A Master Conceptual Model for Hydrogeological Site Characterization in the Piedmont and Mountain Region of North Carolina

A Guidance Manual

North Carolina Department of Environment and Natural Resources
Division of Water Quality
Groundwater Section

Prepared for the Groundwater Section

by

Harry E. LeGrand, Sr.
Independent Hydrogeologist

2004
Preface

Contrary to prevailing thoughts and practices, much knowledge about groundwater conditions at almost any site in the Piedmont and Mountain Region of North Carolina can be developed for practical use before new data are collected. Bringing into focus some useful knowledge gained and recast from past studies can offer optimal value in virtually seeing much of what is underground at any place. This manual attempts to demonstrate that interested persons can gain knowledge quickly at an early stage of investigation.

Groundwater in the Piedmont and Mountain Region of North Carolina occurs in a complex underground environment that is difficult to understand and explain. Adding to the complexities is a variety of reactions that occur as water is withdrawn from wells or as man modifies the natural settings. It is not surprising that in many cases some problems and serious consequences of human actions occur before useful knowledge can be applied.

Groundwater occurs almost everywhere throughout the Region, not in a single, widespread aquifer, but in thousands of local aquifer systems and compartments that have similar characteristics and are hydraulically connected. Interspersed among water-supply wells are at least an equal number of waste sites or contaminated zones beneath land surface. Some environmental problems are known to exist. Others are unrecognized and may reach serious proportions. Wherever activities involving groundwater exist, there are likely degrees of concern about problems that could occur. Unanswered questions prevail.

Trying to sort out favorable and unfavorable actions related to groundwater is essential, but elements of contrariness are commonly involved in considering actions and reactions. For example, relatively low-yield wells on nearly flat, populated uplands in the Piedmont tend to compete for space under ground with nearby waste sites and contamination zones. High-yielding wells are more likely in adjacent, low topographic positions, but are likely to be inconvenient for human use and may be in the path of contaminated groundwater from upland areas. The opposite conditions occur in the Mountains, where the population and groundwater activity are chiefly in the valleys. Striving for favorable conditions in the environmental mix with unfavorable conditions places constraints and limitations on proper human actions and decisions. Some types of constraints and serious undesirable consequences have not been fully studied. Ideal regulatory measures are difficult to achieve.

Rather than trying to focus on solving specific problems, this manual puts forward some key generalizations, or scientific rules of thumb that should help interested persons gain a basic understanding of some groundwater features common to the Region. In doing so, the report brings into play many useful, imprecise statements that are difficult to express with precision-oriented approaches. The proposed methodology should enable an investigator to forge ahead at the earliest opportunity with the best information available.

Many useful studies of the Region have been made, but they have not completely jelled in a form for widespread use. In spite of misgivings and shortcomings, we attempt to improve overall knowledge of many groundwater activities and problems in the Region.
The manual is written in common narrative language without quantitative values and equation-based expressions. Although planned chiefly for groundwater specialists, much information should be understandable and useful to others. The manual contains concise, synthesized scientific information that can be expanded by logical reasoning. The typical local system can serve as a generic, or master, conceptual model for all other local systems without the need to collect new data at each locality during the early stages of study. Good reasoning and expressions in narrative language are stressed.

How are benefits derived from use of this manual? Study of the manual and reasoning from the generalizations should offer some useful information. By using the methodology a trained groundwater specialist can prepare a reliable early-stage report of conditions for a setting in a brief period of time, at little or moderate cost, without relying on specific data. This needed approach has been lacking. In spite of an assertion here that more good information can be readily disclosed, modesty is almost everywhere needed because knowledge about the groundwater system must be expressed in imprecise and qualified terms. Inherent vagueness and uncertainty can be reduced readily but rarely eliminated.

Harry E. LeGrand, Sr.
February 2004
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td>ii</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>2</td>
</tr>
<tr>
<td>Use of Generalizations and Connecting Inferences</td>
<td>2</td>
</tr>
<tr>
<td>Benefits of Conceptual Model Application</td>
<td>3</td>
</tr>
<tr>
<td>Description of the Region</td>
<td>4</td>
</tr>
<tr>
<td>Physiography</td>
<td>4</td>
</tr>
<tr>
<td>Geology</td>
<td>5</td>
</tr>
<tr>
<td>Hydrogeology</td>
<td>5</td>
</tr>
<tr>
<td>The Master Conceptual Model</td>
<td>6</td>
</tr>
<tr>
<td>Key Generalizations</td>
<td>8</td>
</tr>
<tr>
<td>Generalizations Associated with Natural Conditions</td>
<td>8</td>
</tr>
<tr>
<td>Generalizations Associated with Conditions Imposed by Humans</td>
<td>23</td>
</tr>
<tr>
<td>Model Procedures and Application</td>
<td>28</td>
</tr>
<tr>
<td>Case 1</td>
<td>29</td>
</tr>
<tr>
<td>Case 2</td>
<td>30</td>
</tr>
<tr>
<td>Conclusions</td>
<td>30</td>
</tr>
<tr>
<td>Bibliography</td>
<td>32</td>
</tr>
<tr>
<td>Glossary</td>
<td>36</td>
</tr>
</tbody>
</table>

### Figures

1. Physiographic provinces in North Carolina. ........................................ 4
2. Diagram showing the principal components of the groundwater system in the Piedmont and Mountain Region of North Carolina. ....................... 6
3. Diagram showing a conceptual view of the groundwater flow system in the Piedmont and Mountain Region of North Carolina. ....................... 7
4. Diagram showing some inter-relationships of key generalizations ........ 9
5. Distribution of annual precipitation in North Carolina. .................... 11
6. Diagram showing the relative storage and transmission capabilities of the Piedmont and Mountains groundwater system. ......................... 12
7. Hydrograph of USGS observation well NC 146, Mecklenburg Co., NC, for the 2002 water year................................................................. 13
8. Slope-aquifer systems (A, B, and C) delineated on the USGS (1987) 7.5 minute Harrisburg Quadrangle topographic map.................................. 15
9. Conceptual view of double slope-aquifer system and included compartments................................................................. 16
10. Topographic map showing fracture controlled tributaries of Rocky River, Stanly, and Cabarrus Counties, NC......................................... 20
11. Idealized cross-section showing hydraulic head relationships in recharge and discharge areas.................................................................21
12. Well-yield probability graph .........................................................................................................................26
13. Schematic diagram showing the areal extent and direction of movement of a hypothetical contaminant plume. ........................................................................27

Tables

Table 1. Comparison of natural chemical constituents of groundwater from acidic (granite) and basic or intermediate rocks (diorite) in the Piedmont and Mountain Region, North Carolina. ...........................................23
Table 2. Site topographic ratings. .........................................................................................................................25
Table 3. Soil-thickness rating table..................................................................................................................26

Appendix

A-1 Site Evaluation Matrix
A-2 Site Evaluation Worksheet
A-3 Site Evaluation Inventory
Introduction

Public and private interests have directed much effort, often at great cost, toward the study and application of remedies to existing and potential groundwater related problems in the Piedmont and Mountain Region of North Carolina. Yet, these efforts represent only a small fraction of the problems, potential problems, and concerns that prevail. A better distribution of work and funding is critically needed, and a greater understanding of groundwater conditions in the region is required for proper management of groundwater related issues. A method of developing an early-stage conceptual model of key groundwater conditions is needed.

The purpose of this manual is to present a new method to help interested persons understand groundwater conditions in the Region. A challenge to any method is the fact that the geologic settings in the Region are very complex. The proposed method relies on extensive use of conventional language and reasoning to develop an understanding of site groundwater conditions without the collection of new data. The manual is planned chiefly for use by groundwater specialists but should benefit interested non-professionals as well.

It may seem strange that the method is designed for both specialists in groundwater and others having limited knowledge of the science. The narrative language and reasoning allows the interested individual to assemble bits of information, sort, and integrate them to develop a reasonable picture of various groundwater conditions. For example, using the conceptual model, one may observe a nearly flat wetland and reason that the water table is near land surface, and that the wetland is underlain by relatively impermeable material, such as clay or poorly fractured rock.

By using this manual groundwater specialists can broaden their reasoning power to see how many factors interplay to form a reasonable, preliminary conceptual model. The specialists should be able to express the results of their reasoning in narrative language, which can be more understandable than mathematical and technical language. The specialists should be able to prepare a two- to five-page informal report of conditions at a site that approximates the state-of-the-art understanding. LeGrand and Rosen (2000) refer to this type of report as a Prior Conceptual Model Explanation (PCME).

At the core of the method are 25 key statements, or generalizations, that encapsulate much needed knowledge and from which many useful inferences may be generated. The generalizations are somewhat similar to laws of other sciences, such as physics and chemistry, although, by correctness and necessity, they are not universal in application but are expressed in imprecise and qualified terms. Their value lies in their interrelationship and associated inferences, which often results in the creation of more knowledge. The key generalizations and inferences derived from them constitute the master conceptual model.
Although many excellent studies of groundwater in the Region have been conducted, they typically provide specific data and expansive information about local sites and areas. Though helpful, they may not be adequate for public needs. The prevailing effort and mindset has been to put early emphasis on the collection of new data for processing by precision-oriented mathematical methods and routine interpretations. The process is commonly directed from an arena of rigid regulatory procedures. Being time consuming and costly to varying degrees, studies and investigations relying on this process can only cope with a small fraction of the problems and questions needing attention.

To some extent, the mathematical approach is based on the assumption that the computational results of data from the Piedmont and Mountain groundwater system are equivalent to the results derived from data from porous, granular aquifer material, such as is typical of the Coastal Plain. This precision-oriented approach can be pretentious or misleading when applied to the complex geology of the Region. Moreover, this approach is difficult to understand for those not trained in hydrogeology. Thus, the distribution of useful information to the public has been limited. In this manual, the main effort is directed toward making optimal use of imprecise information.

Missing from the work being done is a knowledge base that can be widely applied. The method proposed here derives optimal value from past experience and knowledge for application at an early stage in the evaluation of a site.

Acknowledgements
The author wishes to thank the many members of the North Carolina Department of Environment and Natural Resources, the Raleigh District Office of the U.S. Geological Survey, and Ralph Heath, consulting hydrogeologist, for their assistance in the critical review of this manual. Special thanks are extended to Perry Nelson, who assisted the author throughout the preparation of the manuscript, particularly in confirming the validity of the generalizations and their application. The author also wishes to thank Walter Haven, of the Groundwater Section, for his assistance in the preparation of the manual, and Carl Bailey, Assistant Chief of the Groundwater Section, for his sponsorship and continuing support of the project.

Use of Generalizations and Connecting Inferences
Twenty-five generalizations represent the core of the method by which a broad understanding of the groundwater conditions can be generated. They have been reproduced, with modifications, from a paper (LeGrand, 1992) included in a symposium volume published by Clemson University (Daniel and others, editors, 1992). The generalizations have been developed from many years of study by experienced groundwater specialists and are drawn chiefly from various reports included in the references listed at the end of this document. The generalized statements were developed by a combination of statistical studies, observations, and logical deductive reasoning. The skillful and intensive studies by Charles C. Daniel, III, of the U.S. Geological Survey, in the past two decades have verified almost all of the general statements, as indicated in his referenced published reports. The studies conducted by Ralph Heath have also contributed greatly to the development of the generalizations.
Most of the generalizations are expressed in the form of tendencies because precise information at a particular place is not likely to be known. The generalizations provide a reservoir of background information from which inferences can be exploited for optimal value.

Values of various parameters and factors are needed in the evaluation of a site. Although specific values from measured data have appeal and are needed in quantitative studies, they may not fit in this practical, early-stage method. Rather, the values selected are imprecise estimates from a range of conditions. If the approximate value of one factor is not easily known, connective inferences of the other factors can help to estimate an acceptable value.

Each generalization need not stand alone for routine interpretation. An inference derived from a generalization can be connected to another inference of the same generalization or another associated generalization. For example, a view of a specific topographic setting likely reveals the (1) direction of groundwater flow, (2) concentration or divergence of flow, (3) approximate hydraulic gradient, (4) area of groundwater discharge, (5) depth to the water table at various positions, and (6) inklings of the relative distribution of permeability.

The interplay of cause and effect relations can be compounded and anchored to many generalizations. The generalizations and various inferences can be linked and connected to reveal a true conceptual model. The linkage is not of a decision tree or single-chain type that can be simply weakened or broken. Rather, the linkage is derived from a matrix of various generalizations and inferences that form a pictorial fabric. If one or more inferences do not fit, the situation is re-examined and flagged as an anomaly or error. There can be almost interlocking proof that a conceptual model constructed in this manner is reliable and fairly expansive in broad interpretations.

**Benefits of Conceptual Model Application**

The following benefits may be expected from application of the Master Conceptual Model:

- Assisting in early-stage planning of hydrogeological investigations.
- Screening contamination sites for priority ranking.
- Reducing costs of site studies.
- Assisting in wellhead protection studies.
- Providing information in the early stages of environmental audits and brownfield studies.
- Providing early orientation on possible remedial action.
- Providing a basis for early-stage risk assessments.
• Estimating potential for natural attenuation at groundwater contamination sites.
• Providing insight to prevent purely mechanical interpolation and extrapolation of hydrogeologic information.

Description of the Region

As shown in Figure 1, North Carolina includes parts of three physiographic provinces: the Atlantic Coastal Plain, Piedmont, and Blue Ridge (Fenneman, 1938). All of North Carolina, west of the Coastal Plain, lies in the Piedmont and Blue Ridge Provinces. They include all or part of 65 of the state’s 100 counties and a population of over six million, of which approximately 47 percent rely on groundwater as a source of water supply. The authors have taken the liberty of referring to the two provinces as “the “Region,” and to the Blue Ridge Province as the “Mountains.”

Figure 1. Physiographic provinces in North Carolina.

Physiography

In North Carolina the Piedmont extends from its boundary with the Coastal Plain westward to the escarpment of the Blue Ridge Mountains, a distance of 150 to 225 miles. It is characterized by gently rolling hills rising from a base altitude of about 300 feet above mean sea level at its eastern boundary, to about 1500 feet at the foot of the Blue Ridge escarpment. Topographic relief, from stream valley to ridge top, ranges from 75 to 200 feet. Scattered across the province are remnants of ancient mountains that have resisted erosion and now stand from 500 to 1,500 feet above the surrounding terrain.
The Mountains extend from the base of the Blue Ridge escarpment, west into Tennessee, a distance of from 30 to 120 miles, where they border the Valley and Ridge Province. They comprise an area of rugged, forested slopes rising from an altitude of about 1,500 feet at the base of the escarpment, to over 6,000 feet among the highest mountain peaks. Of the many rivers that drain the mountains, all but three, the Broad, Catawba, and the Yadkin-Peebee, rise on the western side of the eastern continental divide and flow generally northwest towards the Tennessee River. It is interesting to note that the rural population in the Mountains tends to congregate in the valleys, while in the Piedmont, communities are generally found along the ridgelines. From the standpoint of hydrogeology such positioning of rural homes and communities could have important implications.

Geology

The geology of the Region is complex and includes representatives of all of the three main classes of rocks; igneous, metamorphic, and sedimentary. Of these, metamorphic rocks predominate. Among the metamorphic rocks, gneiss, schist and metamorphosed granitic rocks are the most prevalent. Quartzite, slate, phyllite, argillite, and marble are less widely distributed. Intrusive igneous rocks, such as granite, diorite, and gabbro are significant, but account for only about 6 percent of the area (Daniel and Dahlen, 2002). Over geologic time all or part of the region has experienced uplift, folding and faulting, alteration, and erosion.

The major rock units occur as northeast trending belts, corresponding to the trend of the regional geologic structure. Four sedimentary basins, formed during the Triassic and Jurassic Periods, occur in a southwest-northeast trending belt across the Piedmont. As this report pertains primarily to areas underlain by igneous and metamorphic rocks, a discussion of the Triassic sediments is excluded.

Throughout the Region, bedrock is overlain by a mantle of unconsolidated material known as regolith. The regolith includes, where present, the soil zone, a zone of weathered, decomposed bedrock known as saprolite, and alluvium. Saprolite, the product of chemical and mechanical weathering of the underlying bedrock, is typically composed of clay and coarser granular material up to boulder size, and may reflect the texture of the rock from which it was formed. Thus, the weathering product of granitic rocks may be quartz-rich and sandy-textured, whereas rocks poor in quartz and rich in feldspar and other soluble minerals form a more clayey saprolite. Alluvial and terrace deposits are generally restricted in area and thickness and represent a very small fraction of the geology of the region.

Hydrogeology

The main characteristics of the hydrogeology of the Region are highlighted in the lists of generalizations found on later pages.

The groundwater system in the region is essentially a two-part system (Figure 2) comprised of the regolith and the underlying bedrock.
The regolith, which may have a porosity ranging from 35 to 55 percent (Heath, 1980), serves as the principal storage reservoir for the underlying bedrock. Precipitation infiltrates the regolith until it reaches the saturated zone, typically in saprolite, where it is stored as groundwater in inter-granular pore spaces. Where saprolite is very thin, the saturated zone may be entirely contained in fractured bedrock.

In many locations, the regolith includes a transition zone between saprolite and fractured bedrock. The transition zone consists of coarse fragments of partially weathered bedrock and lesser amounts of saprolite (Daniel and Dahlen, 2002).

Some groundwater moves through the regolith and into interconnected fractures in the underlying bedrock while another component flows through the regolith parallel to the bedrock surface (Figure 3). The destination of both components is an area where groundwater discharges as seepage into streams, lakes, or other surface water bodies, and also as evapotranspiration in lowland areas.

Figure 2. Diagram showing the principal components of the groundwater system in the Piedmont and Mountain Region of North Carolina. (from Harned and Daniel, 1992)

**The Master Conceptual Model**

In the event of groundwater contamination, or threat of contamination, it is imperative to assess rapidly the effect on groundwater users and inform them of the nature and severity of the
incident. In the likely event that multiple incidents compete for attention, priority must be determined swiftly in order to minimize the threat to human health and the environment.

The Master Conceptual Model is designed to create a plateau of knowledge of the hydrogeology of the Region in the early stage of site characterization, not dependent upon acquisition of new data. The model thus developed establishes a sound foundation for more detailed studies and provides an early indication of site vulnerability and sensitivity.

Fortunately, significant knowledge exists concerning the occurrence and movement of groundwater in the Piedmont and Mountain Region. From this body of knowledge, certain conclusions have been reached regarding the groundwater system. Where individual sites have geologic and terrain characteristics in common, conclusions concerning groundwater conditions may be drawn that are applicable to most sites sharing those features. These common characteristics are referred to as “generalizations.”

![Diagram showing a conceptual view of the groundwater flow system in the Piedmont and Mountain Region of North Carolina](image)

Figure 3. Diagram showing a conceptual view of the groundwater flow system in the Piedmont and Mountain Region of North Carolina. (from Daniel, 1990)

Armed with a foreknowledge of conditions affecting a site, it is possible to develop a rational estimate of site conditions before the first test boring is advanced, allowing specific additional data needs to be defined more accurately and acquired at the least cost and in the most timely manner.
Key Generalizations

A generalization may be defined as an inductive conclusion stating that something is true about all or some members of a class. Some generalizations, such as in Darcy’s law, are considered universal, and are applicable in almost all situations. Many universal generalizations are derived directly from physics and chemistry and can be translated into mathematical form for application. Non-universal generalizations, such as those offered herein, have their basis in empirical knowledge derived from decades of field observations by trained investigators. They may be applicable in every conceivable geologic setting and are necessary for proper interpretation and expression.

Generalizations may be used in the absence of typical site-specific data such as soil borings, test wells, cores, and geophysical surveys, to establish a reasonable level of knowledge about a site. On the strength of that knowledge, decisions may be reached regarding such factors as water-table depth, direction of groundwater flow, hydraulic gradient, recharge potential, and groundwater vulnerability. The generalizations may form the foundation for locating and designing monitoring wells, as well as production or recovery wells, and may indicate the need for the provision of alternative water supplies to local users.

It is important to understand that the generalizations presented in this report have limitations in their application and, in many circumstances, must be augmented with traditional investigative methods, such as drilling or geophysical technology.

The following generalizations, grouped into those associated with natural conditions and those resulting from man’s activities, are directly applicable to the Piedmont and Mountain Region. Most of the generalizations associated with natural conditions are products of geologic processes and are interrelated in varying degrees (Figure 4).

Generalizations Associated with Natural Conditions

The following generalizations are associated with natural conditions. Additional commentary follows the generalizations where appropriate.

N-1. ROCK TYPES

Igneous and metamorphic rocks are closely interspersed throughout most of the Region. Geologic maps at various scales show the distribution of rock types, which tend to have locally erratic outcrop and subsurface distribution patterns, but regionally trend generally northeast-southwest. Although the igneous rocks are predominantly granite, subordinate amounts of diorite and gabbro are widespread. Metamorphic rocks, chiefly gneiss and schist, are common and tend to be folded and faulted extensively. Argillites occur extensively in the southeastern Piedmont.

As the bedrock is characterized by fracture-type permeability,
some general knowledge of the fracture characteristics of the predominant rock type in a specific area or site is desirable. Fortunately, indirect evidence of the degree of fracturing of a particular rock may be derived from terrain analysis, chiefly soil thickness and topographic expression. In most places, massive granite and gabbro have thin soils and are poorly fractured, whereas gneiss and schist have thicker soils and moderate to relatively high fracture densities.

![Diagram showing some interrelationships of key generalizations.](image)

Figure 4. Diagram showing some interrelationships of key generalizations. Arrows indicate significant influence of one characteristic (generalization) on others. Numbers in parenthesis correspond to numbered generalizations in text.

As igneous and metamorphic rocks have little or no primary porosity, their importance as sources of groundwater is dependent upon the extent to which they have developed, or have the potential to develop, secondary porosity in the form of fractures and solution openings. Daniel (1989) developed a hydrogeologic classification based on the origin, composition and texture of rocks and their water-bearing potential. His statistical analysis of 4,815 wells (excluding those in the Triassic basins) indicated that the highest average yields occurred in wells constructed in schist, phyllite, and undifferentiated metavolcanics. Lowest average yields occurred in argillite and metavolcanic tuffs.
N-2. **SOIL–SAPROLITE**

Soil and soft, highly weathered rock, known as saprolite, overlie bedrock in most places. The soil-saprolite and the underlying fractured bedrock represent a composite water-table aquifer system. There are no underlying aquifers. The thickness of the soil-saprolite zone varies according to the type of parent rock, topography, and geologic history. Saprolite thickness ranges from zero to as much as 100 feet in some places. In the Piedmont, the zone is usually thicker beneath broad upland areas than in valleys. In the Mountains, ridge tops and upper slopes generally have thin soil-saprolite zones due to the resistant nature of the underlying, ridge-forming bedrock. A soil-saprolite zone only a few feet thick may suggest poorly fractured rocks below, especially in the Piedmont.

A transition zone of partially weathered rock may occur at the base of the regolith between the soil-saprolite and unweathered bedrock (Stewart and others, 1964; Nutter and Otten, 1969; Harned and Daniel, 1992). A transition zone is a zone of relatively high permeability resulting from incomplete mechanical and chemical alteration of the bedrock. It may be composed of rock fragments of varying size, depending upon the composition of the parent rock, and generally contains less clay than the overlying saprolite. The transition zone may serve as a zone of rapid flow within the fractured rock system and may also be a conduit for the transmission of contaminated groundwater to a well or other point or area of discharge. The concept of the transition zone is useful in distinguishing between distinctive soil-saprolite and unweathered bedrock. The zone may thicken and thin within short distances, and upper and lower boundaries may be difficult to identify. Thus, establishing a reasonable thickness or the degree of permeability within an area of a few acres is arbitrary. Figure 2 illustrates the relationship between the transition zone, soil-saprolite, and bedrock.

N-3 **TOPOGRAPHY**

The topography of the Piedmont is characterized by hills and valleys; the hills commonly having gentle, rounded slopes. A close network of perennial streams prevails, and in most inter-stream areas a perennial stream is within 3,000 feet. The topography of the Mountains is more rugged, and typified by steep, forested slopes.

Subtleties or extremes of terrain and vegetation may limit visual analysis of site physiography. A topographic map reveals in detail the arrangement of landscape features such as surface water bodies, hills, ridges and valleys, slope steepness, population centers, and isolated structures. It also may provide evidence of land-use practices and geological features such as rock type and bedrock fractures. A topographic map of a scale of 1:24,000, or larger, is essential to a preliminary site evaluation using the conceptual model. The evaluation of some sites may be improved by enlarging a
1:24,000 map to 1:6,000 scale. The maps may also be used to determine the direction of groundwater movement and provide estimates of water table depth and velocity of groundwater movement.

**N-4 PRECIPITATION**

*Precipitation, the source of groundwater recharge, averages 3.0 to 3.5 inches per month in the Piedmont and 4.0 to 4.5 inches per month in the Mountains. Extreme variations in precipitation occur locally, especially in the southwestern Mountains where more than 80 inches per year has been recorded.*

As shown in Figure 5, annual precipitation ranges from less than 40 inches per year in the central Piedmont to more than 80 inches per year in the southwestern mountains (Daniel and Dahlen, 2002).

In much of the Region the annual distribution of precipitation is fairly even throughout the year; yet, the three- or four-inch average monthly precipitation can be misleading. Droughts and floods are common. Droughts tend to reduce greatly groundwater storage in the soil-saprolite zone to the extent that many wells may produce less water or fail completely. Also, a decline in groundwater discharge to streams and lakes during droughts severely affects surface-water supplies. During periods of excessive precipitation, the high stage of the water table can flood some buildings and adversely affect certain human activities.

![Figure 5. Distribution of mean annual precipitation in North Carolina. (isohyetal lines in inches)](image)

**N-5 GROUNDWATER OCCURRENCE**

*Groundwater occurs in two contrasting media: (a) clayey, granular soil-saprolite that typically becomes less clayey with depth and (b) underlying...*
fractures and other planar openings in bedrock (Figure 2). The soil-saprolite zone is capable of storing water readily, but transmits it slowly. In contrast, the bedrock fracture system has a relatively low storage capacity but is capable of transmitting water readily where interconnecting fractures occur (Figure 6).

Figure 6. Diagram showing the relative storage and transmission capabilities of the Piedmont and Mountain groundwater system. (modified from Heath, 1984)

The extent to which bedrock functions as a source of water supply to wells depends upon precipitation, the permeability and saturated thickness of the overlying regolith, and the density and interconnection of bedrock fractures. Because igneous and metamorphic rocks consist of interlocking crystals, primary porosity is very low, generally less than three percent. Secondary porosity of crystalline bedrock results from weathering and fracturing and generally ranges from one to ten percent (Freeze and Cherry, 1979) but according to Daniel and Sharpless (1983), porosity values of from one to three percent are more typical. Daniel (1990) reported that the porosity of the regolith ranges from 35 to 55 percent near land surface but decreases with depth as the degree of weathering decreases.

N-6 DEPTH OF WATER TABLE

The water table is near land surface in valleys and as much as 30 to 50 feet below land surface beneath hills. The range of seasonal fluctuation of the water table is as little as two feet in valleys, but may exceed ten feet beneath hills.

Although precipitation is relatively evenly distributed throughout the year, the water table fluctuates noticeably, rising during the winter to an annual high in April or May, and declining steadily during the summer and fall as a result of evapotranspiration (Figure 7).
During the coldest months of the winter and early spring, a lack of evaporation and plant use allows water levels to recover.

N-7  WATER TABLE CONFIGURATION

Streams are linear “lows” in the water table, representing the intersection of the water table and the land surface. Under natural conditions the topography of the water table is crudely similar to that of the land surface, but has less relief (Figure 3).

One may construct synthetic water-table maps without water-table measurements from wells by using USGS 7.5 minute topographic maps scaled at 1:24,000. If possible, the map scale should be increased to 1:12,000 or greater. The maps may be constructed by extrapolating upward from the known elevations along the course of a perennial stream (the points at which topographic contours cross streams) to the hilltop, where the water table is likely to range from 30 to 50 feet below land surface. Water-table contours connecting points along stream courses should be drawn roughly parallel to the topographic contours, but with less intricate curvature. As groundwater moves in the direction of decreasing head, and at right angles to the water-table contour lines, one can approximate the general direction of groundwater flow from the surface topography.

N-8  RECHARGE AND DISCHARGE

Most recharge and discharge is through porous granular material (clayey soil-saprolite or floodplain deposits), but much of the intermediate flow between recharge and discharge areas is through bedrock openings. Recharge occurs chiefly on upland areas and slopes, while discharge is concentrated in lowland areas bordering surface water bodies, marshes, and floodplains. Natural discharge from fractures into a surface body of water is common. Evapotranspiration is a significant part of the natural discharge. Although not easily quantifiable, evapotranspiration is
especially high in lower parts of draws and from flood plains, especially at high stages of the water table.

On reaching the water table, groundwater flow paths vary greatly in length, depth, and travel time to areas of discharge, depending upon local hydrogeologic conditions. Some moves laterally in the soil-saprolite zone and may remain there until reaching a discharge area. Other paths may be deeper and longer and require groundwater to move erratically through the fractured bedrock and pass again through the soil or alluvium before discharging into a surface stream.

N-9 GROUNDWATER FLOW CYCLE

Groundwater moves continuously toward streams. In transit to an area of discharge, some groundwater is lost to evapotranspiration, especially in valleys; the remainder discharges as small springs and as bank channel seepage into streams. Small springs and seeps are common in draws and other topographic depressions, especially near the base of valleys. Springs and seeps at higher elevations are commonly of the wet-weather type and may suggest poorly fractured rocks below.

N-10 GROUNDWATER FLOW PATH

The path of natural groundwater movement is relatively short. It is almost invariably restricted to the zone underlying the topographic slope extending from a topographic divide to an adjacent stream. Groundwater rarely passes beneath a perennial stream to another, more distant, stream. Thus the concept of a local slope-aquifer system applies. On the opposite sides of an inter-stream topographic divide are two similar slope-aquifer systems, as shown by (A) and (B) in Figure 8. Two similar slope-aquifer systems occur on the opposite sides of a drainage basin (B) and (C).

As described, the region is a network of slope-aquifer systems, the boundaries of which may be arbitrary or indistinct. A double slope-aquifer system can be considered in the vicinity of the groundwater divide at the ridgetop (Figures 8 and 9).

A slope-aquifer system is a unit of the groundwater flow regime that is seemingly separated and free of impact from adjacent, similar units. Commonly, the slope-aquifer system includes smaller hill-and-dale configurations that are observed as topographic “spurs” (ridges branching from a main ridge or mountain crest). Similar undulations, although of lesser amplitude, may also occur in the underlying water table and form important natural groundwater flow-control features. The crests of the water table undulations represent natural groundwater divides within a slope-aquifer system and may limit the area of influence of wells or contaminant plumes located within their boundaries. The concave topographic areas between the topographic divides may be considered as flow compartments that are open-ended down slope.
Figure 8. Slope-aquifer systems (A, B, and C) delineated on the USGS (1987) 7.5 minute Harrisburg Quadrangle topographic map.
Figure 9. Conceptual view of double slope-aquifer system and included compartments.
Each compartment is hydraulically connected to adjacent compartments but has distinct hydrologic characteristics such as flow direction and gradient. Although each compartment is connected hydraulically to adjacent compartments, the water-table divide restricts natural groundwater flow between them. The relation to adjacent compartments is such that if contamination occurs in one, it would not naturally move laterally to an adjacent compartment. Several compartments are approximated in Figure 8. It is important to note that, because of their small size, not all topographic undulations necessarily describe underlying groundwater compartments. Some groundwater divides defining very small compartments may disappear during periods of water table decline.

Within a slope-aquifer system the behavior of contaminated water from a waste site or spill can be reasonably approximated where natural conditions exist. Where the natural flow of contaminated water reaches a cone of depression surrounding a pumping well, it may be expected to move toward the point of groundwater withdrawal. Even after pumping has ceased for months or years, some contaminated water may likely be trapped in fractures where natural groundwater circulation is restricted.

It is possible, although unusual, that an isolated fracture receiving recharge from one slope-aquifer system could extend beneath a boundary stream and intercept, or fall within, the area of pumping influence of a well in the neighboring slope-aquifer. In that case, the pumping well could have a hydraulic affect on the slope aquifer from which the fracture receives recharge, inducing flow toward the pumped well.

By identifying the slope-aquifer systems and their included compartments, and applying the generalizations, many useful deductions may be made regarding groundwater and the affect of human actions on it. As stated in the generalization, the stream, river, or lake serving as the lower hydraulic boundary is distinctive and the upper boundary is normally the topographic divide at the ridge top. The boundary defining the lateral extent of the system may be indistinct and somewhat arbitrary.

**N-11 DEPTH OF CIRCULATION**

The upper boundary of the zone of groundwater circulation, the water table, typically lies in the clayey soil-saprolite zone, except in upland areas of the Mountains where it may be in bedrock. The depth of circulation is difficult to define as it is determined by the presence of interconnected bedrock fractures. Although productive fractures have been penetrated at depths exceeding 700 feet, notably in the mountains, they are more likely to occur above a depth of 300-350 feet below bedrock surface.
The permeability of an aquifer is a measure of its capacity to transmit fluid through its interconnected pore spaces or fractures. Complex geologic features in the Region result in variations in permeability. Three categories of permeability may be considered. The soil-saprolite zone has many features of the low permeability of clays. Where present, the underlying transition zone of prominent, interconnecting fractures has a moderately high permeability. The bedrock, in which fractures typically decrease in number with increasing depth, can be considered also as a zone of low permeability. The aggregate permeability may not be meaningful in many cases, but it affects groundwater movement when wells are pumped. The resulting composite permeability is reflected in the yields of wells and the extension of the cone of depression.

The term “hydraulic conductivity,” normally applied in quantitative studies, is not substituted for permeability in the conceptual model because of its implied mathematical precision.

Fracture systems occur in bedrock almost everywhere in the region. Fractures typically occur in sets, which are often composed of two sets of vertical fractures at approximately right angles to each other, and a third, nearly horizontal, set. In gneiss and schist, the orientation of some joints and fractures tends to parallel the foliation and compositional layering, which are rarely horizontal. In massive rocks, particularly granite, nearly horizontal tension joints often occur in the upper one hundred feet of bedrock.

Many non-horizontal fracture patterns can be traced by observing their topographic expression on the ground or on topographic maps scaled at 1:24,000 (USGS 7.5-min sheets).

Almost invariably, fractures that are not horizontal are represented by depressions in the topography or by an alignment of topographic features such as stream segments. In pursuing the simple fracture technique developed by Mundorff (1948), LeGrand (1952) demonstrated that many fractures are enlarged by dissolution, especially in gneiss and schist containing silicates of calcium. Many of these enlarged fractures underlie draws or linear depressions in surface topography. Draws, representing zones of relatively high permeability in the bedrock, are now considered by most groundwater specialists as favorable indicators of high well yields.
Although high-yielding wells are more common in topographic lows than in uplands, exceptions to this tendency can be attributed to geological history. The erosion of land surface and deepening of valleys over geologic time may have removed pre-existing fractures, leaving few or none below the relict depression (LeGrand, 1979). This condition is especially true in some valley bottoms where rocks are exposed. On the upland areas, under certain conditions, small tension fractures may develop and become sufficiently enlarged by circulating groundwater to provide substantial yields to wells. Where the upland joints extend laterally to a valley, or the confluence of two valleys, high well yields may be developed.

Fractures are the principal sources of permeability in many bedrock aquifers. They may be observed directly in exposed bedrock but, because of the scarcity of outcrops, are frequently easier to identify by examination of topographic maps. Straight stream segments or draws and tributaries arranged in a more or less parallel pattern and aligned across a main stream at angles of 90 degrees or less are indicators of drainage controlled by vertical or high-angle fractures (Figure 10).

Faults are fractures along which movement has taken place. They are widely distributed throughout the region, and may serve as conduits for groundwater movement, or as impediments, depending upon the extent to which the permeability of the fault zone has been affected by the mechanics of rock movement or mineralization, or both. Examples of major faults are those forming the boundaries of the Triassic basins, and the Brevard fault, which forms much of the boundary between the Piedmont and Mountain Region.

In the early geologic stage of topographic development, many faults have influenced topographic expression, especially stream settings. Most of them may be considered as fractures of moderate significance.

The local unevenness in the size, character and distribution of fractures, and in soil-saprolite characteristics, result in difficulties in extrapolation of hydrogeologic conditions. For example, of three wells in a row, spaced fairly close together, the respective yields may be 40, 6, and 20 gallons per minute, depending primarily on the number, interconnectivity, and character of the fractures they intercept.
Figure 10. Topographic map showing fracture controlled tributaries of Rock River, Stanly and Cabarrus Counties, N.C.
Hydraulic head beneath upland areas decreases with depth, resulting in the overall downward movement of groundwater and providing the mechanism for recharge to the aquifer. For example, a well 75 feet deep is likely to have a higher water level than a well 300 feet deep at the same site.

Hydraulic head beneath lowland areas increases with depth, indicating upward movement of groundwater. For example, a well 300 feet deep is likely to have a higher water level than a well 75 feet deep at the same site.

Hydraulic head provides the impetus for groundwater movement. Groundwater flows from areas of high head to areas of low head. The total hydraulic head, in feet or meters of water, in a non-flowing well is determined by subtracting the depth to water in the well from the elevation of the measuring point. The elevation is typically referenced to a common datum, usually mean sea level.

Figure 11 illustrates head differences in recharge and discharge areas in an unconfined aquifer. The solid lines are equipotential lines, representing the elevation of points of equal hydraulic head. The dashed lines are idealized groundwater flow lines illustrating the path of groundwater movement. The water level in the wells in the recharge area rises to the elevation represented by the equipotential line at which the well is open. The deeper the well, the less head is encountered. As depicted in Figure 11, the water level in well A, cased to a depth of 1 meter is higher than that in well B, cased to a depth of 4 meters. On the other hand, open-end wells in the discharge area encounter higher potential at increasing depth and consequently display higher water levels. In Figure 11, the water level in well D, cased to a depth of 7 meters is higher than that in well C, cased to a depth of 4.5 meters.

Figure 11. Idealized cross-section showing hydraulic head relationships in recharge and discharge areas. (Modified from Heath, 1983)
The rate of flow (velocity) of groundwater depends on the permeability and porosity of the medium through which it is moving, and on the hydraulic gradient, a slope defined by the difference in total head between two points of measurement over a unit distance. The greater the permeability and the hydraulic gradient, the higher the velocity. The overall rate of flow is fairly slow because the soil-saprolite zone has low permeability, and the fractures in the bedrock become sparse and poorly connected at increasing depths. Where it consistently occurs, the transition zone, including the uppermost part of bedrock, has the highest permeability and higher rate of flow than other parts of the system. The complex local geologic conditions cause wide differences in rates of flow, ranging from greater than one foot per day to less than one foot per century. Much of the flow is at the rate slightly greater than 10 feet per year.

The residence time for water to stay in the system also ranges greatly, and much of the water stays in the ground for many years. It must be emphasized that water collected at a well or that discharges naturally is a mix of water from both short and long flow paths. Thus, the average rate of travel of contaminated ground water to a well or natural outlet may be much slower than that of the first arrival of the water.

The chemical character of ground water in the Region can be classified as either acidic or basic. Acidic groundwater is typically found in light-colored rocks such as granite, granite gneiss, mica schist, slate, and rhyolite flows and tuffs, and is soft, and low in dissolved solids. Basic groundwater is typically found in dark rocks, such as diorite, gabbro, hornblende gneiss, and andesite flows and tuffs, and is typically hard, slightly alkaline, and relatively high in dissolved solids. Table 1 depicts the chemical characteristics of water from the two predominant rock types.
Table 1. Comparison of natural chemical constituents of groundwater from acidic (granite) and basic or intermediate rocks (diorite) in the Piedmont and Mountain Region, North Carolina (after LeGrand, 1958).

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Acidic (granite)</th>
<th>Basic (diorite and gabbro)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica (SiO2)</td>
<td>30.0</td>
<td>32.0</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>5.0</td>
<td>38.0</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>2.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Sodium and potassium (Na+K)</td>
<td>7.0</td>
<td>11.0</td>
</tr>
<tr>
<td>Bicarbonate (HCO₃⁻)</td>
<td>34.0</td>
<td>127.0</td>
</tr>
<tr>
<td>Sulfate (SO₄²⁻)</td>
<td>2.0</td>
<td>17.0</td>
</tr>
<tr>
<td>Chloride (Cl)</td>
<td>2.0</td>
<td>14.0</td>
</tr>
<tr>
<td>Fluoride (F)</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Nitrate (NO₃⁻)</td>
<td>0.9</td>
<td>1.3</td>
</tr>
<tr>
<td>Dissolved solids</td>
<td>71.0</td>
<td>233.0</td>
</tr>
<tr>
<td>Hardness as CaCO₃</td>
<td>23.0</td>
<td>145.0</td>
</tr>
<tr>
<td>pH</td>
<td>6.5</td>
<td>7.1</td>
</tr>
</tbody>
</table>

1Chemical constituents in parts per million (ppm) except pH.
2Median value of 29 analyses from wells in the granite group.
3Median value of 23 analyses from wells in the diorite group.

Generalizations Associated with Conditions Imposed by Humans

Generalizations listed here relate to conditions imposed by humans that are generally in the form of diversion or withdrawal of water. They are designated H-1 through H-9, and include the following:

**H-1 DIVERSION OF RUNOFF**

Rolling topography and poorly permeable subsoil allow humans to divert water readily from the land surface toward nearby streams by way of paved surfaces and other drainage structures. Diversion of runoff may result in a slightly lower than normal water table beneath the upland areas and a reduction in the flow of groundwater to streams.

**H-2 TURBULENT FLOW**

Much of the flow in fractures is turbulent near pumping wells because of the velocity and erratic direction of movement of groundwater toward the well bore. The erratic movement of water in fractures is related to (a) the cross-linking of fractures, (b) the differing physical characteristics of the soil-saprolite zone and the bedrock, and (c) the conventional sporadic pumping and resting of wells. The mixing and churning of water, trapped air and, in some cases, contaminants in the cone of depression during alternate periods of pumping and non-pumping, result in complex conditions that may affect groundwater quality or well efficiency, or both.
H-3  CONE OF DEPRESSION

When a well is pumped, the decline of the water level in the well creates a hydraulic gradient toward the well in the area from which the groundwater is derived. The gradient steepens as the well is approached because the water converges from all directions and moves through a continually decreasing area until it enters the well bore. The area in which water level decline occurs takes the general shape of an inverted cone.

A crude estimate of the configuration of the cone of depression surrounding a pumped well can be constructed before pumping is begun. In fractured-rock aquifer systems, the cone of depression may not be a smooth circular area as viewed from above, as is common in regional aquifers consisting of porous, granular material. Because of the pronounced slope of the natural water table, the cone of depression tends to extend farther down-gradient from the well than it does up-gradient. Moreover, the cone tends to be elongated parallel to the trend of the greater fractures, generally along the foliation or trend of the rocks. The irregular distribution of fractures results in an irregular shape and extent of the cone of depression. These irregularities are almost never mappable in the absence of numerous monitoring wells. However for the purpose of wellhead protection of a public water supply well, a rough estimate of the size and configuration of the area can be estimated. The area contributing groundwater to a well includes not only the area within the cone of depression, but also the area up-gradient of the well as far as the water-table divide, in which the natural flow of groundwater is down-gradient into the cone of depression. Methods for delineating areas contributing groundwater to wells have been described by Heath (1991).

H-4  AREAL EFFECT OF PUMPING

The hydraulic effect of pumping a domestic well does not generally interfere with another domestic well located more than a few hundred yards away. Closer spacing of wells may result in increased drawdown and a reduction in well efficiency.

The drawdown resulting from pumping a high yield, municipal or industrial well may be areally extensive and may breach the natural barriers imposed by the groundwater divides defining slope-aquifer systems or compartments.

H-5  EFFECT OF DEPTH ON WELL YIELD

The tendency for fractures to decrease in size and number with increasing depth results in the tendency for yields per foot of well depth to decrease with increasing depth, especially below a depth of about 350 feet.
The yield per foot of drawdown generally decreases with increasing drawdown. Therefore, increasing the well depth to provide for a deep pump setting, or deep drawdown, may not be practicable.

**H-6 PREDICTABILITY OF WELL YIELD**

The yield of individual wells varies greatly and cannot be predicted within a narrow range of certainty. However, the yield of most wells ranges from less than one gallon per minute to as much as 60 gallons per minute. Wells located in draws where the soil-saprolite zone is thick are likely to have high yields; conversely, wells located on ridges underlain by a very thin soil-saprolite zone are likely to have low yields. Other types of topographic locations and places of intermediate soil-saprolite thickness are likely to have moderate yields. By using the slope-aquifer concept in relation to other generalizations, useful approximations of yield can be made. Hydrogeologic evidence notwithstanding, however, the ultimate selection of a well site may be determined by state and local health regulations.

LeGrand (1967) developed a rating system for estimating potential well yields by comparing topographic and soil conditions at a site. The system is based on the premise that high-yielding wells are common where thick residual soils and relatively low topographic areas are combined, and low-yielding wells are common where thin soils and hilltops are combined. Topographic settings and soil-saprolite thickness are assigned point values as shown in Tables 2 and 3.

The sum of the values determined for topographic setting and estimated soil-saprolite thickness may be used to determine the estimated average yield of a well and the chance, in percent, of obtaining higher yield. In the example shown in Figure 12, a site having a total value of 16 points has a 30 percent chance of yielding 30 gallons per minute and a 60 percent chance of yielding 10 gallons per minute.

<table>
<thead>
<tr>
<th>Points</th>
<th>Topography</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Steep ridge top</td>
</tr>
<tr>
<td>2</td>
<td>Upland steep slope</td>
</tr>
<tr>
<td>4</td>
<td>Pronounced rounded upland</td>
</tr>
<tr>
<td>5</td>
<td>Midpoint ridge slope</td>
</tr>
<tr>
<td>7</td>
<td>Gentle upland slope</td>
</tr>
<tr>
<td>8</td>
<td>Broad flat upland</td>
</tr>
<tr>
<td>9</td>
<td>Lower part of upland slope</td>
</tr>
<tr>
<td>12</td>
<td>Valley bottom or flood plain</td>
</tr>
<tr>
<td>15</td>
<td>Draw in narrow catchment area</td>
</tr>
<tr>
<td>18</td>
<td>Draw in large catchment area</td>
</tr>
</tbody>
</table>

Table 2. Site topographic ratings.
Table 3. Soil-thickness rating table.

<table>
<thead>
<tr>
<th>Points</th>
<th>Character of soil and rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2</td>
<td>Bare Rock; almost no soil</td>
</tr>
<tr>
<td>2-6</td>
<td>Very thin soil; some rock outcrops</td>
</tr>
<tr>
<td>6-9</td>
<td>Soil thin; a few rock outcrops</td>
</tr>
<tr>
<td>9-12</td>
<td>Moderately thick soil; no fresh outcrops</td>
</tr>
<tr>
<td>12-15</td>
<td>Thick soil; no rock outcrops</td>
</tr>
</tbody>
</table>

Figure 12. Well-yield probability graph.

**H-7 CONTAMINANT MIGRATION AND NATURAL ATTENUATION**

Although a thorough discussion of factors affecting contaminant transport is beyond the scope of this report, some general parameters are applicable in the Region.

*Of principal importance is the chemical nature of the contaminants and the media through which they move. As the groundwater in the Region includes both porous media (regolith) and fractured bedrock, the nature of the contaminant plume migration may be very complex. Yet, it is fortunate that by using the slope-aquifer concept, the behavior of contaminated water from a waste site or spill may be reasonably approximated where natural conditions prevail (Figure 13). However, where the natural flow of contaminated water is diverted by a cone of pumping depression, the future behavior of persistent contaminants cannot be predicted with a high degree of certainty.*
The tendency for contaminants to weaken in strength as they move in groundwater flow from a contaminated source is not easily determined at a site during early stages of an investigation. In simple terms, a measure of natural attenuation can be regarded as a combination of (1) dispersion and dilution, (2) a die-away or transformation of contaminants, (3) sorption on earth materials, and (4) distance to a critical spot, as the contaminated water moves in a buffer zone before reaching a water-supply well or spring. As natural attenuation may be expected to be more effective in soil-saprolite than in fractured bedrock, a thick saprolite zone may be considered favorable. In addition to the type of contaminants, other factors to be considered are the volume and total concentration of the contaminant and the distinction between a one-time spill or leak and the long-term persistence of contaminant movement from the source.

Figure 13. Schematic diagram showing the areal extent and direction of movement of a hypothetical contaminant plume (LeGrand, 1965). Shading indicates relative degrees of contaminant concentration.

The merits of pumping contaminated water from wells for remedial purposes must be determined on a case-by-case basis. Most remedial wells reduce the concentration of contaminants with increased pumping. However, if the goal is complete removal of all contamination, success is rare. Although pumping may have ceased for months or years, some contaminated water is likely trapped for years in fractures where natural groundwater circulation is retarded.
INFLUENCE OF TOPOGRAPHIC LOCATION ON PUMPING OR CONTAMINANT MIGRATION

Environmental concerns regarding water supply or waste disposal are commonly related to only one slope-aquifer system. However, if a pumping well or contamination zone is situated near a hilltop, both adjoining slope-aquifer systems are likely to be involved. Thus, a double slope-aquifer system, or compartment, applies, and the area of concern may extend to the perennial streams on both sides of a ridge, as shown by A and B in Figure 8. Wells near hilltops can draw water from both compartments, and contaminated groundwater near hilltops may spread divergently according to the varying water-table gradients.

CHANGE IN GROUNDWATER CHEMISTRY

The chemical character of water may change following the original pumping of a well. For example, in the cone of depression, radon may be trapped and may accumulate in air-filled fractures (LeGrand, 1987). Also, oxidation of pyrite and arsenic-bearing sulfide minerals such as arsenopyrite, in the air-filled part of the cone of depression, may result in increased iron and arsenic, as well as a decrease in pH (LeGrand, 1958).

Model Procedures and Application

No intrusive mechanical or geophysical equipment is required to apply the conceptual model to a site. Prior to a field investigation of a site, the evaluator should determine whether hydrogeologic information pertinent to the site is available in publications or open-file reports of state and federal agencies. Such reports typically contain data on wells, well yield, and groundwater levels, as well as brief geological descriptions and groundwater quality information.

At the site, the evaluator should have in hand the part of a topographic map that includes the particular slope-aquifer system and compartments that display the area of concern. The map should be of a scale of 1:24,000 or larger (a 1:6,000 scale may be ideal for most sites). Sites of interest, such as a well or waste site, should be located. A duplicate topographic map may be helpful for marking various features not included on the original map. In addition to the topographic map, the evaluator should have a geologic map of the area, a copy of the Site Evaluation Matrix (Appendix A-1), the Site Evaluation Worksheet (Appendix A-2), and the Site Evaluation Inventory (Appendix A-3).

Using the Site Evaluation Matrix as a guide, the evaluator should complete the Site Evaluation Worksheet. In the absence of site-specific, subsurface information, it may seem difficult and awkward to complete all factors included in the Worksheet. If the estimated value entered for each factor is not considered to be sufficiently true or representative, the evaluator should make an effort to explain, in each “comment” space, the best estimate of conditions. This explanation
may be derived from a study of the generalizations and their interrelations, and from the Site Evaluation Matrix. The interrelations help provide an understanding of the site characteristics and guide the development of an early-stage conceptual model. Each estimated value or expression should be checked for compatibility with values of other factors. For example, a relatively deep water table may not fit with a setting having minimal rock fractures or nearly flat topographic setting.

After completing the Worksheet, the evaluator should follow the instructions and answer the applicable questions contained in the Site Evaluation Inventory.

After considering the various values in their integrated form, and expanding the comments and explanations, the overall conceptual model begins to unfold. No precision or pinpoint accuracy is claimed, but much useful information about the setting is now at one’s fingertips. Some evaluated settings may reveal better information than others, but the quality of the results of the model application should exceed that of any other method or procedure at an early stage.

Evaluators not trained in hydrogeology should be able to derive useful information from this process without pursuing the study to the report phase. Those who wish to prepare a report of their findings may wish to use the format of the Prior Conceptual Model Explanation (PCME) described by LeGrand and Rosen (2000). The report may be prepared in narrative form and may be based largely on approximations and best estimates.

At a minimum, the report should describe:

- the location of the site,
- the purpose of the evaluation (e.g. vulnerability to contamination from a known or anticipated source, groundwater development potential, etc.),
- geologic and topographic characteristics,
- direction of groundwater movement and gradient,
- location and extent of recharge-discharge areas,
- natural groundwater quality, and
- approximations of the potential for groundwater contamination or water-supply development at critical places.

The following are abbreviated examples of the use of the generalizations.

**Case 1**

The setting consists of a waste disposal site on a topographic slope, halfway between a ridge top and a small creek. It is a common granite gneiss setting, having no rock outcrops and
presumably a thick soil-saprolite zone underlying the slope and the adjacent slope across the
creek. Mr. Smith, the owner of the facing property across the creek, plans to drill a well, which
would be about 1,000 feet horizontally from the waste disposal site. The waste site is about 30
feet higher in elevation than the creek, and the elevation of Mr. Smith’s well on the opposite
slope is also about 30 feet above the creek. Mr. Smith is concerned about the possibility of his
well water being contaminated by leakage from the waste site.

Generalizations N-9 and N-7 form the basis for the development of a preliminary water-table
map. They indicate that groundwater naturally flows toward the creek from opposite directions,
thereby eliminating a continuous gradient from the lagoon to the well. Each is in a different
slope-aquifer system from the other (N-10). There is no deep aquifer system to connect the
systems as fractures decrease in size and number with increasing depth (N-12). The creek is a
hydraulic boundary for natural flow, and it is extremely unlikely that the water table during
pumping of Mr. Smith’s well would be depressed to the level of the creek. Even if that were
possible, his well should theoretically dry the creek before a true hydraulic gradient from the
waste site to the well would be possible (H-7). The contaminated plume from the waste site may
reach the creek, where the discharging contaminated groundwater would mix with downstream
creek flow, as shown in Figure 12. By reasoning, it seems unlikely that Mr. Smith’s well water
would be contaminated by the waste disposal site.

Case 2

The setting is a relatively flat area underlain by gabbro, such as that northeast of Harrisburg, in
Cabarrus County. Several houses are planned along a rural road, and questions have been posed
about a well and septic tank system for each house. Dark brown, sticky clays and a few gabbro
boulders are observed on the surface. A thin soil-saprolite zone tends to characterize flat-lying
gabbro settings (N-1), and the nearly flat topography indicates a shallow water table and a gentle
water-table gradient (N-15). The shallow gradient suggests that there is lack of significant
circulation of water deeper than about 100 feet. There are suggestions that fractures do not
extend to great depth (N-12). The topography is largely due to dissolution of the rock as water
moves along the top of the soluble bedrock. These conditions suggest a very thin soil-saprolite
zone and a thin transition zone. The thinness of the soil-saprolite zone results in a thin
groundwater reservoir in dry weather and the possibility of noticeably reduced well yields during
droughts. Some septic tank systems may not be suitable because of the combination of clay soils
and shallow water table. Plumes of contaminated groundwater may rise to the land surface in
spots after heavy precipitation. Local areas of soggy ground during wet weather and a rise of the
water table to land surface at its high stage may lead to environmental problems such as land
drainage. The natural flow of groundwater is slow (N-6). With the prevailing conditions in
mind, a rather sparse spacing of wells and septic tank systems in this setting is suggested.
Although in some cases some exploration wells and testing may be necessary, the logically
deduced information can limit the amount of money spent on projects in this setting.

Conclusions
The generalizations inherently indicate conditions that are normally true. When the generalizations and logical inferences are interrelated and matched, the result is a conceptual model that is presumed to be realistic though imprecise. Extreme or unusual conditions do occur and may be expressed as anomalies. Where an unusual value of a factor appears, further study should be made to determine if the condition is an error in evaluation or an anomaly. Types of anomalies include extremely high well yields and higher than normal concentrations of a chemical constituent in the water.

In summary, the following conclusions support the application of the generalizations to typical hydrogeologic concerns in the Piedmont and Mountain Region.

- Using the generalizations, a higher plateau of knowledge can be developed for an unstudied setting than would otherwise be possible at an early stage of an investigation.
- The generalizations are not mere isolated conclusions, but represent hydrogeologic associations of certain tendencies, which may lead to useful inferences. For example, (1) divergent hydraulic gradients on opposite sides of hills, in combination with (2) a tendency for permeability to decrease with increasing depth beneath all slopes suggest that (3) pumping wells on opposite hill slopes are not likely to have appreciable mutual interference.
- Topography is a major factor in the development of knowledge of groundwater conditions in the Region. As many topographic settings are masked or unclear because of vegetation and buildings, topographic maps of the scale of 1:24,000 are indispensable tools for site evaluations.
- Knowledge that the water table is a subdued replica of land surface topography offers insight to several important aspects of groundwater flow. Thus, by mimicking the land surface contours in a modified way, a local synthetic water table map can be readily developed.
- Fracture traces are almost invariably related to observable topographic expressions.
- The region contains numerous small slope-aquifer systems, each being bounded by a perennial stream and an upland groundwater divide. Within most slope-aquifer systems are smaller, concave topographic configurations representing topographic draws and groundwater compartments that are open-ended toward the perennial streams. Evaluation problems of water supply and waste management can be facilitated by a focus on the hydrogeologic characteristics of the pertinent slope-aquifer system and the compartment.
- The ability to obtain specific information through the use of inferences from the generalizations must be weighed against the objectives of obtaining precise information from drilling and other subsurface techniques. Data collection and costs can be reduced by maximum use of the type of integrated framework derived from the generalizations.
• The proposed method of investigation can lead to a qualitative predictive model expressing likely or common conditions that exist or may occur in the future. Individual deductions may be cross-checked with others derived from the generalizations to confirm the validity of the model. The evaluation process should identify unusual features and anomalous conditions.

Bibliography


Glossary

Alluvium – Sediment, including clay, silt, sand, and gravel deposited by rivers and streams. The term generally refers to deposits of recent geologic time.

Aquifer – A body of rock, consolidated or unconsolidated, that is sufficiently permeable to conduct groundwater and to yield significant quantities of water to wells and springs.

Attenuation – A reduction in concentration of contaminants in the subsurface.

Bedrock – A general term for the rock that underlies soil or other unconsolidated superficial material. In the Piedmont and Blue Ridge provinces bedrock typically consists of granite, gneiss and schist.

Brownfield – An abandoned, idled, or underused property at which expansion or redevelopment is hindered by actual environmental contamination or the possibility of contamination and that may be subject to remediation.

Buffer Zone – An area between a contaminant plume and a down-gradient receptor, such as a water-supply well or a stream, within which natural attenuation may occur. By special designation, it may be defined in terms of the distance to a position of tolerated acceptance, a position where contamination is completely reduced, a property line, or a surface body of water.

Compartment – In a slope-aquifer system, an area formed by an undulation of the water table generally conforming to an undulation in the overlying topography. The crests of the water-table undulations represent natural groundwater divides that, under natural conditions, restrict the movement of groundwater to the boundaries of the compartment.

Cone of Depression – A depression in the potentiometric surface of a body of groundwater that has the shape of an inverted cone and develops around a well from which water is being withdrawn.

Crystalline Rock – An inexact but convenient term designating an igneous or metamorphic rock characterized by interlocking mineral grains.

Diorite – A group of plutonic rocks intermediate between acidic and basic, characteristically composed of hornblende, oligoclase or andesine, pyroxene and sometimes a small amount of quartz.

Discharge Area – An area in which there is an upward component of hydraulic head in an aquifer. Groundwater flows toward land surface in a discharge area and escapes as a spring, seep, baseflow to streams, or by evaporation and transpiration.
**Drainage Basin** – A region or area that contributes water to a specific stream, lake, reservoir, or other body of water. Drainage basins are bounded peripherally by a drainage divide. Synonymous with watershed.

**Drainage Divide** – The boundary between adjacent drainage basins.

**Draw** – A natural depression or swale; a shallow to moderately steep drainage way. A natural watercourse, usually dry except during and immediately following heavy rains. A shallow drainage way.

**Drawdown** – The decline of the water table or potentiometric surface as a result of withdrawals from wells or excavations.

**Equipotential line** – A line in a two-dimensional groundwater flow field on which the total hydraulic head is the same at all points.

**Evapotranspiration** – That portion of precipitation returned to the atmosphere through evaporation and transpiration.

**Fault** – A fracture or fracture zone along which there has been displacement of the sides relative to one another parallel to the fracture.

**Feldspar** – A group of rock-forming aluminosilicate minerals. Feldspars are the most widespread mineral group and constitute 60 percent of the earth’s crust.

**Felsic** – An adjective applied to rocks containing an abundance of light-colored minerals. The chief felsic minerals are quartz, feldspars, feldspathoids, and muscovite. Examples of felsic rocks are granite and syenite. Contrasted with mafic.

**Fracture** – A crack, joint, fault or other break in rocks caused by mechanical failure.

**Gabbro** – A group of dark-colored, basic intrusive igneous rocks composed principally of pyroxene and plagioclase feldspar.

**Gneiss** – A foliated, metamorphic rock in which light colored bands of granular minerals alternate with darker bands of flaky minerals.

**Granite** – A plutonic rock consisting chiefly of quartz and feldspar. Mica and hornblende may be included.

**Hydraulic Conductivity** – A coefficient of proportionality describing the rate at which a specific fluid can move through a permeable medium.

**Hydraulic Head** – Generally, the altitude of the free surface of a body of water above a given datum.
Igneous Rock – A rock that solidified from molten or partially molten material. Examples are solidified lava and plutonic rocks.

Interflow – The lateral movement of water in the unsaturated zone during and immediately after precipitation. Interflow occurs when the zone above a low permeability horizon becomes saturated and lateral flow is initiated parallel to the barrier.

Intermittent Stream – A stream that flows only at certain times of the year, as when it receives water from springs or a surface source. Also known as ephemeral or wet-weather streams.

Isohyetal Line – A line on a map connecting points receiving the same amounts of precipitation.

Joint – A fracture in rock along which there has been no visible movement.

Mafic – An adjective describing igneous rock composed chiefly of dark, ferromagnesian minerals. The complement of felsic.

Metamorphic Rock – A rock formed at depth in the earth’s crust from preexisting rocks by mineralogical, chemical and structural changes caused by high temperature, pressure and other factors. Examples include slate, schist and gneiss.

Natural Attenuation – The natural processes contributing to the degradation and dissipation of contaminants. Some of the processes contributing to natural attenuation include dilution, sorption, filtration, oxidation, volatilization, and microbial degradation.

Perched Water Table – The upper surface of a body of unconfined groundwater separated from the main body of groundwater by unsaturated material.

Perennial Stream – A stream that flows continuously throughout the year and whose upper surface generally stands lower than the water table in the region adjoining the stream.

Permeability – The capacity of rock or unconsolidated material to transmit a fluid.

Plume – A body of contaminated groundwater originating from a specific source or sources and influenced by such factors as the local groundwater flow pattern, density of contaminants, and the physical characteristics of the aquifer.

Plutonic – Pertaining to igneous rocks formed at great depth.

Porosity – The ratio of the aggregate volume of interstices in a rock or soil to its total volume. It is usually stated as a percentage.

Potentiometric Surface – An imaginary surface representing the total head of groundwater and defined by the level to which water rises in tightly cased wells. The water table is a particular potentiometric surface.
**Regolith** – The unconsolidated material lying above bedrock, whether residual or transported, consisting of saprolite, alluvium and soil. The regolith may include a transition zone grading from unaltered bedrock into true saprolite.

**Saprolite** – A soft, earthy, clay-rich thoroughly decomposed rock formed in place by chemical weathering of igneous or metamorphic rocks. Saprolite is characterized by preservation of structures that were present in the unweathered rock.

**Schist** – A foliated, crystalline, metamorphic rock of intermediate grain size. Individual folia are relatively thin. Parallel, platy minerals commonly make up one-half of the rock.

**Sedimentary Rock** – A layered rock resulting from the consolidation of sediment deposited by some geologic agent such as water, wind, or ice. Typical sedimentary rocks include sandstone, limestone and shale.

**Slate** – A compact, fine-grained metamorphic rock that possesses slaty cleavage. It is generally formed by the metamorphism of shale.

**Slope-Aquifer System** – In the Piedmont and Mountain Region, a part of the region-wide regolith-bedrock aquifer system in which groundwater recharge, transient flow, and discharge are confined, under natural conditions, to an area bounded up-gradient by a topographic divide, and down-gradient by a perennial stream. Laterally, the system is bounded on one side by an extension of the centerline of the draw containing the headwaters of the perennial stream, up-gradient to the ridge crest, and on the other side, by the terminus of the gross topographic ridge.

**Soil** – The relatively fine-grained, surficial material formed as the result of weathering of rock, or unconsolidated sediment. Soil may be found in layered horizons varying in organic and mineral content. It is generally capable of supporting vegetation.

**Spur** – A hill or ridge extending from the crest or side of a more prominent ridge or mountain.

**Tension fracture** – A fracture caused by stress that tends to pull a body apart.

**Water table** – The surface of a body of unconfined groundwater at which the pore pressure is atmospheric.

**Wellhead Protection Area.** – An area designated under the authority of the 1986 Amendments to the Safe Drinking Water Act within which measures to protect groundwater quality may be taken by operators of public water systems. A wellhead protection area is the surface and subsurface area surrounding a well or wellfield supplying a public water system through which contaminants are reasonably likely to move toward and reach the well or well field.

**Well Yield** – An inexact term referring to the volume of fluid removed from a well per unit period of time, typically measured in gallons per minute.
Appendix

A-1 Site Evaluation Matrix

A-2 Site Evaluation Inventory

A-3 Worksheet for the Evaluation of Factors Influencing the Occurrence and Availability of Groundwater
## Appendix A-1
### Site Evaluation Matrix
(modified from LeGrand, 1983)

<table>
<thead>
<tr>
<th>Hydrogeologic Factors</th>
<th>Advantageous Aspects</th>
<th>Disadvantageous Aspects</th>
<th>Remarks</th>
<th>Interrelation of Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Permeability</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. High surface permeability allows infiltration of contaminated water, preventing or reducing surface contamination and runoff problems.</td>
<td>1. Low surface permeability causes rejection of contaminated water and helps create problems of contaminants on the ground surface and in streams.</td>
<td>Gravel and clean, coarse sand in floodplain deposits are very permeable. Sandy soil on granite and granite gneiss also tends to be fairly permeable. Residual clays on gabbro and diorite tend to have low permeability. Rock permeability ranges according to type of rock and fracture density, but is typically greater at shallow depths.</td>
<td>The higher the permeability the lower the potential for natural attenuation, and, conversely, the lower the permeability the greater the potential for attenuation. The water table tends to be shallow in poorly permeable materials in low topographic sites in humid regions. Conversely, the water table tends to be deep in permeable materials beneath high topographic sites. Other factors not considered, high permeability might lead to a low water-table gradient. High permeability may lead to a low water table and low stream density, and perhaps also to a great distance from a contamination site to a stream.</td>
<td></td>
</tr>
<tr>
<td>2. High permeability may result in a deep water table leading to better opportunities for contaminants to attenuate in the unsaturated zone.</td>
<td>2. High permeability may lead to faster groundwater movement and less opportunity for decay with time.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Low permeability retards movement, resulting in additional time for attenuation. Low permeability in porous materials may be related to good sorption.</td>
<td>3. Low permeability may result in a shallow water table and less opportunity for attenuation in the unsaturated zone.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Depth of Water Table</strong></td>
<td>1. A deep water table generally allows infiltration of contaminants, preventing overland flow or emergence at the land surface.</td>
<td>1. A shallow water table may cause contaminants to emerge at land surface.</td>
<td>For this discussion, a shallow water table is less than 15 feet below land surface, and a deep water table is more than 50 feet below land surface. Shallow water tables are common in humid regions. A moderately deep water table is desirable. A water table that rises during its high stage to the main body of wastes or near land surface is not desirable.</td>
<td>High water table may be associated with material having a high capacity for natural attenuation and low permeability. High water table may be associated with steep gradient of the water table.</td>
</tr>
<tr>
<td>2. A deep water table allows increased attenuation of contaminants in the unsaturated zone, relative to a shallow water table.</td>
<td>2. A shallow water table reduces attenuation in the unsaturated zone and enables contaminants to enter the saturated zone where lateral dispersion occurs.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Some contaminants may never reach a deep water table. They appear to remain in the unsaturated zone, where their potential for harm may be less than in the saturated zone.</td>
<td>3. A deep water table makes monitoring and control of contaminated zones difficult.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. A shallow water table may allow easy and cheap methods of monitoring and controlling contaminated zones.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Site Evaluation Matrix (continued)

<table>
<thead>
<tr>
<th>Hydrogeologic Factors</th>
<th>Advantageous Aspects</th>
<th>Disadvantageous Aspects</th>
<th>Remarks</th>
<th>Interrelation of Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water-Table Gradient</strong></td>
<td>1. It is desirable for a point of water use (e.g., a well) to be up-gradient from a contaminant source so that contaminants will not migrate toward the point of use under natural head conditions. 2. A gentle gradient is more acceptable than a steep gradient where direction is toward a point of water use because of slower water movement and greater time for contaminant decay unless the gentle gradient is due to high transmissivity.</td>
<td>1. A steep gradient from a contaminant source toward a point of water use is undesirable. 2. Any gradient, either natural or caused by pumping of wells, from a contaminant source toward a nearby point of water use is not desirable.</td>
<td>Gradients are easy to determine where water-table maps are available. However, correct inferences lead to fair approximations of water-table gradients. Steep land surfaces, in combination with low permeability and humid climates, tend to yield steep water-table gradients.</td>
<td>Steep gradient may be associated with low permeability and presence of material having a high capacity for natural attenuation or high stream density. A low water table may be associated with a low water-table gradient and a short distance from a contamination site to a stream.</td>
</tr>
<tr>
<td><strong>Stream Density</strong></td>
<td>1. Closely spaced streams limit the areal extent of contaminated zones in the ground and may prevent spread of contamination across streams. 2. Widely spaced streams may allow for attenuation in the ground and thus avoid stream contamination.</td>
<td><strong>(1) where streams are closely spaced, contaminants may have a short underground course before dispersing into a stream, where they may be objectionable.</strong> 2. Widely spaced streams may result in large contaminated zones in the ground that may be more nearly permanent than where streams are closely spaced.</td>
<td>For this discussion, a network of closely spaced streams has a perennial stream within a mile of all inter-stream points. A stream is a surface outlet for groundwater, and if the groundwater is contaminated the stream generally represents a boundary beyond which the contamination may not extend.</td>
<td>A close network of streams may be related to low permeability; conversely, widely spaced streams may be related to high permeability.</td>
</tr>
</tbody>
</table>
| **Topography**  
(1) low relief | 1. Low relief is commonly associated with a low water-table gradient and, if permeability is low, with slow movement of ground water. 2. High relief is commonly associated with a deep water table (where permeability is moderate to good). | 1. Low relief is commonly associated with a shallow water table, with a minimum of attenuation in the unsaturated zone. 2. High relief is commonly associated with rapidly moving groundwater, which may limit the time for attenuation of contaminants. | For this discussion, topography of low relief does not have high hills or deep valleys. Topography is an important factor, but its value is more tangibly considered within the interrelations of the factors of permeability, depth to the water table, and gradient of the water table. | High topographic relief with high permeability leads to a deep water table and low water-table gradient; high topographic relief with low permeability leads to a shallow water table and steep water-table gradient. |
| (2) high relief | 1. Great distance is a desirable factor, a factor easy to evaluate. | 1. Short distance may be undesirable. | For this discussion, a short distance is less than 100 feet and a great distance is more than 1,000 feet. Distance is the most distinct factor and, by far, the most often used. | Great distance is a favorable factor because favorable aspects of other factors may be included in “great distance.” |
## Appendix A-2

**Site Evaluation Worksheet**

<table>
<thead>
<tr>
<th>Type of Rock</th>
<th>Granite</th>
<th>Granite Gneiss</th>
<th>Schist</th>
<th>Quartzite</th>
<th>Gabbro or Diorite</th>
<th>Mafic Gneiss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comments and</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explanation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Topography</th>
<th>Upland Flat</th>
<th>Top of Hill</th>
<th>Upland Slope</th>
<th>Steep Slope</th>
<th>Shallow Slope</th>
<th>Valley</th>
</tr>
</thead>
<tbody>
<tr>
<td>(locate site on 1:24000 scale topographic map)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comments and</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explanation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Distance to Nearest Stream or Point of Concern</th>
<th>Less than 100 ft.</th>
<th>100-300 ft.</th>
<th>300-600 ft.</th>
<th>600-1,000 ft.</th>
<th>Greater than 1,000 ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comments and</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explanation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thickness, Soil-Saprolite Zone</th>
<th>0-5 ft.</th>
<th>5-10 ft.</th>
<th>10-20 ft.</th>
<th>20-40 ft</th>
<th>40+ ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comments and Explanation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth to Water Table</td>
<td>0-5 ft.</td>
<td>5-10 ft.</td>
<td>10-20 ft.</td>
<td>20-40 ft</td>
<td>40+ ft</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------</td>
<td>----------</td>
<td>-----------</td>
<td>----------</td>
<td>--------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Comments and Explanation**

<table>
<thead>
<tr>
<th>Water-table Gradient</th>
<th>Nearly Flat</th>
<th>Gentle Gradient</th>
<th>Moderately Steep</th>
<th>Steep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comments and Explanation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Water-table Fluctuation</th>
<th>Less than 2 ft.</th>
<th>2-4 ft</th>
<th>Greater than 4 ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comments and Explanation</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Base of Aquifer</th>
<th>Less than 100 ft.</th>
<th>100-250 ft.</th>
<th>250-300 ft.</th>
<th>300-500 ft.</th>
<th>Greater than 500 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comments and Explanation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Evapo-transpiration

<table>
<thead>
<tr>
<th>Comments and Explanation</th>
<th>High</th>
<th>Moderate</th>
<th>Low</th>
</tr>
</thead>
</table>

### Overall Permeability

<table>
<thead>
<tr>
<th>Comments and Explanation</th>
<th>Relatively High</th>
<th>Relatively Moderate</th>
<th>Below Average</th>
<th>Poor</th>
</tr>
</thead>
</table>

### Type of Contaminant

<table>
<thead>
<tr>
<th>Comments and Explanation</th>
<th>Chemical Leaks or Spills</th>
<th>Human or Animal Waste</th>
<th>Landfill Leachate</th>
<th>Agricultural Applications</th>
<th>Other (naturally occurring constituents or physical characteristics)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>gasoline, diesel, chlorinated hydrocarbons, other</td>
<td>septic tank, mun. or commercial system, animal waste lagoons, other</td>
<td>sanitary landfill, open dump, other</td>
<td>fertilizer, pesticides, herbicides, other</td>
<td></td>
</tr>
</tbody>
</table>

### Natural Attenuation Potential

<table>
<thead>
<tr>
<th>Comments and Explanation</th>
<th>High</th>
<th>Moderate</th>
<th>Low</th>
</tr>
</thead>
</table>
Appendix A-3

Site Evaluation Inventory

The following questions and instructions are offered as guidance in evaluating the site. Answers should be expressed in approximate or qualified terms, using ranges of conditions and probabilities as necessary. Degrees of probability may be expressed by use of terms such as “likely,” “probably,” “unlikely,” and “slightly.” Avoid precision-oriented terms and express modestly the judgements and inferences.

The comments and answers to the following questions include a selection of topics that make up the Prior Conceptual Model Explanation. The preparation of a separate PCME report is desirable but may be optional in some cases.

1. On a topographic map, plot the site of main interest, which may be a well or contamination setting. Plot other features as needed.

2. Is bedrock or saprolite exposed anywhere in the vicinity of the site? If so, describe.

3. Does the type of soil suggest the type of underlying bedrock? If so, describe.

4. Based on physical evidence or generalizations, estimate the approximate thickness of the soil-saprolite zone at key points.

5. Are there surface indications of the trends of geologic structure, such as lineations or fracture trends? If so, describe.

6. Is there evidence that a transition zone exists? If so, is there any evidence suggestive of its consistency and physical character?
7. What is the approximate depth to the water table at key points? If well data is not available, estimate from generalizations.

8. On the premise that the water table is a subdued replica of the land surface with less topographic relief, draw a synthetic water-table map, or indicate by arrows the probable direction of groundwater flow. Can you define the area at the hilltop where the direction of flow is questionable? It would be helpful to circumscribe that area on the map.

9. Is the water table in soil-saprolite in both wet and dry seasons at the key points?

10. Is the water table in bedrock in both wet and dry seasons at the key points? Lacking well measurements and geologic knowledge, refer to generalizations.

11. What appears to be the consequences of the difference between high and low stages of the water table?

12. Is there any significance to a particular topographic spur, or ridge, and a broad, concave sag in the topography?

13. What particular inferences can be made from the positions of draws and the upland divide?

14. Is there a spring in the compartment?
15. Does the spring seep from the soil-saprolite zone or does it discharge directly from rock?

16. Is there a significant wet-weather zone in the draw?

17. Is there seepage into a floodplain or from soil-saprolite into the stream?

18. Is there bank seepage from exposed rock?

19. Is bare rock or saprolite exposed in the perennial stream?

20. What is the approximate potential yield of a well at the ridge top or flat upland?

21. What is the approximate yield of a well at two other locations in a compartment?

22. For a well site of interest, express the yield in terms of percent chance of success for yields of 3, 10, 20, and 40 gallons per minute.

23. Has the land surface been altered by humans to the extent that it modifies hydrogeological interpretations?
24. Describe or plot the estimated wellhead protection area for a particular site and indicate whether it extends along the upland area and into another compartment.

25. At the well site, express a degree of concern about a contamination site at various distances from the wellhead protection area. Express types of contaminated sites within the area.

26. Comment on the natural quality of groundwater in the area. Consider hardness, total solids, pH, or some other natural constituents.

27. Comment on type of contaminants of concern, such as nitrates, organic chemicals, conventional septic tank effluent, dense non-aqueous phase liquids (DNAPL), etc. Can suggestive comments be made about the possible occurrence of radon, arsenic, and pharmaceuticals?

28. Indicate, by arrows, the likely direction of contaminated groundwater flow.

29. Comment on the need for monitor wells. Why? Where?

30. Check to see if you have drawn all useful conclusions or best approximations from the generalizations and inferences in the system.

32. Comment on the risk or degree of concern associated with the major problem or proposed activity.
33. If more information in the form of new data were suggested, how would the data be used? Would the benefits justify the cost of the additional work?

34. Express in essay or tabular form, useful thoughts or approximations that may involve some of the following subjects:

(a) *What are some constraints or limitations, such as a well near a contamination zone?*

(b) *Describe any favorable or unfavorable situations.*

(c) “Brinkmanship” (approaching regulatory limits or safe environmental limits).

(d) *Is the subject of incremental permissiveness involved?*

(e) *Possible consequences of some action.*

(f) *Aspects of attenuation at contamination site*

(g) *Property boundaries.*

(h) *Degree of confidence in statements (slight, moderate, considerable).*