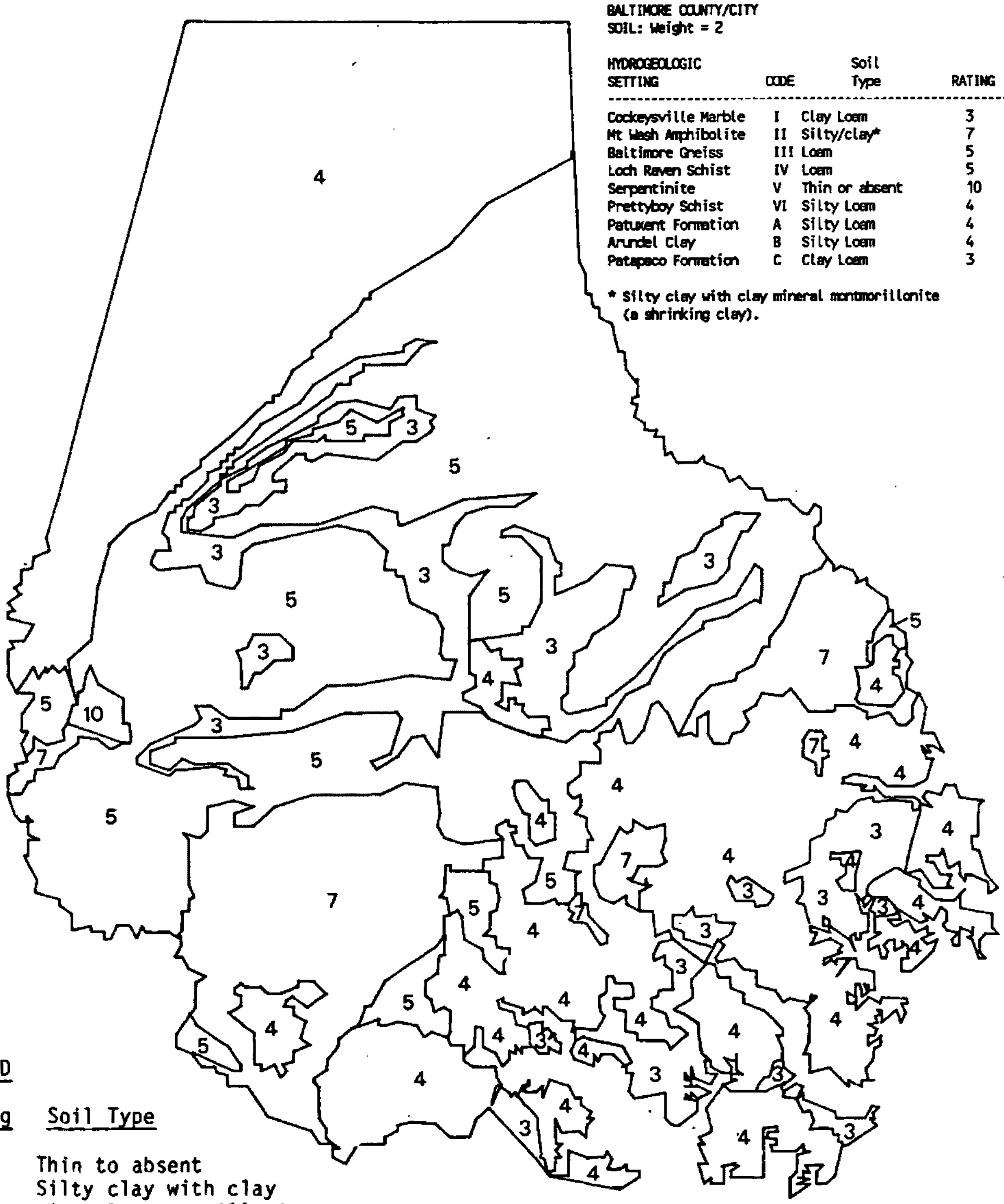
** The DRASTIC category 'massive shale' best describes the aquifer media of the Serpentinite and Arundel Clay hydrogeologic settings.

EXHIBIT III.14: Soil Media in Baltimore County

BALTIMORE COUNTY/CITY
SOIL: Weight = 2

HYDROGEOLOGIC SETTING	CODE	Soil Type	RATING	SCORE
Cockeysville Marble	I	Clay Loam	3	6
Mt Wash Amphibolite	II	Silty/clay*	7	14
Baltimore Gneiss	III	Loam	5	10
Loch Raven Schist	IV	Loam	5	10
Serpentinite	V	Thin or absent	10	20
Prettyboy Schist	VI	Silty Loam	4	8
Patuxent Formation	A	Silty Loam	4	8
Arundel Clay	B	Silty Loam	4	8
Patapsco Formation	C	Clay Loam	3	6

* Silty clay with clay mineral montmorillonite (a shrinking clay).



LEGEND

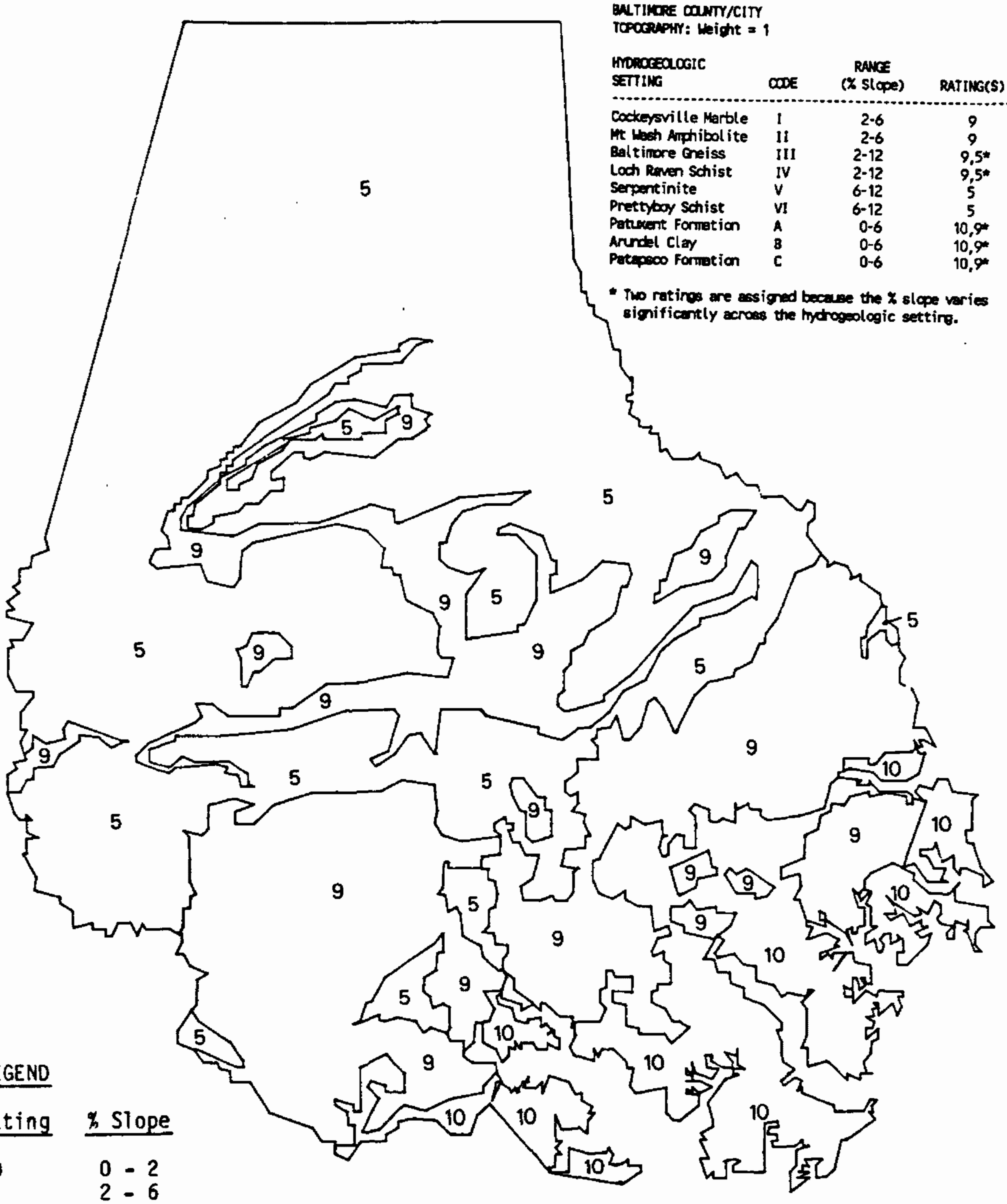
Rating	Soil Type
10	Thin to absent
7	Silty clay with clay mineral montmorillonite (a shrinking clay)
5	Loam
4	Silty loam
3	Clay loam

EXHIBIT III.15: Topography in Baltimore County

BALTIMORE COUNTY/CITY
TOPOGRAPHY: Weight = 1

HYDROGEOLOGIC SETTING	CODE	RANGE (% Slope)	RATING(S)	SCORE
Cockeysville Marble	I	2-6	9	9
Mt Wash Amphibolite	II	2-6	9	9
Baltimore Gneiss	III	2-12	9,5*	5-9
Loch Raven Schist	IV	2-12	9,5*	5-9
Serpentinite	V	6-12	5	5
Prettyboy Schist	VI	6-12	5	5
Patuxent Formation	A	0-6	10,9*	9-10
Arundel Clay	B	0-6	10,9*	9-10
Patapsco Formation	C	0-6	10,9*	9-10

* Two ratings are assigned because the % slope varies significantly across the hydrogeologic setting.



LEGEND

Rating	% Slope
10	0 - 2
9	2 - 6
5	6 - 12

Impact of the Vadose Zone (I): For the crystalline rock, unlike the discussion in the DRASTIC report, the primary concern is the combination of path length and tortuosity as impacted by grain size, sorting and packing, sorption, consumptive sorption, and fracturing. Considering these factors and that the primary media are more like silt/clay and sand/gravel with considerable silt and clay, ratings for each setting given in Exhibit III.16 are more representative of actual conditions than those given in DRASTIC. These ratings blend professional judgment based upon the thickness of the saprolite and the jointing, fracturing, and porosity of the bedrock.

Hydraulic Conductivity (C): The values for hydraulic conductivity for Baltimore County were taken from Nutter and Otton (1969).[15] All of the crystalline units except for the Cockeysville Marble had hydraulic conductivities in the range of 1-100 gpd/ft^2, which correspond to a DRASTIC rating of 1. The Cockeysville Marble had a hydraulic conductivity in the range of 300-700 gpd/ft^2, with a corresponding DRASTIC rating of 4 (Exhibit III.17).

III.B.6. Map of Groundwater Pollution Potential in Baltimore County

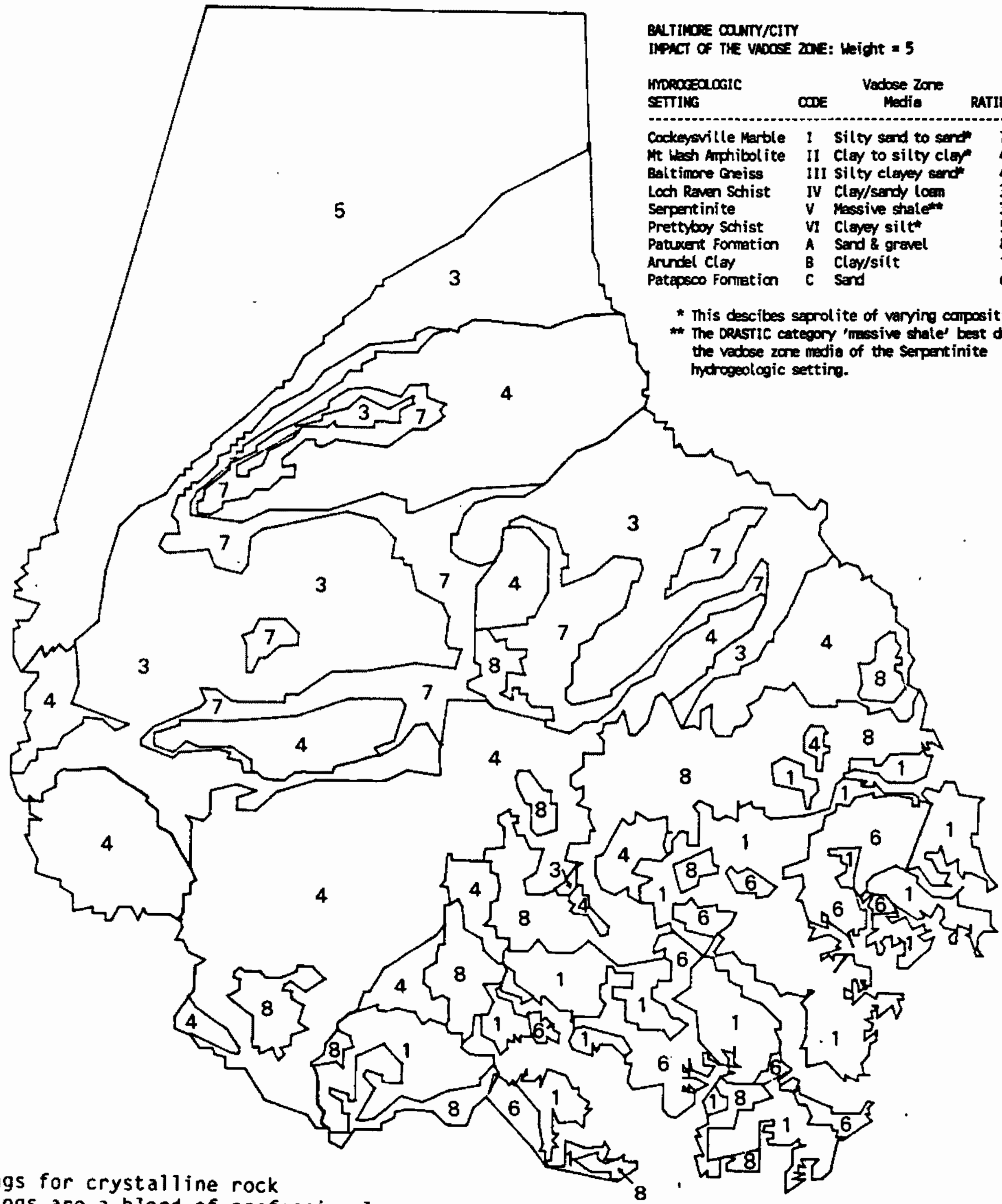
A DRASTIC score for each hydrogeologic setting in Baltimore County was compiled from the seven DRASTIC parameters (Exhibit III.18). This table gives the combined total score for each setting. These scores combined with the map of hydrogeologic settings create a map of "Groundwater Pollution Potential, Baltimore County and Baltimore City" (see the Baltimore County/City map overlays pocket at the back of the report, which contains this map and the UST and well use maps). The setting with the highest potential for groundwater pollution is the Patuxent Setting with a score of 164-175 (note that this setting occurs in both Anne Arundel and Baltimore Counties and is the highest rated in both); the setting with the lowest pollution potential is the Serpentinite Setting with a score of 103.

III.B.7. Guidance for Future Application of DRASTIC

Determining the hydrogeologic vulnerability depends upon the time and personnel resources available, the availability of data, and the desired level of detail for the maps. As stated previously, the DRASTIC report provides ratings for each hydrogeologic setting within the 15 groundwater regions within the United States. If specific data pertaining to a county or state are not available, these ratings can be used to evaluate the hydrogeologic vulnerability of the relevant area.

During the development of DRASTIC scores for individual hydrogeologic settings, we found that the DRASTIC ranges pertaining to several of the hydrogeologic parameters did not include types occurring in the Baltimore study area. For example, the aquifer media types provided by DRASTIC did not provide fine enough detail to allow the various unconsolidated and crystalline rock formations to be adequately differentiated. Consequently, we developed revised ratings to better describe the range of aquifer media in the study area. This kind of fine-tuning and revision may be necessary in other applications, and should be conducted by an experienced geologist or hydrogeologist familiar with the area of interest.

EXHIBIT III.16: Impact of the Vadose Zone in Baltimore County



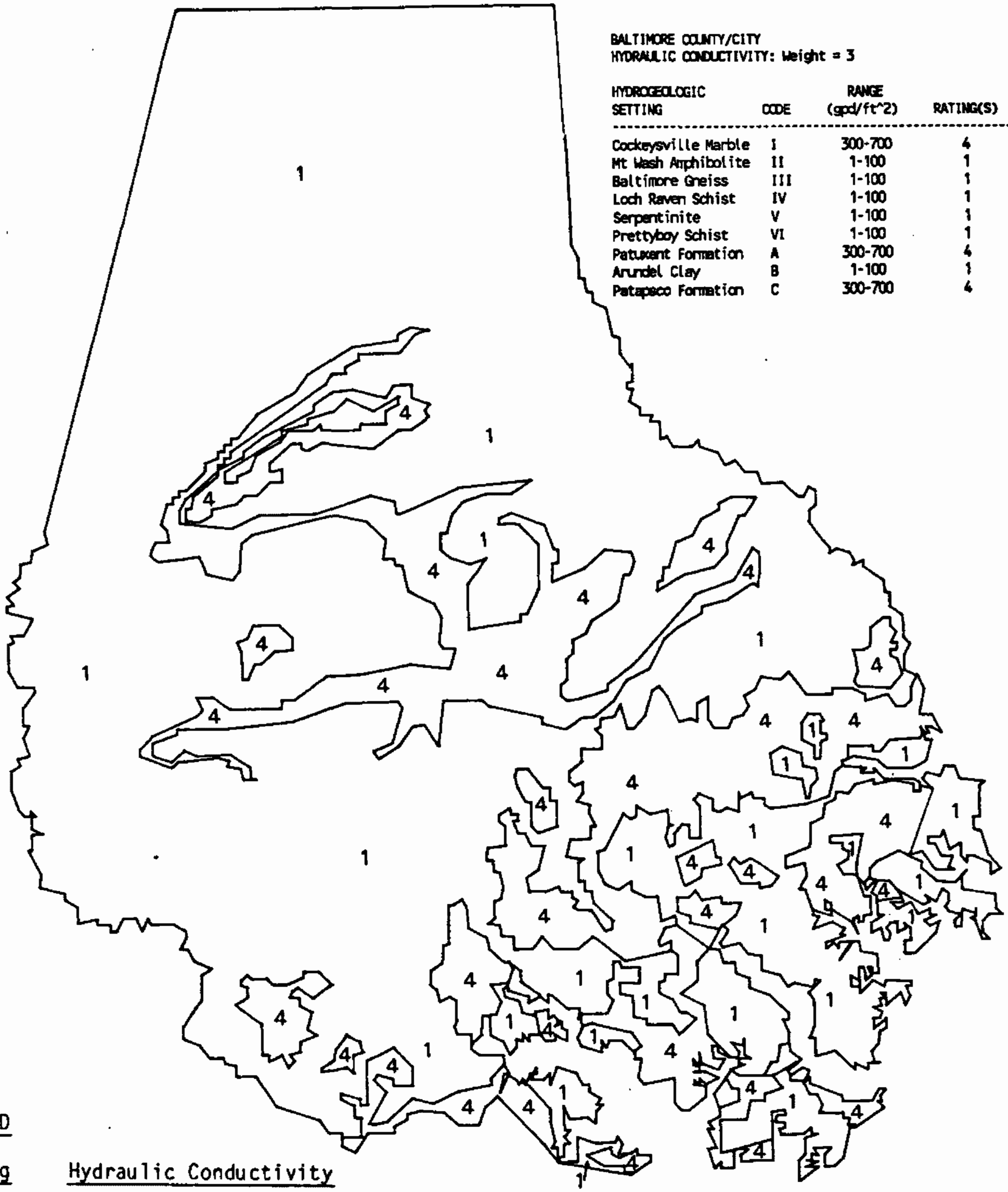
BALTIMORE COUNTY/CITY
IMPACT OF THE VADOSE ZONE: Weight = 5

HYDROGEOLOGIC SETTING	CODE	Vadose Zone Media	RATING(S)	SCORE
Cockeysville Marble	I	Silty sand to sand*	7	35
Mt Wash Amphibolite	II	Clay to silty clay*	4	20
Baltimore Gneiss	III	Silty clayey sand*	4	20
Loch Raven Schist	IV	Clay/sandy loam	3	15
Serpentinite	V	Massive shale**	3	15
Prettyboy Schist	VI	Clayey silt*	5	25
Patuxent Formation	A	Sand & gravel	8	40
Arundel Clay	B	Clay/silt	1	5
Patapsco Formation	C	Sand	6	30

* This descibes saprolite of varying composition.
** The DRASTIC category 'massive shale' best describes the vadose zone media of the Serpentinite hydrogeologic setting.

Ratings for crystalline rock settings are a blend of professional judgement, based upon thickness of saprolite, renovation capacity of saprolite, jointing, fracturing and porosity of bedrock.

EXHIBIT III.17: Hydraulic Conductivity in Baltimore County



BALTIMORE COUNTY/CITY
HYDRAULIC CONDUCTIVITY: Weight = 3

HYDROGEOLOGIC SETTING	CODE	RANGE (gpd/ft^2)	RATING(S)	SCORE
Cockeysville Marble	I	300-700	4	12
Mt Wash Amphibolite	II	1-100	1	3
Baltimore Gneiss	III	1-100	1	3
Loch Raven Schist	IV	1-100	1	3
Serpentinite	V	1-100	1	3
Prettyboy Schist	VI	1-100	1	3
Patuxent Formation	A	300-700	4	12
Arundel Clay	B	1-100	1	3
Patapsco Formation	C	300-700	4	12

LEGEND

Rating	Hydraulic Conductivity
4	300 - 700 gpd/ft^2
1	1 - 100 gpd/ft^2

EXHIBIT III.18 DRASTIC SCORES IN CRYSTALLINE ROCK SETTINGS OF BALTIMORE COUNTY

Setting		Total Score	Depth to Groundwater	Net Recharge	Aquifer Media	Soil Media	Topography	Impact of Vadose Zone	Hydraulic Conductivity
I.	Cockeysville	147	35	32	18	6	9	35	12
II.	Mt. Washington Amphibolite	109	25	32	6	14	9	20	3
III.	Baltimore Gneiss	107-121	25-35	32	12	10	5-9	20	3
IV.	Lock Raven Schist	102-116	25-35	32	12	10	5-9	15	3
V.	Serpentinite	103	25	32	3	20	5	15	3
VI.	Prettyboy Schist	107-117	25-35	32	9	8	5	25	3

While the DRASTIC methodology was developed for use by relatively junior hydrogeologists, the experience from this application suggests that experienced technical professionals should play a significant role in ranking hydrogeologic vulnerability. The DRASTIC system represents common hydrogeologic conditions observed nationally, and does not provide ratings for all media types that may be encountered. Experienced technical professionals can provide important insights on how to score areas not addressed in the DRASTIC system.

The time and resources required for scoring an area with DRASTIC will depend upon the size of the area and the level of detail desired. A rough scoring of the two counties considered in this report required less than one calendar week (100 person-hours) to complete, which should be representative of most applications. The scoring was performed by one senior level geologist, a mid-level environmental engineer, and a junior level geologist. Once the initial scoring was completed, considerable effort at fine-tuning the approach consumed additional time. Again, the additional effort in fine-tuning the approach will depend upon the experience of the participants, the complexity of the areas, and the level of detail desired.

III.C. Collecting Water Well Data

III.C.1. General Approach

In collecting data on water wells (used here as a surrogate for populations dependent on groundwater), we based the data requirements upon the need to identify data that quantified groundwater use and the number of USTs, and which could be aggregated by zip code and manipulated by the computer software we used to analyze and display it. As discussed in Section II.C.2, we collected both well and UST locational information by zip code. This choice was made in part due to the availability of computer software able to analyze geographic information at this level, and in part due to the availability of data in this format. We would have preferred to use a smaller and more uniformly sized unit than zip codes, or to map data points individually, but compromised due to time and resource limitations.

The Maryland Department of Health and Mental Hygiene provided data on water well locations from its computerized records of water well permits in the State. These records contain well locations (by Maryland grid coordinates and street address of well owner), use type (domestic, municipal, or industrial), well depths, and distance to the nearest town. The records provided information on well location, and information to estimate the number of people served by each well. The location information for many of the records was either missing or incomplete. In general, the data for Anne Arundel County was found to be less reliable than that for Baltimore, mostly due to street name changes. The Maryland grid coordinates for the older records were too general to be useful. It was also discovered that individuals filing for permits apparently interpreted the term "nearest town" differently. Most of the records correspond to well permits received after 1978 and probably correspond to operating wells; some of the well records, however, were received prior to 1970 and some of these wells may no longer be in operation. Although these records were incomplete, they were the best information available on well placement and use.

Because the well records were so incomplete, researchers at the Baltimore Regional Planning Council (RPC), used a software package to assign well owner street addresses to five digit zip codes. Because many of the well owner addresses could not be computer matched with zip codes, and because it was discovered that the well owner address was not always the address for the well itself, the RPC undertook the task of manually matching addresses with zip codes and double checking matches to ensure, whenever possible, that the well was assigned to the zip code in which it was actually located. More than 90 percent of the well records were assigned to zip codes. The data were sorted by zip code to provide the numbers of wells per zip code in both Anne Arundel and Baltimore Counties. The data on private wells were verified by comparing it with maps showing the distribution of municipal water to residents, and other less complete sources of well data, and making adjustments where appropriate.

In order to analyze potential impacts on private and municipal well systems, we translated the well information into numbers of people served by wells. For private wells, we assumed one well per household. We assumed that 2.58 persons/household are served by wells in Baltimore County and 2.83 persons/household in Anne Arundel County.[16] We obtained estimates of the number of users for the public wells from telephone conversations with employees of appropriate public works departments and by using the Master Water and Sewer plan (Anne Arundel County). We considered all persons using a public well supply to be in the same zip code as the well because pollution of the well directly impacts their water use. Appendix B provides the tables of well data which are used in this report.

After the number of well users within each zip code was determined, we calculated the well use densities for each zip code by dividing the number of users by the surface area of the zip code, to provide the number of well users per square mile. Each zip code was ranked and assigned to three categories -- low, medium, and high density -- for convenience in displaying the densities on maps.

Three density categories were chosen for several reasons. The first is that three is enough to delineate between the densities without cluttering up a map with regions of a finer gradation. By dividing the data into three equal distributions, an equal number of low, medium, and high density zip codes are found within each county. Exhibit III.19 displays the numerical values for the distribution of well usage and UST densities in both Anne Arundel and Baltimore Counties. Maps displaying the geographic distribution of well use density categories are provided in the map overlay pockets at the back of the report for Anne Arundel and Baltimore Counties. An alternative approach to assigning density categories would be to inspect the data for clear break points between observed densities, and defining ranges accordingly. No matter how the density categories are defined, it is important that the ranges be stated so that users may interpret the maps accordingly.

Exhibit III.19

Distribution of Groundwater Usage and USTs in
Anne Arundel and Baltimore Counties

Anne Arundel County

USTs per Square Mile		Number of Zip Codes	Population Served by Wells per Square Mile		Number of Zip Codes
Low:	0-2	12	Low:	6-1078	12
Medium:	3-6	11	Medium:	1644-4465	11
High:	7-49	10	High:	5037-20059	10

Baltimore County

USTs per Square Mile		Number of Zip Codes	Population Served by Wells per Square Mile		Number of Zip Codes
Low:	0-1.98	19	Low:	0	29
Medium:	2-5.2	18	Medium:	4-81	15
High:	5.3-37.1	19	High:	85-630	14

III.C.2. Guidance for Collecting Well Data

Collecting data on groundwater use within an area can be a difficult undertaking depending upon the accuracy of the data available. In the first stages of the Baltimore IEMP UST project, we originally used data from the 1985 Census of the United States to quantify both groundwater use and locations of USTs. We identified numerous problems with the accuracy of the data, however, and decided to examine alternative sources. Thus, we obtained the data on private and public wells from the State of Maryland Department of Health and Mental Hygiene.

As described previously, the State of Maryland provided compiled records of well permits for private wells on computer tape. The Baltimore RPC assigned the locations of wells to zip codes. The cost for this data analysis was approximately $2,400.

Quality control analysis highlighted several problems. In some zip codes, the data suggested more private wells than households, while in others, the percentage of households served appeared to be too low. Additionally, some zip codes located in Baltimore City (which is served entirely by public water) showed private well populations. Cases where there were more wells than households or wells in areas served by public water occurred because well records do not identify whether wells are active or inactive. Because the well records in Maryland date from the late 1940's, some of the wells may not actually be in service.

The RPC conducted a computer match on well permits with known well owner addresses. The RPC found that its automated address-matching technology was successful about one-half as often as it normally is in assigning well permits with owner street addresses to zip codes. Their results are summarized in the following table.

Exhibit III. 20: Automated Address-Matching Results, by Groups of Well Permits

Category	Permits Issued		All Permits
	Before Jan 1970	Since Jan 1970	Issued
Total:	24,976	39,236	64,212
No Address	9,083	6,435	15,518
No Match	10,895	12,325	23,220
Matched	4,998	20,478	25,476

Missing (or unrecognizable) address information was found to be more prevalent than normal. Additionally, well location records with readable addresses failed to match the present-day street system in the three political subdivisions at unusually high rates.

Although disappointing, these results were not total surprises. They reflect the overall geographic distribution of wells, limitations in automated address-matching technology, and the history of development in the Baltimore metropolitan area. The results do not imply poor record-keeping practices by the Department of Health and Mental Hygiene; rather, they reflect the fact that historical data may often not be complete, accurate, or in a useable format.

Note, for example, the differences before and after 1970. More than 1/3 of the well permits issued prior to 1970 had no street address for the well's owners, or, had entries that could not be recognized as "city" style street addresses, because house-numbering didn't exist in the rural parts of Baltimore County until 1970, more or less, and not until nearly 1980 in Anne Arundel County.

We overcame some of the data discrepancies using updated maps showing the distribution of public water supplies. Using these maps, we were able to estimate the percentage of households served by private wells. We also compared the RPC-treated data with other reliable, but less complete, sources of well data, then made adjustments where appropriate.

Depending upon the availability of data, it could take from two weeks to two months to identify populations served by groundwater by zip code within a given study area. Some states or counties may have readily accessible and usable data that will make this data collection relatively straightforward. In other cases, such as in this study, it may be necessary to manipulate large amounts of data, which can add time and expense to the study.

III.D. Collecting Underground Storage Tank Data

III.D.1. General Approach

We obtained UST data from the EPA Region III office in Philadelphia. Region III provided a computer file containing information on number of USTs in both Anne Arundel and Baltimore Counties. These data were sorted by zip code and the total number of USTs per square mile in each zip code was calculated.

In order to integrate the well and UST information, we calculated UST densities for each zip code in a procedure similar to that followed for wells. The number of USTs in each zip code was divided by the surface area of the zip code in order to generate a value for the number of USTs per square mile. We created a distribution of UST densities corresponding to low density, medium density, and high density with 1/3 of the zip codes in each of the categories (see Appendix B). We printed maps of both Anne Arundel and Baltimore Counties displaying the distribution of USTs by zip code (see the map overlay pockets at the end of the report).

III.D.2. Guidance for Collecting UST Data

Data collection for USTs was relatively straightforward due to the availability of data from the EPA Region III UST Notification survey. The Hazardous and Solid Waste Amendments (HSWA) of 1984 required States to collect this UST data, and most states have complied. These data were collected by EPA Regional Offices for those states, like Maryland, that did not participate. EPA Region III is now providing these data to Maryland. The only difficulty was that the data were formatted by a proprietary software package which was not initially available to the project. Once arrangements were made to reformat the UST data, it took about two days to sort the data by zip code and calculate UST densities.

The initial data collection efforts relied upon data from the 1985 Census, the accuracy of which was questioned by members of the UST Work Group. In future applications, users should take care to check data carefully to ensure their usefulness and accuracy for the intended goals of the study. It is recommended for quality control purposes that one zip code area (or more) be physically inventoried (by driving the roads within the zip code and mapping the occurence of every gas station and UST located on other properties). For example, a physical survey for USTs in the Cockeysville 7.5-minute quadrangle (a 50 square mile area in central Baltimore County), took two people one working day. By way of contrast, a well inventory for a county like Baltimore could be expected to take one person two to eight months, depending upon the existence of prior well inventories (Emery T. Cleaves, Maryland Geological Survey, personal communication).

III.E. Map Overlays: Well and UST Densities and Groundwater Pollution Potential

III.E.1. General Approach

The maps of groundwater pollution potential, well usage density, and UST density are laid over each other to identify the relative risk of groundwater contamination from possible UST leaks. (See the Anne Arundel County and Baltimore County/City map overlay pockets at the end of the report). The map overlays are the primary product of the Baltimore IEMP screening analysis in that they provide an indication of geographic areas where potential impacts are greatest. Based upon these overlays, state and county environmental planners can identify those areas where tank and well use is high, and/or where the groundwater is especially vulnerable, in order to focus inspection and enforcement resources on the most vulnerable areas.

III.E.2. Guidance for Future Application of the Methodology

Appendix C describes the computer hardware and software we used to generate map overlays which integrate the three measures of vulnerability. The resource requirements for this aspect of the study will depend primarily upon the amount and types of computer equipment within the organization conducting the screening analysis. While this work does not require staff with advanced computer programming skills, it does require persons possessing a working familiarity with computer applications.

Some difficulty arose in digitizing the map boundaries for hydrogeologic settings. Only a few software packages are designed to support the creation of boundary files through digitizing map information on personal computers. While the mapping software relied upon in the study had the capability to digitize new geographic boundaries, numerous difficulties were encountered in carrying out this portion of the study. In general, these experiences highlighted the importance of obtaining a well-tested digitizing software package before undertaking this section of the analysis. Future applications will benefit from rapid advances in computerized graphics technology taking place.

The resources required for developing map overlays will depend upon the type of products desired. In this study, we developed four sets of full scale maps (1/62,500) printed on mylar to facilitate their use as overlays by Anne Arundel County, Baltimore County, and Baltimore City officials. The cost for mylar and pens to print these maps may be $100 to $500 for four sets of maps. Thus, these maps should be test plotted on paper to be sure they are correct before plotting on mylar. The costs for printing report-sized maps, like those presented here, however, is considerably less given the appropriate computer hardware (see Appendix C).

The time required for developing the three maps varies depending upon the system used and the ease of access to the system. Several months were required to develop the final maps of groundwater pollution potential for this study, although we believe that much of this time resulted from the exploratory nature of the project and time needed to coordinate between agencies and consultants in different cities. With experience, and proper computer hardware and software, one person-month is a reasonable estimate.

It is possible to develop a map in which we aggregate the three measures of vulnerability. We chose not to do this because we would lose detail if we aggregated the factors into fewer composite categories. And we would lose the capability to evaluate each measure individually as well as together with the other measures. It is also possible to create one composite map of the three measures retaining the level of detail we now have, but it would be prohibitively expensive to do this on the computer, and we would again lose the capability to view each measure individually.

IV. STUDY FINDINGS AND CONCLUSIONS

IV.A. UST Screening Methodology: General Findings

The UST screening methodology developed for the Baltimore IEMP identifies areas vulnerable to leaking UST's by quantifying and integrating hydrogeologic settings, UST density, and population served by groundwater. The keys to the methodology are:

(1) The use of maps to identify and display the geographic distribution and variability of the three major factors (settings, UST's, and populations dependent on groundwater).

(2) The use of DRASTIC to identify and evaluate mappable units with common hydrogeologic characteristics and common vulnerability to contamination.

(3) The potential groundwater resource impact is determined by the location of the counties, USTs, and drinking water wells relative to the "natural" hydrogeologic settings.

The UST screening methodology provides a useful tool for assisting State, county, and local environmental officials to focus inspection and enforcement resources on areas within their jurisdiction exhibiting the greatest vulnerability to leaking USTs. The strength of the methodology lies in its map overlays, which allow environmental officials to exercise their judgment on which locations are most vulnerable. While the methodology does not integrate the three measures of vulnerability into one overall score, the maps allow officials to analyze three major factors contributing to the vulnerability of a region, and evaluate the interaction of these factors on maps.

A successful application of the methodology depends upon the accuracy of data used to quantify groundwater pollution potential, UST density, and well-dependent population density. Before undertaking an UST screening analysis in future applications, the data format to be used in the analysis should be determined. In the application to the Baltimore area, well and UST data were aggregated to the zip code level. While the participants in this study believe the analysis will provide a useful tool, many stated a preference for using individual geographic coordinates for each well and UST, or finding a more uniformly sized and smaller base geographic unit. Decisions on data format will affect both the utility of the map overlays and the resources required to develop them.

It is difficult to estimate the amount of time that would be necessary for other states, counties, or localities to undertake an UST screening analysis. The UST screening methodology evolved simultaneously with its application to the Baltimore area and, therefore, required more time and resources than will be necessary in future applications. Data collection will often consume the most resources during applications. Groundwater pollution potential maps may be developed with DRASTIC in less than one person-week if at least one experienced hydrogeologist contributes to their development. Well and UST data collection may require from two person-weeks to two person-months, depending upon the data's accuracy, availability, and format.

Because of the importance of data availability, accuracy, and format, jurisdictions may wish to evaluate their current UST and groundwater data reporting. If the needed variables are not currently collected, or if these data are not reasonably complete and in a useable format, jurisdictions may wish to revise their reporting requirements in order to facilitate efficient updates and improve the accuracy of these screening products.

IV.B. Analytical Findings in the Baltimore Study Area

The UST screening analysis allows a number of conclusions to be drawn concerning the potential for groundwater contamination from USTs in the Baltimore IEMP study area. The DRASTIC scores for the hydrogeologic settings reveal the relative vulnerability of the settings to groundwater contamination. In general, hydrogeologic settings in sedimentary rocks are relatively more vulnerable to groundwater pollution than those in crystalline rock settings in the study area. The ranking of the settings is shown in Exhibit IV.1. Because Anne Arundel County is underlain by sedimentary rocks, groundwater pollution of the water table aquifer there is a much greater potential problem than in Baltimore County, which is mostly underlain by crystalline rock settings. The contrasting relative vulnerability between sedimentary and crystalline settings reflects the geologic and hydrogeologic contrast between the Coastal Plain and Piedmont Physiographic Provinces in Maryland.

EXHIBIT IV.1 Relative Ranking of Hydrogeologic Settings by DRASTIC Scores

Rank*	Setting		Setting Type	DRASTIC Score	Median Score
1	A.	Patuxent Formation	Sedimentary	164-175	169.5
2	D.	Potomac Group	Sedimentary	160	160
3	C.	Patapsco Formation	Sedimentary	146-157	151.5
4	I.	Cockeysville Marble	Crystalline	147	147
5	H.	Aquia Formation	Sedimentary	131-145	138
6	F.	Monmouth Formation	Sedimentary	137	137
7	E.	Calvert Formation	Sedimentary	116-131	123.5
8	III.	Baltimore Gneiss	Crystalline	107-121	114
9	VI.	Prettyboy Schist	Crystalline	107-117	112
10,11,12	G.	Marlboro Clay	Sedimentary	109	109
10,11,12	II.	Mt. Wash. Amphibolite	Crystalline	109	109
10,11,12	IV.	Loch Raven Schist	Crystalline	102-116	109
13	B.	Arundel Clay	Sedimentary	102-113	107.5
14	V.	Serpentinite	Crystalline	103	103

* The setting with the highest potential for groundwater pollution is ranked first; the lowest is ranked last.

The hydrogeologic settings in the region received DRASTIC scores ranging from a low score of 102 to a high score of 175. The Patuxent setting, located in both Anne Arundel and Baltimore Counties, was found to be the most vulnerable setting, with a score ranging from 164 to 175. The Potomac setting, found only in Anne Arundel County, had nearly the same pollution potential, with a DRASTIC score of 160. Several crystalline rock settings exhibit low pollution potential, with DRASTIC scores between 100 and 119: Mt. Washington Amphibolite, Loch Raven Schist, Prettyboy Schist, and the Serpentinite. The Arundel Clay, found in both counties, also exhibits a low pollution potential with a DRASTIC score of 102-113.

The density of USTs within the study area ranges from 0 to 49 USTs per square mile and the distribution is relatively similar in both counties. The highest density of USTs is generally found in Baltimore City and near Annapolis, the most concentrated population centers in the study area. Because the distribution of USTs does not vary as widely as either groundwater use or hydrogeologic vulnerability, this study suggests that the other two measures of vulnerability will be more critical to the targeting of resources in the Baltimore IEMP study area.

Groundwater use is significantly greater in Anne Arundel County than in Baltimore County. The high well use category in Anne Arundel County ranges from 5,037 to 20,569 users per square mile, compared to that of Baltimore County, which ranges from 85 to 630 users per square mile (Appendix B). Baltimore City falls into the low well use category because surface water supplies are used for drinking water.

The map overlays reveal a number of areas within Anne Arundel County where zip codes with high densities of wells and USTs are located in vulnerable hydrogeologic settings. The Glen Burnie area, situated in the Potomac setting, is one of the most vulnerable areas within Anne Arundel County due to its high well usage and UST density. Generally, most of the northern portion of the County is within one of the two highest groundwater vulnerability categories (except for those areas overlying the Arundel Clay setting), and has high well use and medium to high UST density.

The South River Neck area near Annapolis overlies the Aquia Setting (DRASTIC score of 131-145), and has both high well usage and UST density, making it a relatively vulnerable area in the County. The western edge of Anne Arundel County borders on the Patuxent River, and overlies the vulnerable Patuxent setting. While well and UST densities vary along this border from low to high, the vulnerability of the groundwater in this area indicates a potential for damages from USTs. Because the southern portion of the County overlies the less vulnerable Calvert setting and exhibits lower densities of both USTs and wells, it will not demand the same degree of attention as the more vulnerable areas described above.

Baltimore County has fewer areas with a high vulnerability to leaking USTs than Anne Arundel County. While the highly vulnerable Patuxent setting outcrops in the southern portions of Baltimore County, the population in most of these areas are not dependent on groundwater (although the high UST density in these areas indicate the potential for resource damages). The most vulnerable area where groundwater is used occurs in the center of the County in the Cockeysville Marble setting. The Cockeysville setting received a DRASTIC score of 147. Significant portions of this setting exhibit both high UST and well densities, indicating a high vulnerability to leaking USTs. Other than the Cockeysville Marble, the other crystalline rock settings in

Baltimore County generally fall into the lowest pollution potential category (DRASTIC score of 100-119), and pose relatively less threat from leaking USTs.

Baltimore City overlies portions of the Baltimore Gneiss setting, the Patuxent setting, and the Arundel Clay setting. While the Patuxent setting is highly vulnerable to pollution, the entire city is in the low well use category due to the use of surface public water supplies.

DRASTIC notes that net recharge, soil, and topography are not as important in evaluating pollution potential from USTs because of their location below ground. As a sensitivity analysis, we calculated the DRASTIC scores omitting these three factors and found that the relative rank of the hydrogeologic settings changed only slightly. (See Appendix D.)

IV.C. Assumptions of the Analysis

Conclusions from this application of the UST screening methodology to the Baltimore area must be evaluated in light of certain assumptions and limitations inherent to the application. These factors generally relate to each of the three measures of vulnerability examined in this approach: hydrogeologic vulnerability, density of populations served by groundwater, and UST density.

In developing the DRASTIC maps, we assumed that depth to groundwater in the study area referred to the depth to groundwater in the water table aquifer. In some cases, however, the surficial aquifer may not be a source of drinking water; many wells in Anne Arundel County tap lower artesian aquifers for drinking water supplies. Because of this, the vulnerability of the actual drinking water source may not always have been rated.

These assumptions were made for two reasons. First, because gasoline USTs release contaminants that are predominantly lighter than water and will float on the water table, it is not likely that these contaminants will migrate through several confining layers into lower aquifers. Second, poorly sealed well bores may serve as conduits transporting contaminants floating on the water table into wells, where they may contaminate the drinking water supply. Therefore, we assumed that the potential for UST impacts at wells can be characterized by the ability of the constituents to migrate in the surficial aquifer toward the well.

In developing the DRASTIC maps of hydrogeologic vulnerability, we based the division of DRASTIC scores (which ranged from 102 to 175) into separate ranges upon suggestions from the DRASTIC report for preparing final maps. While most of the hydrogeologic settings received a range of scores rather than one single score, most of these ranges fell completely within the ranges defined by a single color. For those settings with a range falling between two categories, the unit was colored to match that of the more vulnerable category in order to be conservative.

For both counties, the final definition of the hydrogeologic settings and the assignment of the DRASTIC ratings were made by Dr. Emery T. Cleaves, Maryland Geological Survey. As noted in the text, he modified some DRASTIC factors and their ratings to better reflect regional conditions. The initial ratings were assigned based on the assessments of a senior geologist familiar with the hydrogeology of Maryland, a mid-level environmental engineer, and a junior level geologist. It is Dr. Cleaves' opinion that an experienced geologist knowledgeable in local hydrogeology and geology is necessary for reasonable and timely application of the DRASTIC methodology.

We made a number of assumptions in assigning wells to zip codes from the data supplied by the State of Maryland Department of Health and Mental Hygiene and the counties. In some cases, it appeared that the address of a well owner did not coincide with its actual location. As stated previously, these wells could have been assigned to incorrect zip codes in these instances despite significant efforts to assign wells to the correct zip code. The well data also indicated areas where a low percentage of the population used groundwater when it was expected that the entire population relied upon private wells. In these cases, we used public water supply maps and other sources to identify zip codes where no populations were served by public water, and zip codes in these areas were changed to indicate 100% private well use.

We obtained locations and population served by public wells from the State of Maryland Water Resources Administration, Anne Arundel County Department of Utilities, and the Baltimore County Department of Environmental Protection and Resource Management. Only municipal wells and those privately owned well systems supplying the domestic needs of a residential population (such as trailer parks and small towns) were considered. Commercial wells, such as those serving hotels, schools, or religious, social, or military organizations (except for military housing), were not included in the well use information.

Because of the complexity of the Anne Arundel County municipal water system, population served by well fields was provided by the Anne Arundel County Master Water and Sewerage Plan (1984) or estimated from pumpage data. All population information was for a projected 1985 population, while the pumpage data were from 1987. Where there was insufficient information regarding the number of people served by privately owned water systems, the service populations were estimated from pumpage data by assuming domestic use of 80 gallons/person/day. Appendix B provides the data on both wells and USTs in both counties.

EPA Region III supplied the UST data which represent the result of the notification requirement for owners and operators of USTs. These are probably the most complete and accurate data available on the locations and characteristics of USTs. Because the survey relied upon submission of the notification forms by UST owners and operators, some USTs may not have been considered. The analysis did not consider gasoline USTs located on farms, which often have their own gasoline storage. The analysis also considered only gasoline USTs, and did not attempt to quantify impacts associated with USTs containing other types of chemical products.

V. PLANNED AND POTENTIAL USES OF THE UST SCREENING METHODOLOGY

The State and local officials involved in the IEMP thought that it was important to develop a priority-setting tool to enable them to respond to the most serious UST leaks first. The tool we developed may be used by state officials for determining priority areas across the state, and by state, county, and local officials for targeting inspection and enforcement activities within their jurisdiction. The approach will allow officials not ony to practice better UST management, but to also evaluate other potential sources of groundwater contamination, and to better plan future development.

The State Waste Management Administration, the Baltimore County Department of Environmental Protection and Resource Management, and the Anne Arundel County Health Department have each indicated that they intend to use the UST study's methodology to help set priorities regarding staff and resource allocation for UST leak investigation and cleanup. (The State Waste Management Administration has primary responsibility for investigating and enforcing cleanup from leaking USTs under the state regulations, while the county health and environmental departments respond to reports of oil pollution in wells, storm drains, and excavations.) The hydrogeologic information presented by this study for specific areas, especially soil type and depth to groundwater, will help inspectors assess the vulnerability of a site to groundwater damage before they specify remedial actions. Information on UST density and well-dependent population density may help the State determine the degree of groundwater remediation that will be required.

The State of Maryland plans to use our priority-setting methodology to fulfill requirements for a cooperative agreement with the EPA's Office of Underground Storage Tanks. EPA amendments to Subtitle I of the Resource Recovery and Conservation Act (part of the Superfund Amendments and Reauthorization Act of 1986) have established a trust fund to finance the cleanup of petroleum releases from USTs. EPA, and States who enter into cooperative agreements with EPA, can access this fund for cleanup when appropriate. EPA will manage the trust fund monies in ways which will best protect human health and the environment. Thus, one of the requirements for the cooperative agreement is that a state must have a priority-setting system either in-place or under development. This screening device will enable enforcement agencies to address the potentially most serious UST leaks first. The State of Maryland has chosen the methodology developed in the UST Phase II study as its requisite priority-setting management tool, and will attempt to apply the methodology to all Maryland's counties.

Another major application of the UST Phase II screening methodology and maps will be in reviewing proposed development. A large part of the work of the Baltimore County Department of Environmental Protection and Resource Management and the Anne Arundel County Health Department involves reviewing plans for proposed residential and commercial development. The hydrogeologic information developed in this study will help the departments to evaluate these proposed plans, especially siting new USTs. Specific design, operating, monitoring, or inspection requirements for USTs may differ, depending on the vulnerability of an area due to populations dependent on groundwater or hydrogeologic setting. The departments may negotiate with developers to locate UST-dependent facilities on less vulnerable sites. Or, in highly vulnerable areas, the departments may require extra tank containment, alarm and detection systems, above-ground tanks, or may not allow storage tanks at all.

The UST Phase II study maps are designed to be used by planning and zoning offices. The DRASTIC, UST, and well maps will be plotted on high transmission film at a scale of 1:62,500 to be used as overlays on county planning maps. These maps will allow planners to identify broad areas for further site-specific analysis to evaluate proposed development, landfill sites, or other activities in light of groundwater vulnerability.

The information collected in the UST Phase II study can be used in conjunction with other planned studies. The Anne Arundel County Department of Planning and Zoning is planning to conduct a comprehensive survey of the groundwater situation in the county and evaluate future uses in light of the findings. The hydrogeologic information and the impact of USTs presented in our study will be considered in the survey.

Several agencies indicated that that UST study data and maps could be incorporated into existing or planned groundwater quality data bases or used as an adjunct to these data bases. The Baltimore County Department of Environmental Protection and Resource Management now has such a data base, and the State is developing a comprehensive data base to track groundwater quality and another to monitor ambient groundwater statewide. The State is also planning to digitize its geographic data points, including all USTs.

The results of the UST Phase II study can be used to educate UST users, developers, and others. The agencies involved in this study plan to use it to educate developers, engineers, and other segments of the public. If these individuals understand the importance of groundwater protection in vulnerable areas, they may be more inclined to cooperate with protection strategies, and developers may be motivated to develop environmentally sound storage practices prior to submitting their plans for review.

The UST screening approach can be applied to the analysis of other potential sources of groundwater contamination. For example, impacts from municipal landfills, industrial surface impoundments and landfills, and road salt piles depend upon the frequency of occurrence of each source, the dependence on groundwater, and the pollution potential of the hydrogeologic setting. Any of these potential sources of pollution could be substituted for USTs in this analysis.

Other potential uses of the UST Phase II products vary. The state and counties are required, under the Safe Drinking Water Act, to develop management standards of facilities that fall into the critical protection areas that surround public drinking water wells. The information developed by our study could be used to evalute these critical areas and develop well-head protection program or to help site new public wells. Various public agencies that use USTs may install extra protection in hydrogeologically vulnerable areas or locate USTs in less vulnerable areas. Fire departments may wish to pay special attention to areas with high UST density to track potential leaks, especially where leaked fuel may travel quickly, to prevent dangerous seepage of fuel or fumes into sewers and basements.

VI. ALTERNATIVE APPROACHES TO ASSESSING VULNERABILITY FROM LEAKING USTs

EPA's Office of Underground Storage Tanks (OUST) has developed an alternative approach for assisting State administrators in setting priorities for effectively expending their resources in the UST programs.[17] The OUST approach focuses on groundwater use within zip code areas from public and private wells, and the likelihood that tanks within a zip code will leak based upon their numbers and age. These two factors are quantified into two numeric values: the Geographic Potential Impact Factor (GPIF) and the Leak Likelihood Factor (LLF). These two values are combined to produce a numeric ranking for each zip code considered, and taken together, a relative ranking of zip codes can be generated.

This approach is similar to the UST screening methodology presented in this report in that both approaches produce a relative ranking of areas of potential vulnerability. Both approaches identifying vulnerable locations address similar scales (State- and county-wide), and focus on zip codes as the basic geographic unit.

The approaches differ in that the Baltimore UST screening methodology addresses the inherent pollution potential of groundwater using the DRASTIC methodology. The Baltimore screening approach thus integrates three components affecting potential groundwater impacts rather than two: groundwater use, UST density, and hydrogeologic setting. The OUST approach will generally require less time to develop on a regional basis but omits consideration of the hydrogeologic environment. The IEMP methodology does not project the probability of UST leaks, but does not require the collection of UST age data.

In evaluating which methodology to use, a jurisdiction should consider the hydrogeologic variability of an area, the financial and staff time resources available, and the availability of hydrogeologic and UST age data, as well as the preferences of the agencies. If an area is varied in its hydrogeology, and there is a reasonable amount of hydrogeologic information available, the jurisdiction may wish to use the IEMP methodology. On the other hand, if the hydrogeology is very uniform, and age data is available, the jurisdiction may wish to use the OUST methodology. The financial and staff resources and the preferences of the agencies, including the use of the screening products for other uses, will also influence the decision of which methodology to use.

FOOTNOTES

1. National Water Well Association, DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings, EPA/600/2-85-018, May 1985.

2. Mack, Frederick K., Ground Water Supplies for Industrial and Urban Development in Anne Arundel County, Maryland Department of Geology, Mines, and Water Resources, 1962.

3. Ibid.

4. Dingman, R.J., and Ferguson, H.F., The Water Resources of Baltimore and Harford Counties, Maryland Department of Geology, Mines, and Water Resources, 1956.

5. Mack, Frederick K., op. cit.

6. Chapelle, Francis H., "A Solute-Transport Simulation of Brackish-Water Intrusion Near Baltimore, Maryland", Ground Water, Vol. 24:3, May-June 1986.

7. State of Maryland, Maryland Geologic Survey, Geologic Map of Anne Arundel County, 1976.

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10. Kirby, R.M., Matthews, E.D. 1973. Soil Survey of Anne Arundel County, Maryland: Soil Conservation Service, U.S. Department of Agriculture, Washington, D.C. 127 pp.

11. Mack, Frederick K., op. cit.

12. State of Maryland, Maryland Geologic Survey, Geologic Map of Baltimore County and City, 1976.

13. E.G. Otton, E.T. Cleaves, Cockeysville Quadrangle, Geology, Hydrology, and Mineral Resources Maps, Maryland Geologic Survey, 1975.

14. Reybold, N.U., III, Matthews, E.D., 1976. Soil Survey of Baltimore County, Maryland: Soil Conservation Service, U.S. Department of Agriculture, Washington, D.C. 149 pp.

15. Nutter, L.J. and Otton, E.G.. 1969. R.I. 10. Ground-Water Occurrence in the Maryland Piedmont: Maryland Geological Survey, Baltimore, Maryland. 56 pp.

16. 1985 statistics used by the State of Maryland. Telephone discussion, Cindy Powell, State of Maryland Water Resources Administration, April 29, 1987, verified May 13, 1987.

17. Development and Application of an UST Program Targeting Methodology, draft, prepared for Office of Underground Storage Tanks, USEPA, by Camp Dresser & McKee, October 1, 1986. (Final report expected in early 1988)

APPENDIX A

UNDERGROUND STORAGE TANK WORK GROUP MEMBERS

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APPENDIX B WELL AND UST DATA

Table 1

ANNE ARUNDEL COUNTY WELL AND UST DATA

ZIP CODE	USTs	PRIVATE WELLS	POPULATION SERVED	PUBLIC WELLS [1]	POPULATION SERVED	AREA SQ.MILES	1985 POP	NUMBER OF HH 1985 [2]	% OF HH WITH PRIVATE WELLS		USTs PER SQ.M		PRIVATE WELLS PER SQ.M		PUBLIC WELLS PER SQ.M		POPULATION SERVED BY GW PER SQ.M	
20707	--	--	--	3	5203	--	--	--	--		--		--		--		--	
20701	11	980	2772	0	0	6.42	2772	980	100.00%	HIGH	1.71	LOW	152.57	MED	0.000	LOW	2772	MED
20711	51	510	1442	5	2575	33.66	4017	1419	35.90%	MED	1.52	LOW	15.14	LOW	0.149	MED	1519	MED
20714	--	--	--	1	528	--	--	--	--		--		--		--		--	
20733	4	952	2693	1	30	4.09	2723	962	98.90%	HIGH	0.98	LOW	232.66	HIGH	0.244	MED	2700	MED
20751	34	287	811	0	0	3.51	811	287	100.00%	HIGH	9.69	HIGH	81.64	MED	0.000	LOW	811	LOW
20754	5	--	--	0	0	--	--	--	--		--		--		--		--	
20755	152	67	190	0	0	21.79	15421	5449	1.23%	LOW	6.98	HIGH	3.07	LOW	0.000	LOW	190	LOW
20758	5	336	952	0	0	6.32	952	336	100.00%	HIGH	0.79	LOW	53.23	MED	0.000	LOW	952	LOW
20764	10	696	1969	0	0	4.02	1969	696	100.00%	HIGH	2.49	MED	173.07	HIGH	0.000	LOW	1969	MED
20765	19	226	640	0	0	0.92	640	226	100.00%	HIGH	20.65	HIGH	245.81	HIGH	0.000	LOW	640	LOW
20776	7	368	1043	2	821	23.67	1864	659	55.94%	MED	0.30	LOW	15.57	LOW	0.084	MED	1077	LOW
20778	6	568	1606	2	394	9.24	2000	707	80.31%	MED	0.65	LOW	61.43	MED	0.216	MED	1649	MED
20779	4	231	654	2	64	4.69	718	254	91.12%	HIGH	0.85	LOW	49.29	LOW	0.426	MED	668	LOW
20794	35	--	--	1	774	--	--	--	--		--		--		--		--	
21012	28	669	1893	1	9121	9.45	17635	6231	10.74%	LOW	2.96	MED	70.79	MED	0.106	MED	2858	MED
21032	50	2425	6862	4	2278	19.41	7639	2699	89.82%	HIGH	2.58	MED	124.91	MED	0.206	MED	6979	HIGH
21035	31	2064	5841	1	270	27.45	6111	2159	95.58%	HIGH	1.13	LOW	75.19	MED	0.036	MED	5851	HIGH
21037	126	3729	10552	2	517	19.67	13022	4601	81.03%	HIGH	6.41	MED	189.56	HIGH	0.102	MED	10578	HIGH
21054	60	1578	4465	1	11	17.86	6394	2259	69.82%	MED	3.36	MED	88.33	MED	0.056	MED	4465	MED
21056	2	37	105	1	305	1.38	325	115	32.22%	MED	1.45	LOW	26.81	LOW	0.725	MED	326	LOW
21061	373	1106	3130	10	84468	25.61	77687	27451	4.03%	LOW	14.56	HIGH	43.18	LOW	0.390	MED	6428	HIGH
21076	34	95	269	3	1033	12.68	3838	1356	7.02%	LOW	2.68	MED	7.51	LOW	0.237	MED	351	LOW
21077	5	51	144	0	0	0.18	1602	566	9.01%	LOW	27.78	HIGH	283.33	HIGH	0.000	LOW	144	LOW
21090	76	1780	5037	0	0	6.99	10073	3559	50.00%	MED	10.87	HIGH	254.60	HIGH	0.000	LOW	5037	HIGH
21108	61	908	2570	5	540	15.22	11633	4111	22.09%	LOW	4.01	MED	59.66	MED	0.329	MED	2605	MED
21113	91	486	1375	2	14772	14.13	6483	2291	21.22%	LOW	6.44	MED	34.39	LOW	0.142	MED	2421	MED
21114	18	143	405	1	7631	5.68	14472	5114	2.80%	LOW	3.17	MED	25.18	LOW	0.176	MED	1748	MED
21122	168	7267	20565	3	128	31.48	46250	16343	44.46%	MED	5.34	MED	230.84	HIGH	0.095	MED	20569	HIGH
21140	2	178	503	1	504	1.18	1509	533	33.36%	MED	1.69	LOW	150.75	MED	0.847	MED	931	LOW
21144	28	1483	4198	10	20521	16.28	23463	8291	17.89%	LOW	1.72	LOW	91.12	MED	0.614	MED	5459	HIGH
21146	74	1782	5043	2	17329	8.31	19594	6924	25.74%	MED	8.90	HIGH	214.44	HIGH	0.241	MED	7128	HIGH
21240	87	10	27	1	22185	5.46	27	10	100.00%	HIGH	15.93	HIGH	1.75	LOW	0.183	MED	4090	MED
21401	334	6564	18577	7	46287	33.97	41321	14601	44.96%	MED	9.83	HIGH	193.23	HIGH	0.206	MED	19939	HIGH
21402	58	25	71	0	0	1.18	5281	1866	1.34%	LOW	49.15	HIGH	21.19	LOW	0.000	LOW	71	LOW
21403	42	1882	5325	1	1	8.74	22623	7994	23.54%	MED	4.81	MED	215.28	HIGH	0.114	MED	5325	HIGH
21404	3	--	--	0	0	--	--	--	--		--		--		--		--	
21405	1	2	6	0	0	0.75	1153	407	0.49%	LOW	1.33	LOW	2.66	LOW	0.000	LOW	6	LOW
AVERAGE	58.24	1164	2947	1.92	5839	12.18	10070.38	3990	50.02%		7.06		105.92		0.18		3853	
MEDIAN	32.50	539	1209	1.00	357	8.74	3838.00	1866	44.46%		3.17		75.19		0.11		2325	
HIGH	373.00	7267	20565	10.00	81227	33.97	77687.00	27451	100.00%		49.15		283.33		0.85		20569	
LOW	1.00	0	0	0.00	0	0.18	0.00	10	0.49%		0.30		1.75		0.00		6	
LOW									0.5% - 22.1%		0 - 2		2 - 49		0		6 - 1078	
MED									23.5% - 80.3%		3 - 6		61 - 153		0 - 1		1644 - 4465	
HIGH									81.0% - 100%		7 - 49		173 - 283		NONE		5037 - 20569	

[1] Includes municipal and privately owned community water supplies.
[2] HH = Households

Table 2

BALTIMORE COUNTY WELL AND UST DATA

ZIP CODE	USTs	PRIVATE WELLS	POPULATION SERVED	PUBLIC WELLS [1]	POPULATION SERVED	AREA SQ.MILES	1985 POP	NUMBER OF HH 1985 [2]	% OF HH WITH PRIVATE WELLS		USTs PER SQ.M		PRIVATE WELLS PER SQ.M		PUBLIC WELLS PER SQ.M		POPULATION SERVED BY GW PER SQ.M	
21013	2	--	--	0	0	--	--	--	100.00%	HIGH	--		--		--		--	
21021	9	279	720	0	0	2:8	720	279	100.00%	HIGH	3.21	MED	99.67	HIGH	0.00	LOW	257	HIGH
21022	26	0	0	0	0	0.7	1856	719	0.00%	LOW	37.14	HIGH	0.00	LOW	0.00	LOW	0	LOW
21030	129	1533	3956	0	0	21.6	21168	8205	18.69%	HIGH	5.97	HIGH	70.99	HIGH	0.00	LOW	183	HIGH
21031	20	0	0	0	0	1	245	95	0.00%	LOW	20.00	HIGH	0.00	LOW	0.00	LOW	0	LOW
21051	5	39	100	0	0	0.6	100	39	100.00%	HIGH	8.33	HIGH	64.60	HIGH	0.00	LOW	167	HIGH
21053	13	556	1434	0	0	21.9	1434	556	100.00%	HIGH	0.59	LOW	25.38	MED	0.00	LOW	65	MED
21057	15	2006	5176	0	0	16.8	5176	2006	100.00%	HIGH	0.89	LOW	119.42	HIGH	0.00	LOW	308	HIGH
21071	13	785	2026	0	0	7.8	2026	785	100.00%	HIGH	1.67	LOW	100.68	HIGH	0.00	LOW	260	HIGH
21082	1	1636	4221	0	0	6.7	4221	1636	100.00%	HIGH	0.15	LOW	244.19	HIGH	0.00	LOW	630	HIGH
21087	7	917	2367	0	0	12.2	2367	917	100.00%	HIGH	0.57	LOW	75.20	HIGH	0.00	LOW	194	HIGH
21093	95	576	1486	0	0	20.4	29057	11262	5.11%	MED	4.66	MED [3]	28.24	HIGH	0.00	LOW	73	MED
21107	5	419	1082	0	0	24.5	1082	419	100.00%	HIGH	0.20	LOW	17.12	MED	0.00	LOW	44	MED
21111	3	1129	2912	0	0	34.4	2912	1129	100.00%	HIGH	0.09	LOW	32.81	HIGH	0.00	LOW	85	HIGH
21117	86	1710	4412	0	0	22.3	14730	5709	29.95%	HIGH	3.86	MED	76.68	HIGH	0.00	LOW	198	HIGH
21120	37	3636	9380	0	0	49.6	9380	3636	100.00%	HIGH	0.75	LOW	73.30	HIGH	0.00	LOW	189	HIGH
21128	6	211	544	0	0	6.7	6090	2360	8.94%	MED	0.90	LOW	31.49	HIGH	0.00	LOW	81	MED
21131	22	2636	6800	1	77	23.1	6877	2666	98.87%	HIGH	0.95	LOW	114.09	HIGH	0.04	LOW	298	HIGH
21133	66	726	1873	0	0	7.2	16162	6264	11.59%	MED	9.17	HIGH	100.83	HIGH	0.00	LOW	260	HIGH
21136	79	2316	5975	0	0	56.4	27601	10698	21.65%	HIGH	1.40	LOW	41.06	HIGH	0.00	LOW	106	HIGH
21152	6	365	942	0	0	23.6	2367	917	39.78%	HIGH	0.25	LOW	15.47	MED	0.00	LOW	40	MED
21155	9	--	--	0	0	--	--	--	100.00%	HIGH	--		--		--		--	
21156	--	47	121	0	0	0.4	121	47	100.00%	HIGH	--		117.25	HIGH	0.00	LOW	303	HIGH
21161	14	789	2035	0	0	48.7	2035	789	100.00%	HIGH	0.29	LOW	16.20	MED	0.00	LOW	42	MED
21162	77	422	1089	0	0	15.9	21457	8317	5.07%	MED	4.84	MED	26.54	MED	0.00	LOW	68	MED
21163	1	252	650	0	0	17.3	3340	1295	19.47%	HIGH	0.06	LOW	14.57	MED	0.00	LOW	38	MED
21204	160	0	0	0	0	17.8	41829	16213	0.00%	LOW	8.99	HIGH	0.00	LOW	0.00	LOW	0	LOW
21220	82	466	1203	0	0	19.8	33820	13109	3.56%	MED	4.14	MED	23.54	MED	0.00	LOW	61	MED
21221	90	174	448	0	0	13.6	42464	16459	1.06%	MED	6.62	HIGH	12.77	MED	0.00	LOW	33	MED
21228	99	174	448	0	0	14.8	38727	15010	1.16%	MED	6.69	HIGH	11.73	MED	0.00	LOW	30	MED

[Totals for Baltimore County/City are provided on Table 2a].

[1] Includes municipal and privately owned community water supplies.
[2] HH = Households
[3] ZIP 21093 subsumes ZIP 21022. These two ZIPs together fall into the HIGH category.

Table 2a

BALTIMORE CITY WELL AND UST DATA

ZIP CODE	USTs	PRIVATE WELLS	POPULATION SERVED	PUBLIC WELLS [1]	POPULATION SERVED	AREA SQ.MILES	1985 POP	NUMBER OF HH 1985 [2]	% OF HH WITH PRIVATE WELLS		USTs PER SQ.M		PRIVATE WELLS PER SQ.M		PUBLIC WELLS PER SQ.M		POPULATION SERVED BY GW PER SQ.M	
21201	6	0	0	0	0	1.9	32735	12494	0.00%	LOW	3.16	MED	0.00	LOW	0.00	LOW	0	LOW
21202	10	0	0	0	0	1.6	24899	9503	0.00%	LOW	6.25	HIGH	0.00	LOW	0.00	LOW	0	LOW
21205	12	0	0	0	0	2.3	21740	8298	0.00%	LOW	5.22	MED	0.00	LOW	0.00	LOW	0	LOW
21206	11	0	0	0	0	6.1	54366	20750	0.00%	LOW	1.80	LOW	0.00	LOW	0.00	LOW	0	LOW
21207	112	294	770	0	0	26.6	72918	27831	1.06%	MED	4.21	MED	11.05	MED	0.00	LOW	29	MED
21208	48	306	802	0	0	24.3	36089	13774	2.22%	MED	1.98	LOW	12.59	MED	0.00	LOW	33	MED
21209	6	0	0	0	0	3.8	10879	4152	0.00%	LOW	1.58	LOW	0.00	LOW	0.00	LOW	0	LOW
21210	8	0	0	0	0	2.5	6989	2668	0.00%	LOW	3.20	MED	0.00	LOW	0.00	LOW	0	LOW
21211	14	0	0	0	0	2.6	20391	7783	0.00%	LOW	5.38	HIGH	0.00	LOW	0.00	LOW	0	LOW
21212	12	0	0	0	0	4.6	36356	13876	0.00%	LOW	2.61	MED	0.00	LOW	0.00	LOW	0	LOW
21213	4	0	0	0	0	4.2	44126	16842	0.00%	LOW	0.95	LOW	0.00	LOW	0.00	LOW	0	LOW
21214	6	0	0	0	0	2.6	20419	7794	0.00%	LOW	2.31	MED	0.00	LOW	0.00	LOW	0	LOW
21215	22	0	0	0	0	6.2	74762	28535	0.00%	LOW	3.55	MED	0.00	LOW	0.00	LOW	0	LOW
21216	9	0	0	0	0	3.2	41711	15920	0.00%	LOW	2.81	MED	0.00	LOW	0.00	LOW	0	LOW
21217	5	0	0	0	0	2.5	49625	18941	0.00%	LOW	2.00	MED	0.00	LOW	0.00	LOW	0	LOW
21218	19	0	0	0	0	4.5	59177	22587	0.00%	LOW	4.22	MED	0.00	LOW	0.00	LOW	0	LOW
21219	58	18	47	0	0	10.6	10366	3956	0.45%	MED	5.47	HIGH	1.70	MED	0.00	LOW	4	MED
21222	156	43	113	0	0	12.3	71833	27417	0.16%	MED	12.68	HIGH	3.50	MED	0.00	LOW	9	MED
21223	5	0	0	0	0	2.2	47376	18082	0.00%	LOW	2.27	MED	0.00	LOW	0.00	LOW	0	LOW
21224	75	0	0	0	0	8.1	54757	20900	0.00%	LOW	9.26	HIGH	0.00	LOW	0.00	LOW	0	LOW
21225	98	0	0	0	0	8.7	34970	13347	0.00%	LOW	11.26	HIGH	0.00	LOW	0.00	LOW	0	LOW
21226	77	0	0	0	0	11.2	6159	2351	0.00%	LOW	6.88	HIGH	0.00	LOW	0.00	LOW	0	LOW
21227	110	0	0	0	0	25.6	43132	16463	0.00%	LOW	4.30	MED	0.00	LOW	0.00	LOW	0	LOW
21229	34	0	0	0	0	6.6	54957	20976	0.00%	LOW	5.15	MED	0.00	LOW	0.00	LOW	0	LOW
21230	33	0	0	0	0	5.4	41704	15918	0.00%	LOW	6.11	HIGH	0.00	LOW	0.00	LOW	0	LOW
21231	--	0	0	0	0	1.2	23968	9148	0.00%	LOW	--		0.00	LOW	0.00	LOW	0	LOW
21234	43	0	0	0	0	12.6	61207	23361	0.00%	LOW	3.41	MED	0.00	LOW	0.00	LOW	0	LOW
21236	54	0	0	0	0	1.5	3103	1184	0.00%	LOW	36.00	HIGH	0.00	LOW	0.00	LOW	0	LOW
21237	68	0	0	0	0	10.5	20892	7974	0.00%	LOW	6.48	HIGH	0.00	LOW	0.00	LOW	0	LOW
21239	1	0	0	0	0	3.2	31724	12108	0.00%	LOW	0.31	LOW	0.00	LOW	0.00	LOW	0	LOW

BALTIMORE COUNTY/CITY TOTAL

	USTs	PRIVATE WELLS	POPULATION SERVED	PUBLIC WELLS [1]	POPULATION SERVED	AREA SQ.MILES	1985 POP	NUMBER OF HH 1985 [2]	% OF HH WITH PRIVATE WELLS	USTs PER SQ.M	PRIVATE WELLS PER SQ.M	PUBLIC WELLS PER SQ.M	POPULATION SERVED BY GW PER SQ.M
AVERAGE	37.59	395	1019	0.02	1	11.74	23430.55	8975	26.51%	4.73	25.55	0.00	64
MEDIAN	14.50	0	0	0.00	0	7.50	21030.00	7974	0.31%	3.21	0.00	0.00	0
HIGH	160.00	3636	9380	1.00	77	56.40	74762.00	28535	100.00%	37.14	244.19	0.04	630
LOW	0.00	0	0	0.00	0	0.00	0.00	0	0.00%	0.00	0.00	0.00	0

	% OF HH WITH PRIVATE WELLS	USTs PER SQ.M	PRIVATE WELLS PER SQ.M	PUBLIC WELLS PER SQ.M	POPULATION SERVED BY GW PER SQ.M
LOW	0.0%	0 - 1.98	0	0.0 - 0.04	0
MED	0.2% - 39.8%	2.0 - 5.2	2 - 27	NONE	4 - 81
HIGH	98.9% - 100%	5.3 - 37.1	28 - 244	NONE	85 - 630

[1] Includes municipal and privately owned community water supplies.
[2] HH = Households

APPENDIX C

SOFTWARE AND HARDWARE REQUIREMENTS FOR SCREENING ANALYSIS

Software

Central to the screening tool developed for the IEMP Baltimore Study is the computer-generated maps of hydrogeologic vulnerability, UST density, and well density. Therefore, the essential software is a micro-computer mapping package. There are several mapping packages on the market; the "best one" depends upon the needs of the user.

Most PC mapping packages are written to be relatively easy to use. Most are menu driven and come with a demonstration or tutorial program. The manuals are generally very thorough and include step-by-step directions for first time users. The user does not have to be a highly skilled computer programmer; most packages can be learned and used by first time computer users in a few days. Some basic understanding of computer operation and some knowledge of the hardware is required for initial use and installation of the software. Many venders provide installation and technical support if the user has difficulty with the manufacturer's installation instructions. Almost all of the software manufacturers provide technical support for registered users of their software over the phone.

One important mapping capability is the mapping of small geological areas. We used zip codes as the analytical unit because it it the smallest geographical area for which we could attain well, population, and UST data. Many mapping software packages do not have the ability to map zip codes, or only map zip codes for major metropolitan areas. Of course, if the user cannot attain data by zip code, then their is no reason to limit the choice of software packages to those only mapping zip code boundaries. Some mapping packages can map the U.S. by census tract, others can map the U.S. by county. A few packages can only map state boundaries. In order to use this screening tool at the state or local level, the smallest possible geographic area for which data can be obtained should be used. Data availability should be the limiting factor to the geographical unit used in the analysis, not the boundaries contained in a software package. Data availability should be verified first, before deciding upon specific software.

Boundary and Data File

Mapping packages generally use two types of files to create maps, boundary files and data files. Some packages also allow the user to create and display a text file. The boundary file contains the coordinates for the geographical boundaries displayed on the maps (i.e., zip code boundaries or county boundaries).

Data files contain statistical data for each geographical unit the user wishes to display. The two files are matched by the software through the use of a common identifier for each individual geographical unit. Boundary files are usually supplied by the software manufacturer. A few packages allow for user-created boundary files. Some mapping software packages allow the user to enter new boundary files with the use of digitizing tablet or a mouse, but most packages only map manufacturer specified boundary files. Most packages have limited capabilities to map self-generated boundary files, such as hydrogeologic setting boundaries.

Data files are usually generated by the user. Some packages come with limited data files created by the manufacturer (i.e., U.S. population by state). Data is entered into the software either by importing data created in a spreadsheet or database package, by entering data directly from the keyboard, or by specifying a proprietary data file provided with the software. Some mapping packages only allow keyboard entry of data in some cases, all data must be read from a manufacturer supplied proprietary data base. Mapping packages that do not allow keyboard entry of data and do not allow data to be entered using a file created in a separate spreadsheet or database package are not recommended. These packages limit the user of data provided in files created by the manufacturer, and do not allow for user- generated data bases.

After specifying the boundary file and data files, the user can specify the number of data ranges and any limits to data ranges for the statistics that are to be displayed on the map. For example, the user may specify that the data be divided into six data ranges, the user may specify that the data be divided into equal frequency ranges, or the user may specify the limits for each data range (1-1000, 1001-10,000, etc.). Different shading patterns or dot patterns are generally available to the user, so that the data range applicable to each geographical unit mapped is denoted by a separate and unique shading. Most packages limit the number of data ranges and shading patterns that can be used per map. More patterns will allow the user greater flexibility.

Printing

After boundary and data input, the next step is drawing the map on the screen and then directing the map to an output file or to a printer or plotter. Most packages can be used on a number of plotters. Not all packages can be used with printers. The user must therefore choose compatible hardware and software. The vendor or manufacturer of the software and hardware can verify compatibility between these two components.

Other Software Considerations

Other features that may or may not be available from a mapping package are enlarging maps, reducing maps, creating dot density maps as well as shaded maps, adding text or labels to maps, and editing boundary files. The features available from each package vary, so the user should inquire about the capabilities and limitations of several packages before choosing one. We recommend choosing a package that has reducing capabilities, and allows the user to create text and add labels.

The cost of any software package varies by geographical area of the country and by the vendor supplying package. Most micro-computer mapping packages which meet the demands for the screening analysis cost between $400 and $800.

Hardware

A goal of this project was to design a management tool, or screening analysis, that could be run on a desktop or personal computer. All the software mentioned above runs on a personal computer, either an IBM PC or a PC compatible. There are mapping systems available for mini or mainframe computers. However, the focus of our analysis is for the design of a PC program.

We recommend that the user attain an IBM XT or AT model computer or compatible if possible. Most micro-computer mapping software will run on an IBM PC, however it will run very slowly. The XT and AT models greatly increase the computational speed and the drawing speed of any software package. If the user must use an IBM PC, most software manufacturers recommend the purchase of a math coprocessor for increased computational speed. In fact, some mapping software requires a math coprocessor. A math coprocessor is a simple computer chip that sits on the main board of the computer. It is very easy to install, and costs approximately $200.

Another great advantage of using an IBM XT or AT, is the ability to store and run the software from a harddisk. most mapping packages use four or five floppy disks. Running the package on a PC requires a great deal of disk swapping between program routines. Data must also be stored on a floppy disk if a PC is used. Using an XT or AT computer allows the user to store the program and the data on the computer's harddisk. Running the program from a harddisk makes program and data retrieval and writing faster and much more convenient. The user does not have to change disks every time a new routine is envoked.

In order to make hard copies of the maps or data files created with the mapping system, the user must have a pen plotter or a printer connected to the computer. As mentioned in the discussion of mapping software, most mapping software packages support a wide range of plotters, some do not support printers. If the output device is limited to one already in use at the office or agency, the software package must be compatible with that device. We recommend calling the vendor or manufacturer of the software prior to purchasing it to be sure that the output device is supported by the software. Some software may support a given printer, but the quality, or resolution, of the graphics may be less than satisfactory. Again, the user should check with the vendor or manufacturer before purchasing the software. For top quality graphics or maps, we recommend a pen plotter. Most pen plotters provide good resolution graphics and allow the user to produce color maps. Most printers are restricted to black and white output.

APPENDIX D

SENSITIVITY ANALYSIS OF DRASTIC

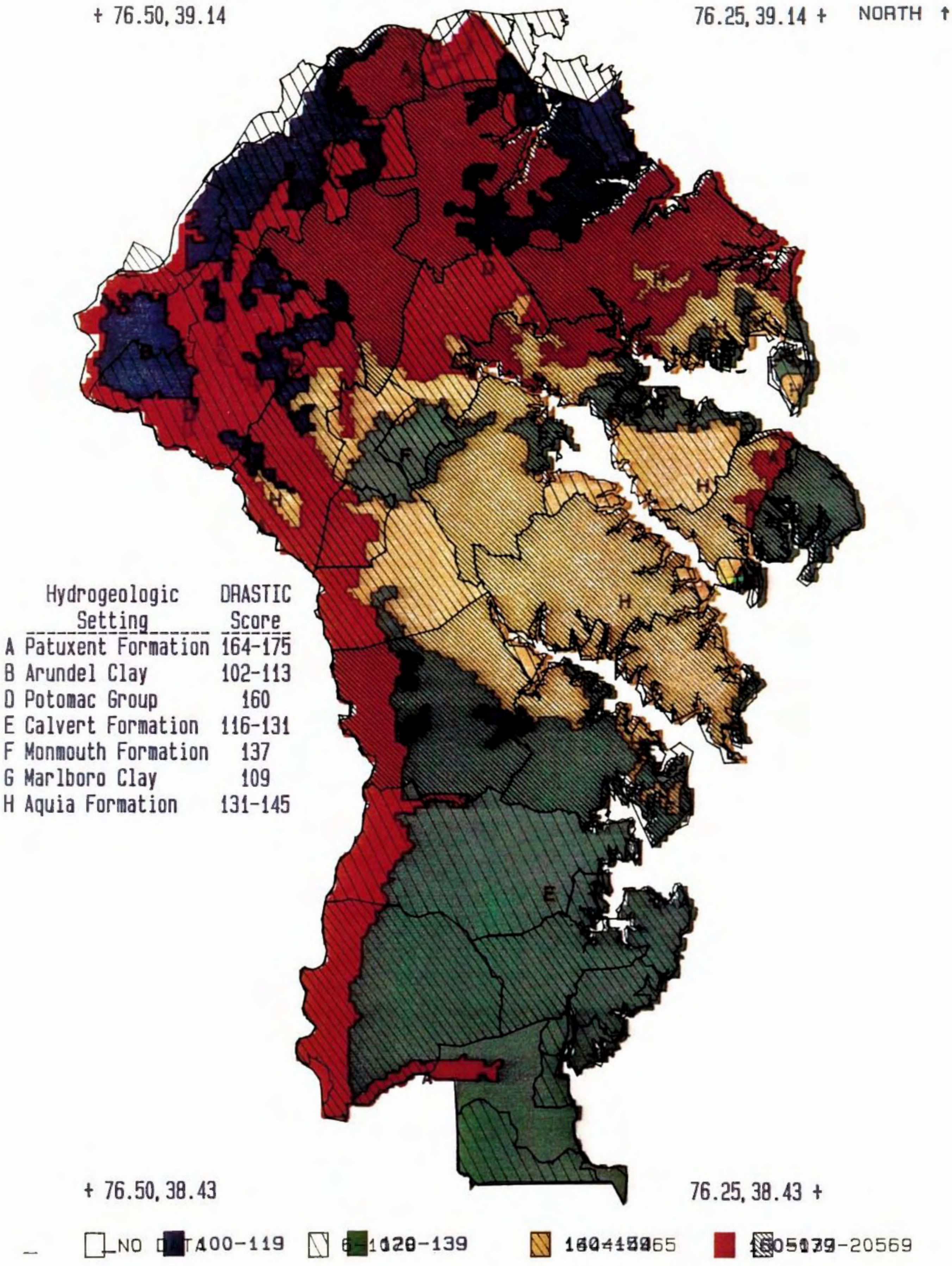
The DRASTIC report notes that net recharge, soil, and topography are "of lesser importance for potential pollution evaluations" for USTs because of their location below ground. The DRASTIC report does not discuss adjustment of these factors for this lessened importance, and rather states that "weights may not be changed for any of the DRASTIC factors...(A)ny changes will make the system invalid." Because of this caution, we did not adjust any DRASTIC factors for this study.

As a sensitivity analysis, we did recalculate the DRASTIC scores using only Depth to groundwater, Aquifer media, Impact of the vadose zone, and hydraulic Conductivity (DAIC). In comparing the rank of the hydrogeologic settings, we found that they changed only slightly when net recharge, soil, and topography are not considered.

	Factors Considered			
	Drastic		DAIC	
Hydrogeologic Setting	Median Score	Rank	Median Score	Rank
A	169.5	1	116	1
B	107.5	13	54	12,13
C	151.5	3	100	3,4
D	160	2	103	2
E	123.5	7	68	7
F	137	6	86	6
G	109	10,11,12	56	11
H	138	5	89	5
I	147	4	100	3,4
II	109	10,11,12	54	12,13
III	114	8	65	9
IV	109	10,11,12	60	10
V	103	14	46	14
VI	112	9	67	8

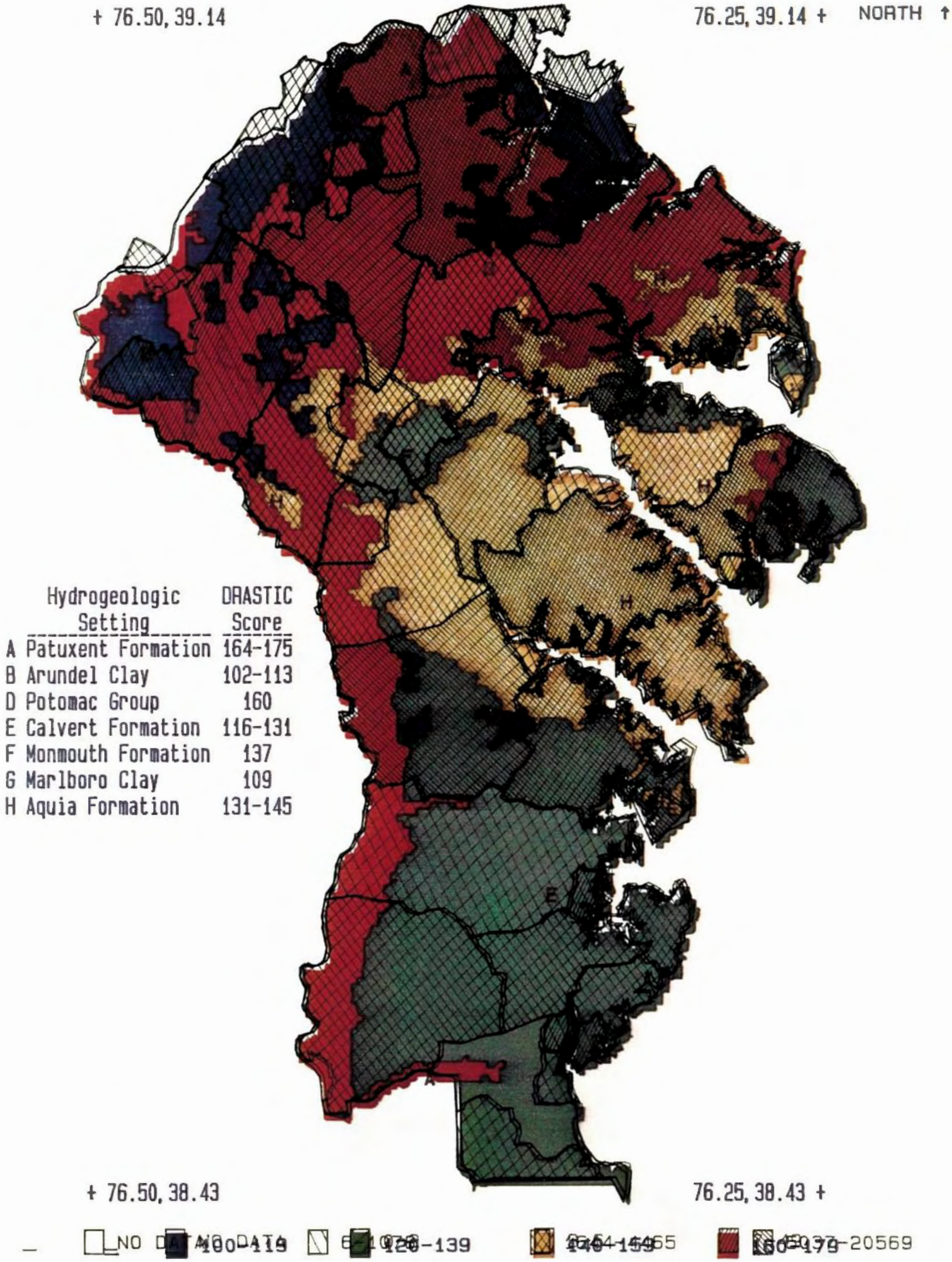
*U.S. Government Printing Office : 1988 -516-002/80039

WELL-DEPENDENT POPULATION (PERSONS/SQ.MI)
BY ZIP CODE, ANNE ARUNDEL COUNTY, MARYLAND

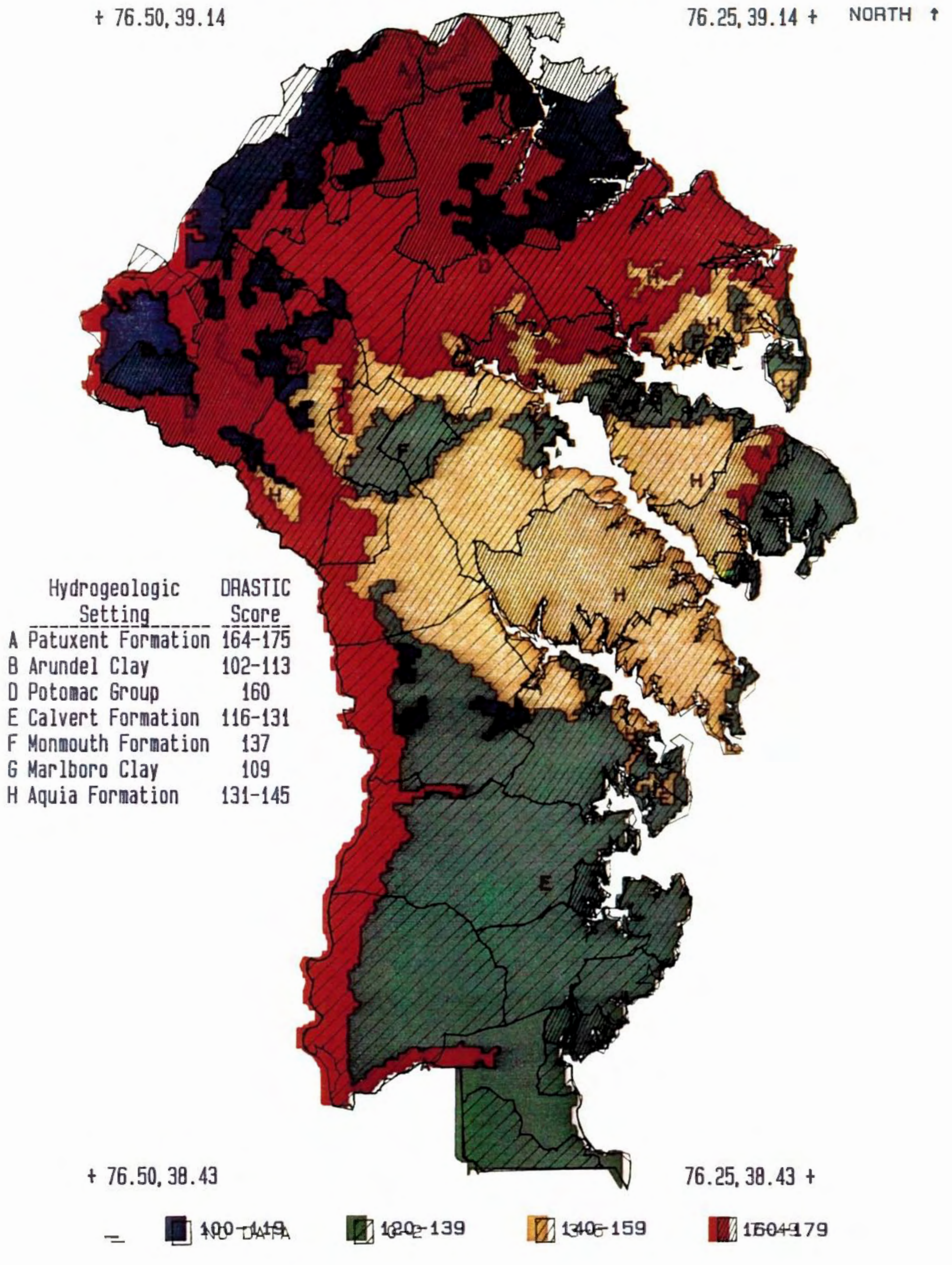


WELL-DEPENDENT POPULATION (PERSONS/SQ MI)
BY ZIP CODE, ANNE ARUNDEL COUNTY, MARYLAND

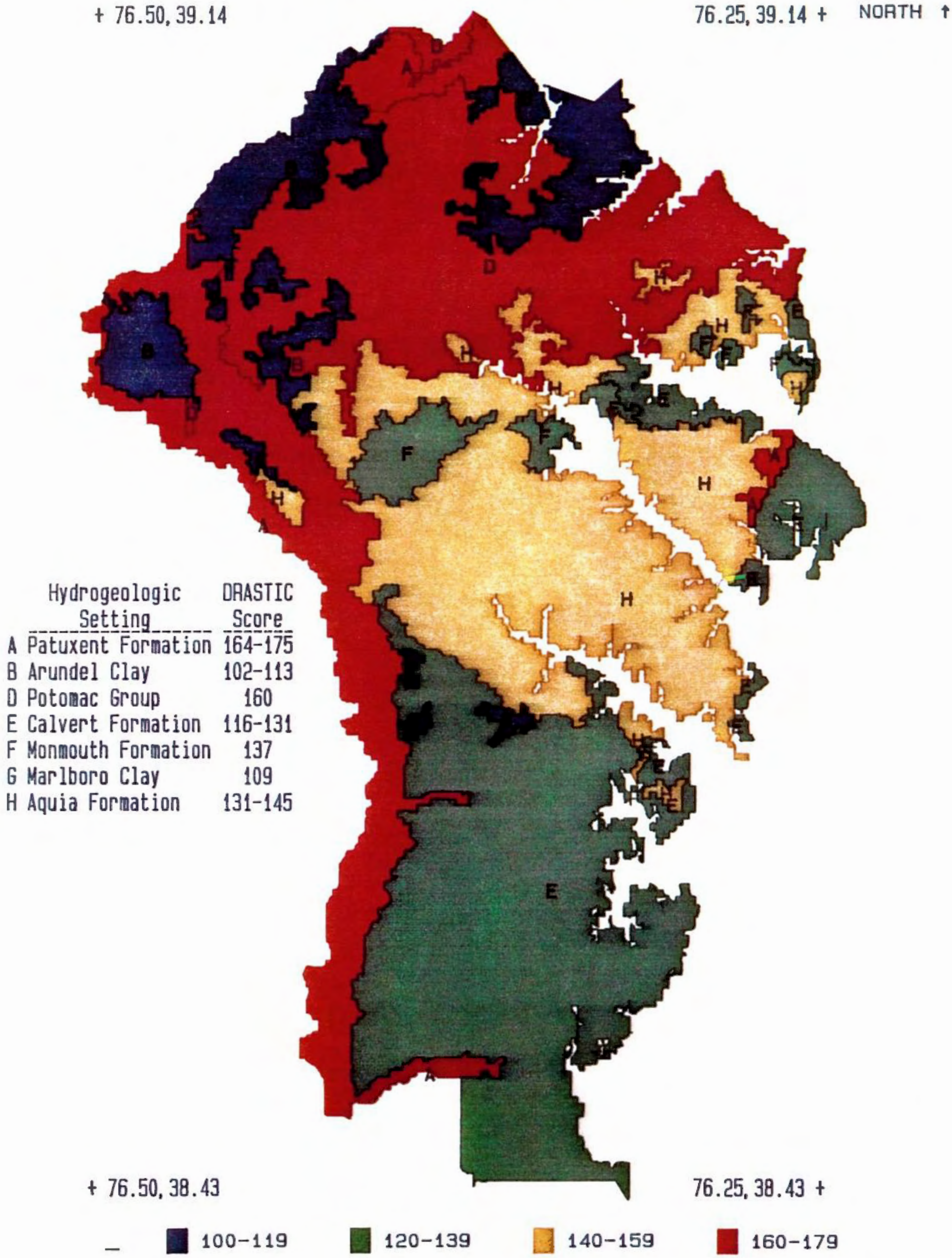
GROUNDWATER POLLUTION POTENTIAL
ANNE ARUNDEL COUNTY, MARYLAND



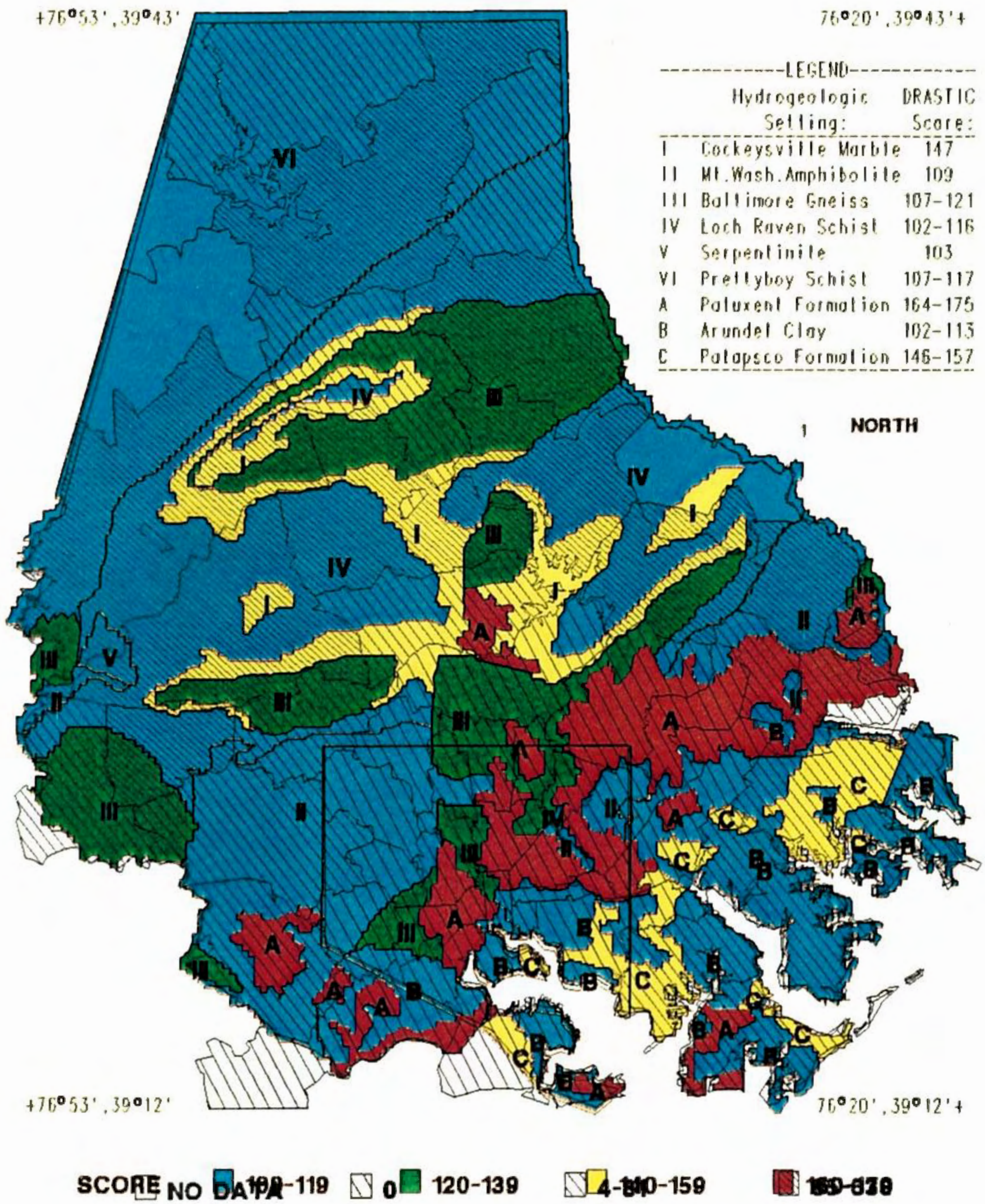
GROUNDWATER POLLUTION POTENTIAL
ANNE ARUNDEL COUNTY, MARYLAND

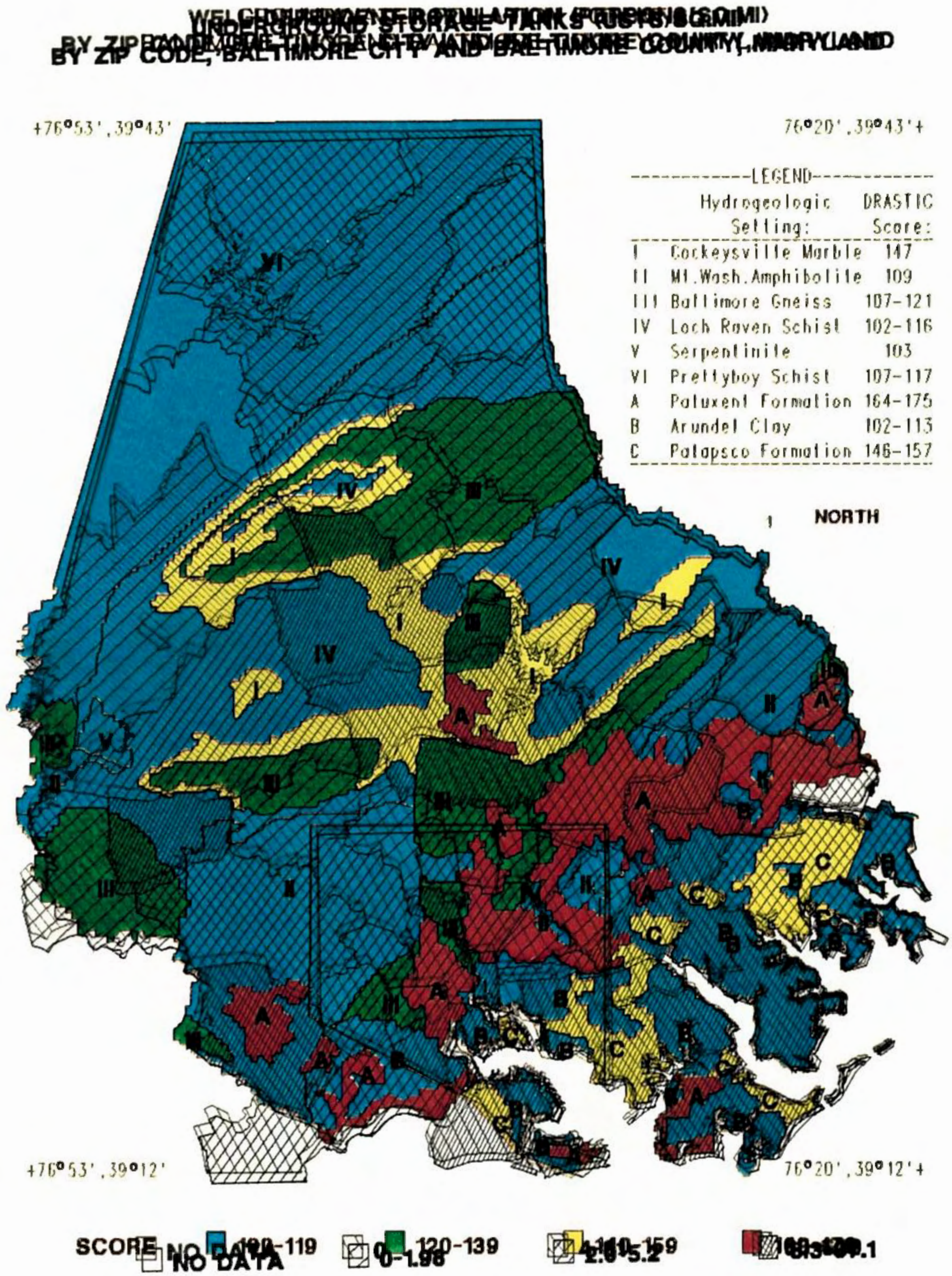


GROUNDWATER POLLUTION POTENTIAL
ANNE ARUNDEL COUNTY, MARYLAND

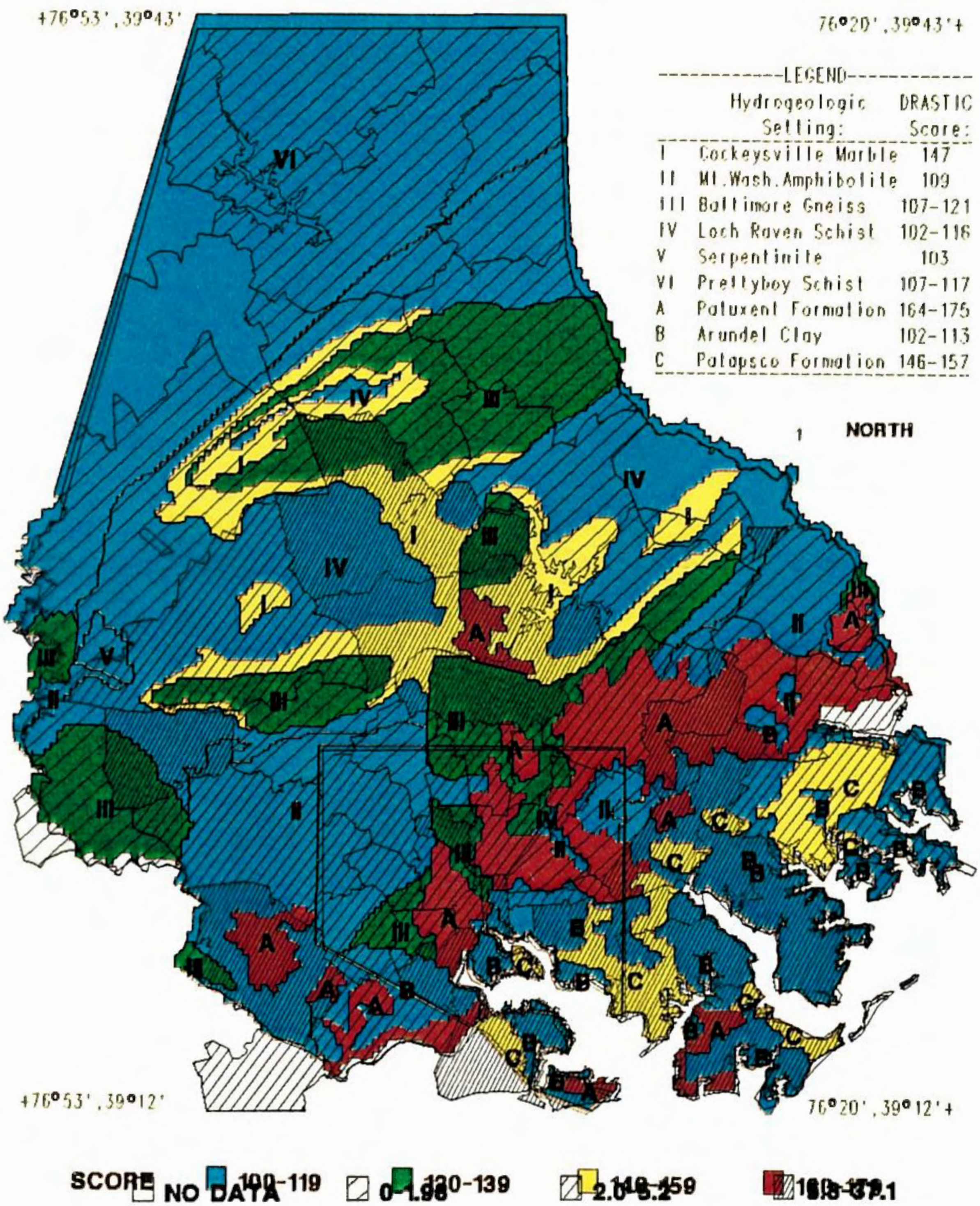


WELL DEPENDENT POPULATION (PERSONS/SQ.MI)
BY ZIP CODE, BALTIMORE CITY AND BALTIMORE COUNTY, MARYLAND

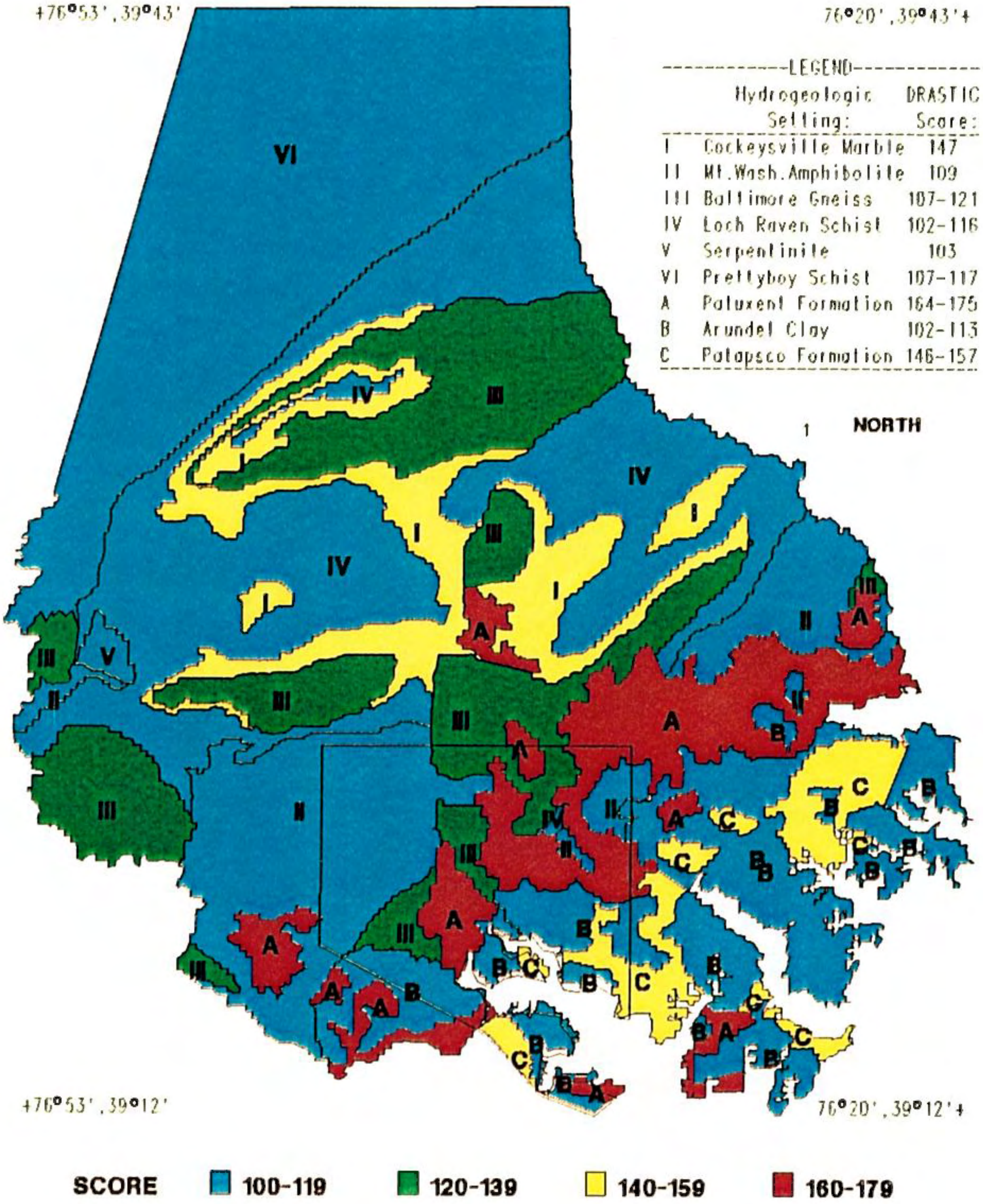



UNDERGROUND STORAGE TANKS (USTS/SQ.MI)
BY ZIP CODE, BALTIMORE CITY AND BALTIMORE COUNTY, MARYLAND
+76°53',39°43'
76°20',39°43'+
LEGEND
Hydrogeologic Setting: DRASTIC Score:
I Cockeysville Marble 147
II Mt.Wash.Amphibolite 109
III Baltimore Gneiss 107-121
IV Loch Raven Schist 102-116
V Serpentinite 103
VI Prettyboy Schist 107-117
A Patuxent Formation 164-175
B Arundel Clay 102-113
C Patapsco Formation 146-157
NORTH
+76°53',39°12'
76°20',39°12'+
SCORE
NO DATA
120-139
0-1.96

UNDERGROUND STORAGE TANKS (USTS/SQ.MI) BY ZIP CODE, BALTIMORE CITY AND BALTIMORE COUNTY, MARYLAND



GROUNDWATER POLLUTION POTENTIAL
BALTIMORE CITY AND BALTIMORE COUNTY, MARYLAND



Talking points (Maps)

1. Digitizing maps:
   - -Originally used MAX-PC and small ditigizer (polygon data sets)
   - -For Final used GS-MAP with Calcomp digitizer at Maryland Geological Survey with IBM-PC

2. Zip Code boundary files used for UST and groundwater maps

3. Developing and printing maps:
   - -line segments to polygons
   - -labels in centers
   - -printed on HP and Calcomp, switched to ink jet
   - -sizing, projection
   - -xeroxing

4. Macintosh for producing maps:
   - -We used MacPaint to produce B&W maps
   - -Some Mac programs can produce maps in color
   - -Much cheaper if you don't need large maps