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

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

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DISCLAIMER

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques and new technologies through which optimum use of the Nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of the facilities, the Robert S. Kerr Environmental Research Laboratory is the Agency's center of expertise for investigation of the soil and subsurface environment. Personnel at the Laboratory are responsible for management of research programs to: (a) determine the fate, transport and transformation rates of pollutants in the soil, the unsaturated zone and the saturated zones of the subsurface environment; (b) define the processes to be used in characterizing the soil and subsurface environment as a receptor of pollutants; (c) develop techniques for predicting the effect of pollutants on grond water, soil and indigenous organisms; and (d) define and demonstrate the applicability and limitations of using natural processes, indigenous to the soil and subsurface environment, for the protection of this resource.

This report contributes to that knowledge which is essential in order for EPA to establish and enforce pollution control standards which are reasonable, cost effective and provide adequate environmental protection for the American public.

Clinton W. Hall

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ABSTRACT

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

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

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

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CONTENTS

Appendices

FIGURES

TABLES

(continued)

TABLES (continued)

ACKNOWLEDGEMENTS

This document creates a standardized system which can be used to evaluate ground-water pollution potential. At the inception of the project, the implications for use of such a system were realized and a technical advisory committee was assembled. Prominent individuals with ground-water expertise represented federal and state agencies, the Canadian government and private consultants. Throughout the development of the system, the committee provided guidance and direction. The document is a result of the synthesis of many approaches and opinions of individual committee members. Although each of the individuals contributed positively and effectively to the process, this report is a product of the National Water Well Association and is not endorsed entirely by each of the committee members. Successful completion of the project is due to the time and effort which an unusually able advisory committee was willing to devote to this activity. To the following named persons, grateful acknowledgement of their contribution is made:

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The basic conceptual foundation for this system is modeled after a waste disposal site evaluation technique developed by Harry LeGrand. The geographic framework for the presented system is developed within ground-water regions as defined by Ralph C. Heath. A special note of acknowledgement and gratitude is made to these two individuals for their inspiration and assistance in developing this document.

In addition to the committee members, many individuals assisted in the demonstration mapping portion of the project. These individuals provided guidance in choosing ratings for DRASTIC factors, helped assemble information about the county, organized and assembled individuals for attendance at the county presentation on DRASTIC, provided vehicles for field checks, peer reviewed the pollution potential maps and participated in the field checking of the county. Without the varied talents of the following individuals, the production of the maps would not have been possible.

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SECTION 1

INTRODUCTION

OBJECTIVES AND SCOPE

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

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

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

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

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

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

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

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

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

PROJECT BACKGROUND

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

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

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

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

CLASSIFICATION SYSTEMS

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

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

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

SOME EXISTING SYSTEMS WHICH EVALUATE GROUND-WATER POLLUTION POTENTIAL

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

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

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

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

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

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

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

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

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

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

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

ORGANIZATION OF THE DOCUMENT

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

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

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SECTION 2

DEVELOPMENT OF THE SYSTEM AND OVERVIEW

DEVELOPING DRASTIC

The focus of this project is to create a system which can be used to evaluate the ground water pollution potential of any area in the United States. At the inception of the project, the far-reaching implications of a standardized system for evaluating ground-water pollution potential were realized, and a broadly-based, highly qualified technical advisory committee was assembled to assist with this effort. Through the direction and help of many, and discussion of opinions and suggestions, this system has evolved to represent a compromise approach. Further reference to the role of the committee will be made in the section discussing the development of the DRASTIC Index. A list of committee members can be found in the acknowledgement section.

The committee was charged with helping to develop a system capable of generalizing the pollution potential for any area 100 acres or larger. Because pollutants vary widely in their mobility and attenuation characteristics, it was necessary to choose a generic pollutant for discussion purposes. The concepts of the system were developed assuming the use of a pollutant having the mobility of water that is introduced at the surface, and carried towards the ground water by recharge from precipitation. The original inception of a pollution potential system incorporated only the evaluation of unconfined aquifers. However, during the course of system development, it became desirable to adapt the methodology for use in confined aquifer situations. To accommodate confined conditions, basic parameter definitions must be modified according to the discussion in Section 4, How to Evaluate Confined Aquifers. A discussion of the parameters and the alterations is also found in Section 3. Further, the system does not easily address the case of semi-confined or leaky aquifer conditions. Proper evaluation of leaky aquifers requires the user to select either confined or unconfined conditions and modify those conditions within the bounds of the system with consideration of hydrogeology and the purpose of the assessment.

POTENTIAL USES

Upon firm recognition of these assumptions, the user may begin to attempt to make full use of the system. The user must also remember that the methodology is neither designed nor intended to replace on-site investigations or to specifically site any type of facility or practice. DRASTIC does not reflect the suitability of a site for waste disposal or land use activities.

The suitability of a waste disposal site is based not only on the ground water pollution potential of an area, but also on other design criteria. DRASTIC provides the user with a measure of relative ground-water vulnerability to pollution and therefore, may be one of many criteria used in siting decisions, but should not be the sole criteria. An example of the correct use of DRASTIC would be to use the system as a screening tool or hydrogeologic zoning map to ascertain whether such a facility is/may be sited in an area which is generally vulnerable to the release of contaminants at the surface. Thus the area around the facility might be the focus of a region where DRASTIC is determined. High DRASTIC scores would indicate that the site is located in a generally sensitive or vulnerable area. An additional site specific evaluation would still be necessary for determining site suitability for waste disposal or land use activities. The primary charge of DRASTIC is to provide assistance in resource allocation and prioritization of many types of ground-water related activites as well as to provide a practical educational tool.

Many other beneficial applications of DRASTIC have also been recognized. For example, DRASTIC may be used for preventative purposes through the prioritization of areas where ground-water protection is critical. The system may also be used to identify areas where special attention, or protection efforts are warranted. For example, DRASTIC might be used as part of a strategy to identify areas where either additional or less stringent protection measures during underground storage tank replacement are advisable. DRASTIC coupled with other factors such as application methods may help delineate areas where pesticides may pose a greater threat to ground water.

Another application of DRASTIC includes the prioritization of areas for monitoring purposes. In this situation a denser monitoring system might be installed in areas where pollution potential is higher and land use suggests a potential source. The efficient allocation of resources for clean-up and restoration efforts after contamination has occured is one more possible use of DRASTIC. Although DRASTIC cannot be used to identify areas where pollution has occurred, it may be desirable to focus clean-up efforts in those areas with the highest pollution potential. In other situations DRASTIC might be better used to point out special hydrogeologic characteristics which would generally influence clean-up efforts. For example, knowledge that the general depth to water was 50 to 75 feet would rule out the use of a suction lift pump in remediation efforts.

DRASTIC may be employed in the evaluation of land use activities with respect to the development of pollution liability insurance and assessment of the economic impacts of disposal costs in highly vulnerable areas. The methodology may be used as a textbook in university courses to teach the fundamentals of pollution potential and resource protection. Finally, DRASTIC may be used to identify data gaps which affect pollution potential assessment. For example, justification could be provided for further reconnaissance of the hydrogeologic parameter which would subsequently form a better data base for future resource assessments or another DRASTIC analysis.

As with any model or classificiation scheme, it is possible to enter inaccurate or erroneous data which affect the reliability of the results. It is also possible to extend the system beyond the intended use of the methodology. For example, the use of DRASTIC to determine the vulnerability of ground water to pollution by an injection well is an inappropriate use of the methodology. By directly injecting the contaminant into the aquifer, the opportunity for the pollutant to be attenuated by the physical factors included in DRASTIC are removed. Any use of DRASTIC as the only assessment for siting a waste disposal or land use activity is also an inappropriate use of the system. For example, DRASTIC might be used as the preliminary screening tool to indicate the relative vulnerability of ground water to pollution in an area. However, the methodology would only be one phase of the actual site selection process because it is oftentimes necessary to consider many other factors in addition to ground-water vulnerability when siting a practice or facility. Another inappropriate use of DRASTIC would be to specifically site a municipal well in a wellfield located in a fractured bedrock area. The methodology might be one tool used to indicate relative ground-water pollution potential, but siting of the actual wells would need to be made based on fracture trace analysis and other considerations.

In summary, in all of the potential applications, DRASTIC cannot be used to replace site specific investigations or to preclude the consideration of particular factors which may be important at a site by a professional hydrogeologist. While DRASTIC can be a very useful tool, the further the application strays from the assumptions inherent in the methodology, the greater the likelihood of problems with resultant accuracy.

THE SYSTEM

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

HYDROGEOLOGIC SETTINGS

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

In order to assist users who may have a limited knowledge of hydrogeology, the entire standardized system for evaluating ground-water pollution potential has been developed within the framework of an existing classification system of ground-water regions of the United States. Heath (1984) divided the United

States into 15 ground-water regions based on the features in a ground-water system which affect the occurrence and availability of ground water (Figure 1). These regions include:

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

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

For the purposes of the present system, Region 12 (Alluvial Valleys) has been reincorporated into each of the other regions and Region 15 (Puerto Rico and Virgin Islands) has been omitted. Since the factors which influence ground-water occurrence and availability also influence the pollution potential of an area, this regional framework is used to help familiarize the user with the basic hydrogeologic features of the region. An annotated description of each of the regions and the significant hydrogeologic factors are included in Section 7, Hydrogeologic Settings of the United States by Ground-Water Regions.

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

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

A set of hydrogeologic settings has been developed for each region. The document is designed so that once the broad geographic area is located the user does not have to refer to other hydrogeologic settings in other regions. This means that similar hydrogeologic settings may appear more than once in the document, but that they have been tailored to reflect the typical hydrogeologic conditions within each individual region.

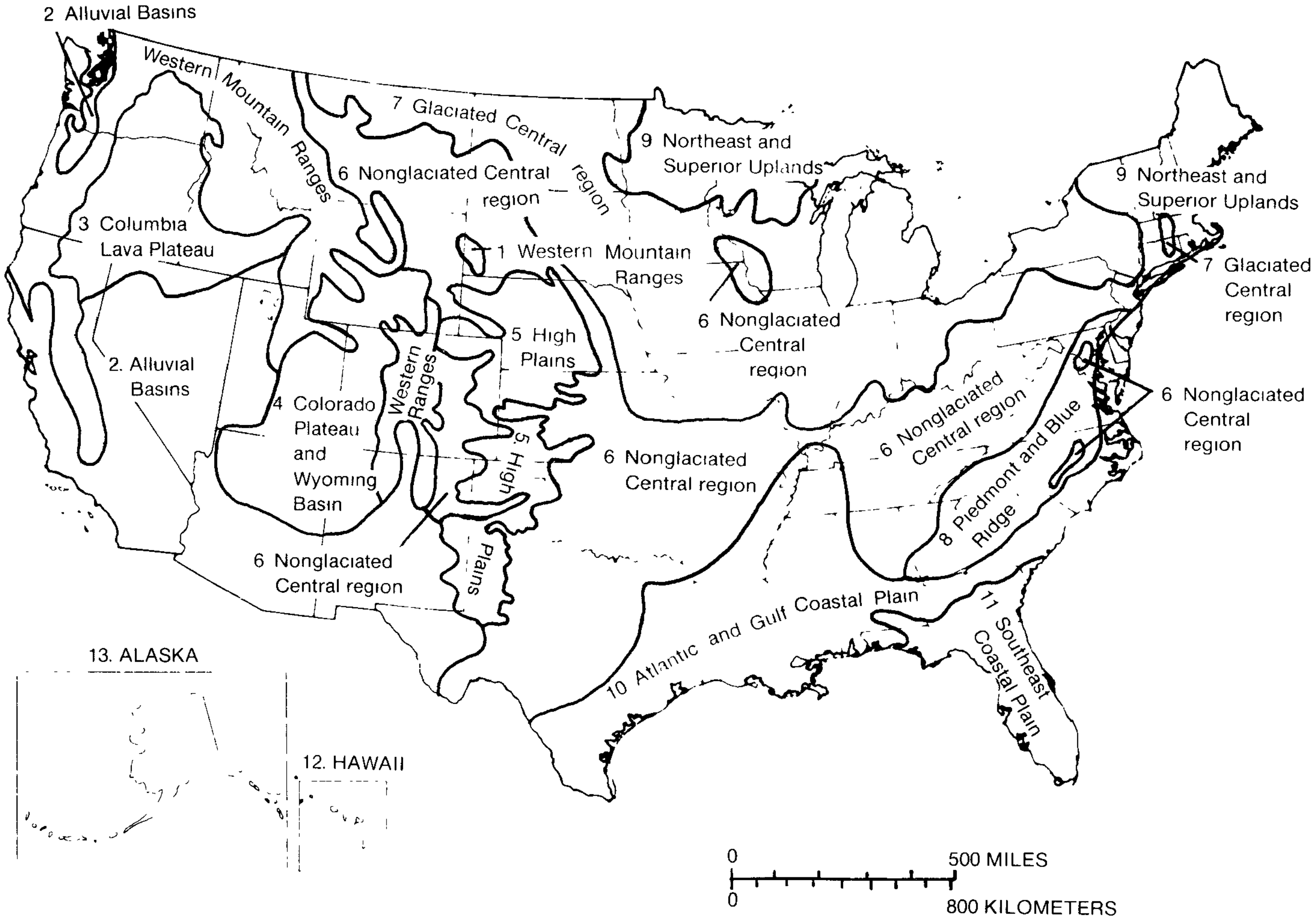


Figure 1. Ground-water regions of the United States (After Heath, 1984).

HAWAII

(12C) Volcanic Uplands

This hydrogeologic setting is characterized by moderately rolling topography, at medium elevations, and rich, dark, soils developed from the basaltic bedrock. The soils are permeable, rainfall is high, and recharge is high. Bedrock is composed primarily of alternating extrusive basaltic lava flows and interlayered weathered zones formed between flows. Ground water occurs at moderate to deep depths, and aquifer yield is controlled by fracture zones, vesicular zones (both primarily cooling features) and the inter-flow weathered zones. Hydraulic conductivity is high. As with other settings in Hawaii, heavy pumping stresses often result in salt-water intrusion. This is a reflection of the fact that each island is surrounded by and underlain by salt water, with the fresh water occurring in a lenticular body that floats on the salt water. Ground water yield is therefore limited quite specifically to the amount of water recharged annually.

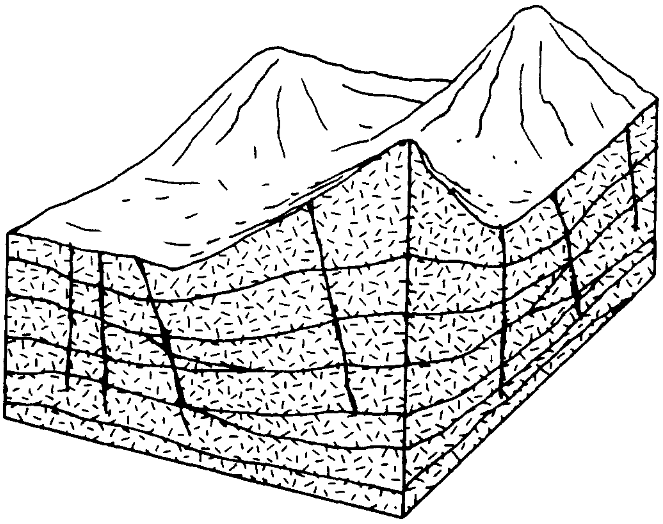


Figure 2. Format of hydrogeologic setting.

DRASTIC

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

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

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

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

1) Weights

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

TABLE 1. SOURCES OF HYDROGEOLOGIC INFORMATION

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

TABLE 2. ASSIGNED WEIGHTS FOR DRASTIC FEATURES

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

TABLE 3. ASSIGNED WEIGHTS FOR PESTICIDE DRASTIC FEATURES

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

2) Ranges

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

3) Ratings

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

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

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

Where:

R = rating
W = weight

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

PESTICIDE DRASTIC

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

TABLE 4. RANGES AND RATINGS FOR DEPTH TO WATER

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

TABLE 5. RANGES AND RATINGS FOR NET RECHARGE

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

TABLE 6. RANGES AND RATINGS FOR AQUIFER MEDIA

AQUIFER MEDIA

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

Weight 3   Pesticide Weight 3

TABLE 7. RANGES AND RATINGS FOR SOIL MEDIA

SOIL MEDIA

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

TABLE 8. RANGES AND RATINGS FOR TOPOGRAPHY

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

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

IMPACT OF THE VADOSE ZONE MEDIA

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

Weight 5 Pesticide Weight 4

TABLE 10. RANGES AND RATINGS FOR HYDRAULIC CONDUCTIVITY

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

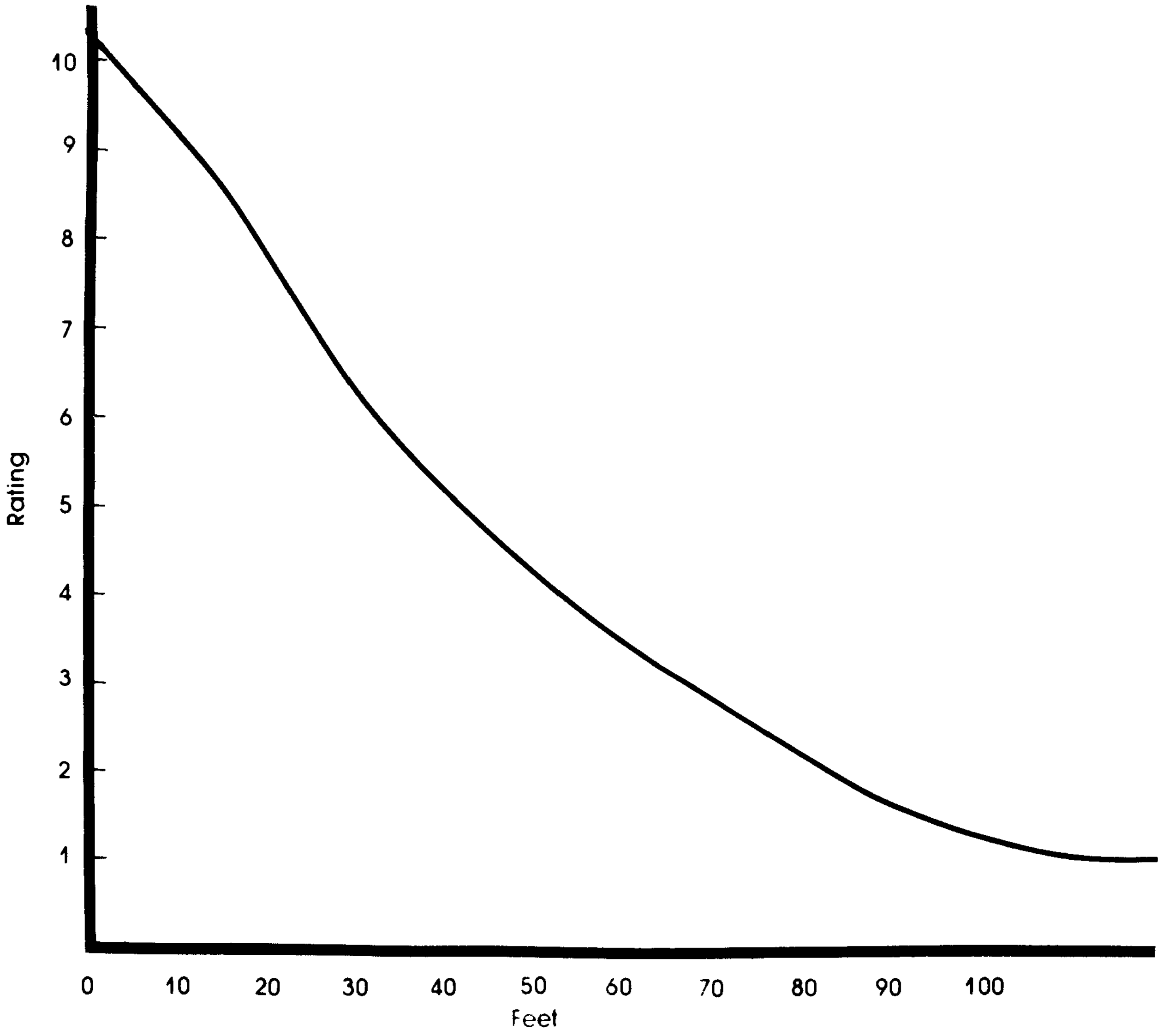


Figure 3. Graph of ranges and ratings for depth to water.

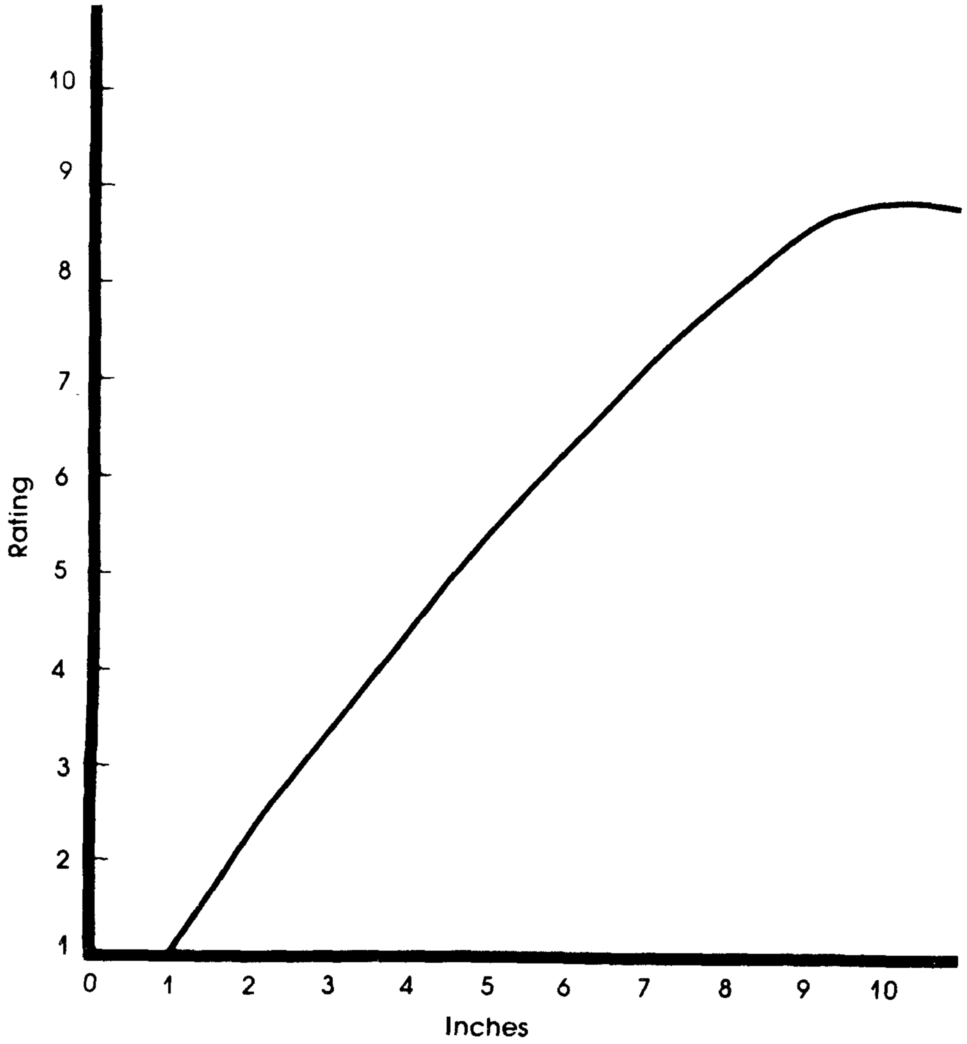
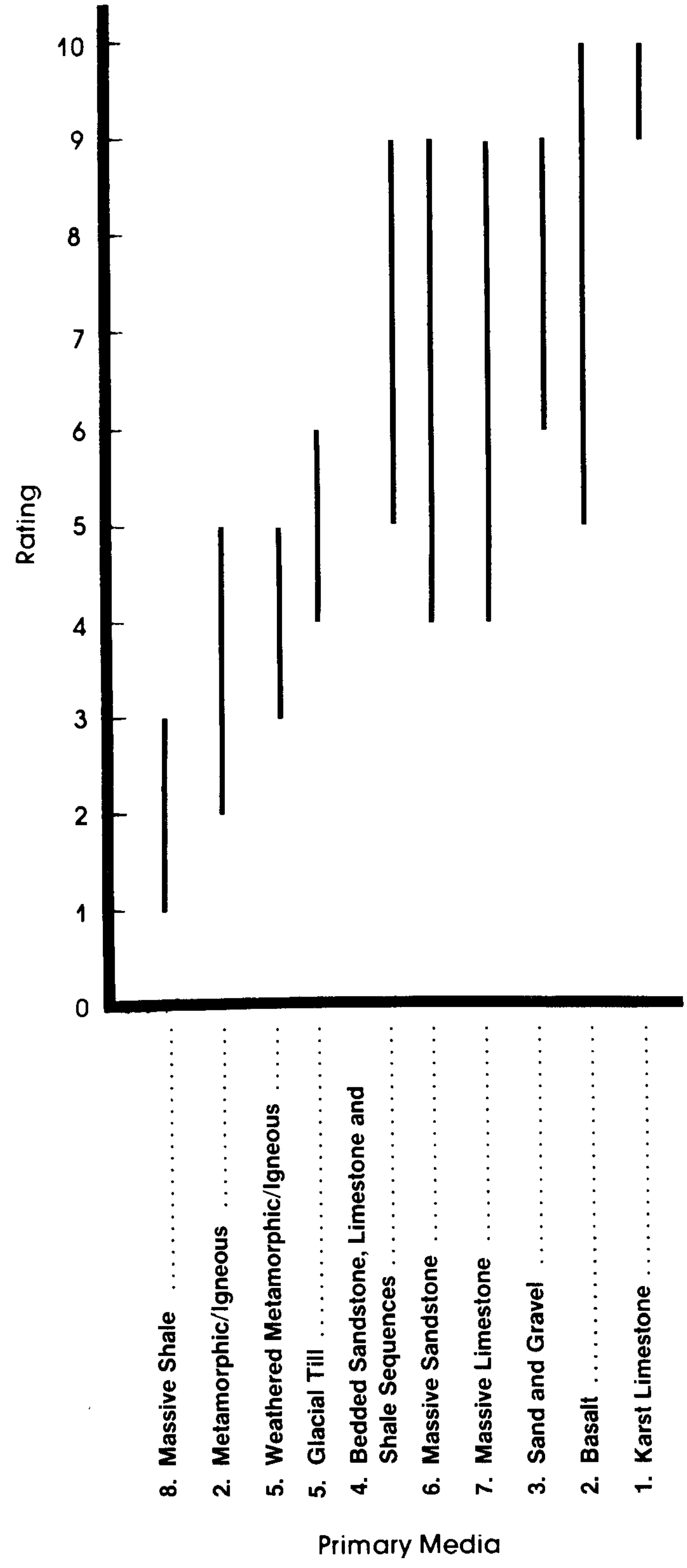


Figure 4. Graph of ranges and ratings for net recharge.



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

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

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

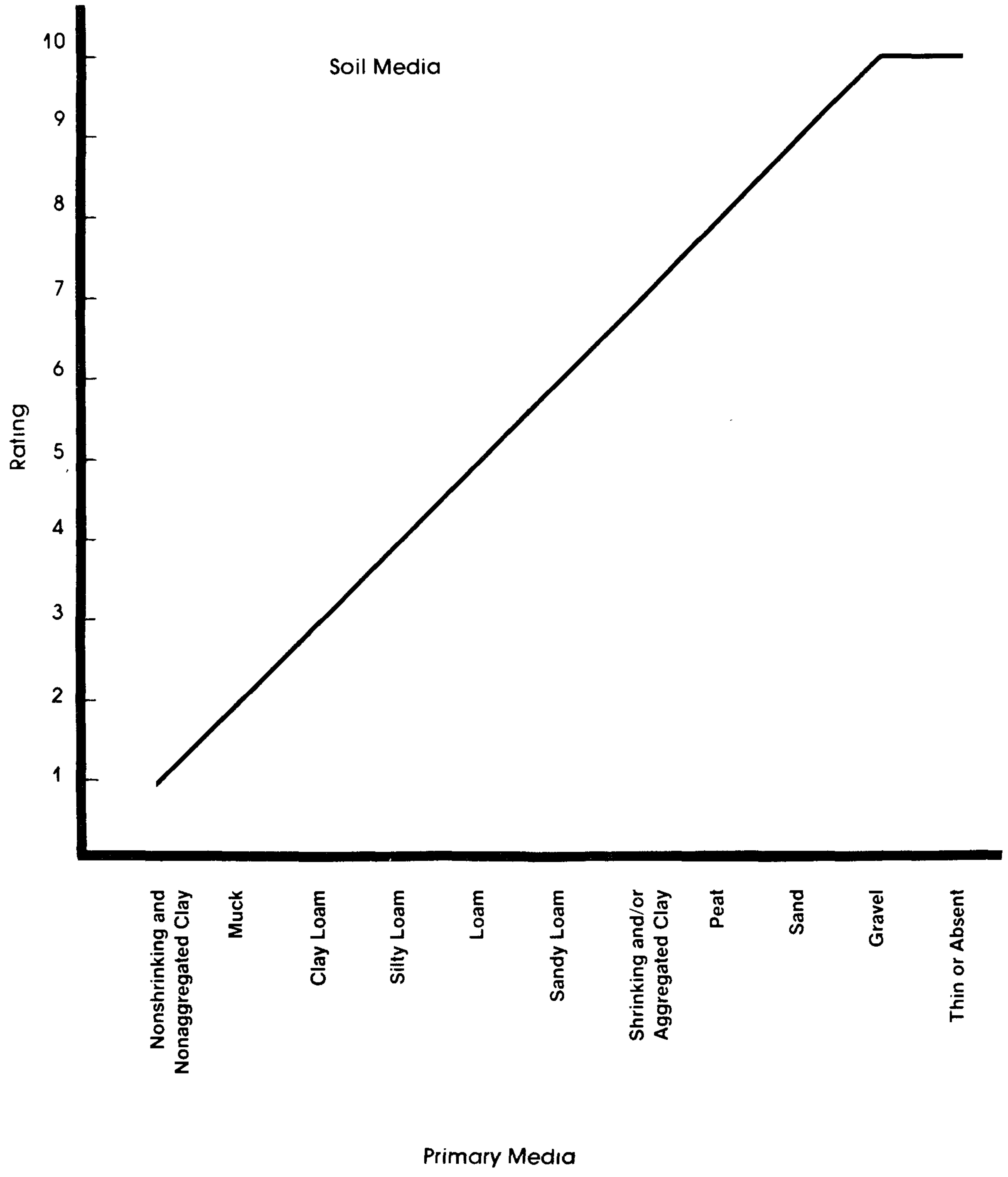


Figure 6. Graph of ranges and ratings for soil media.

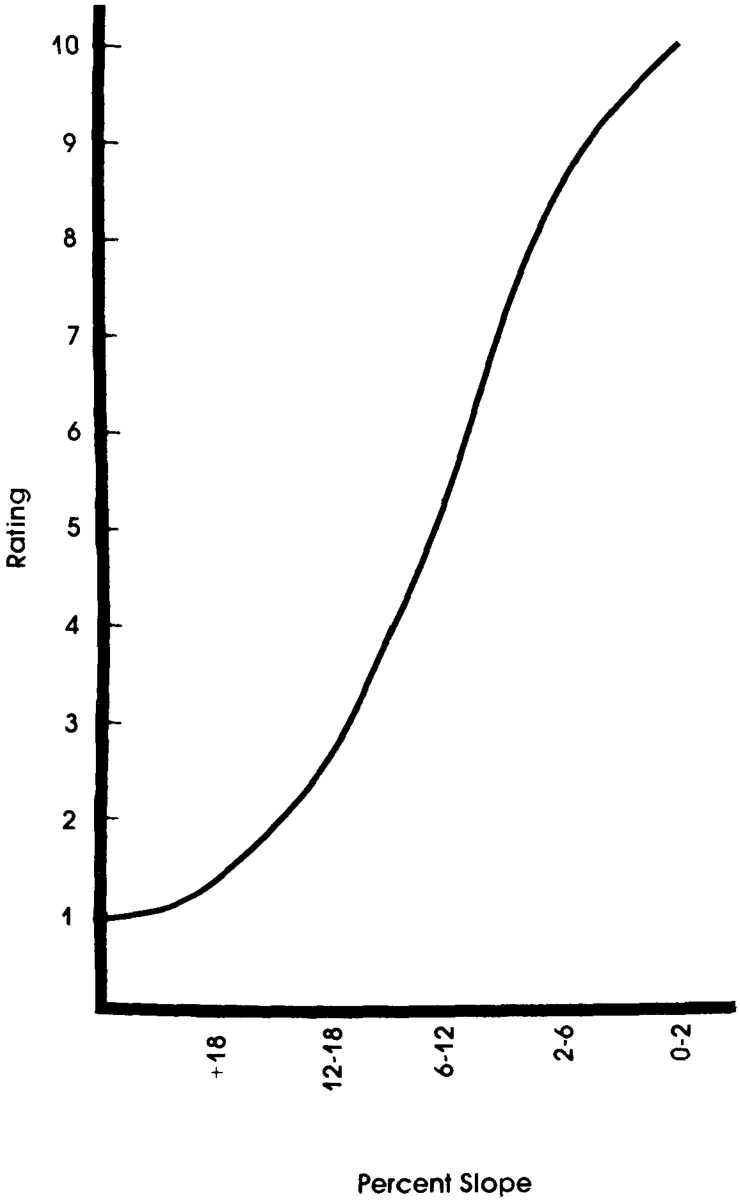
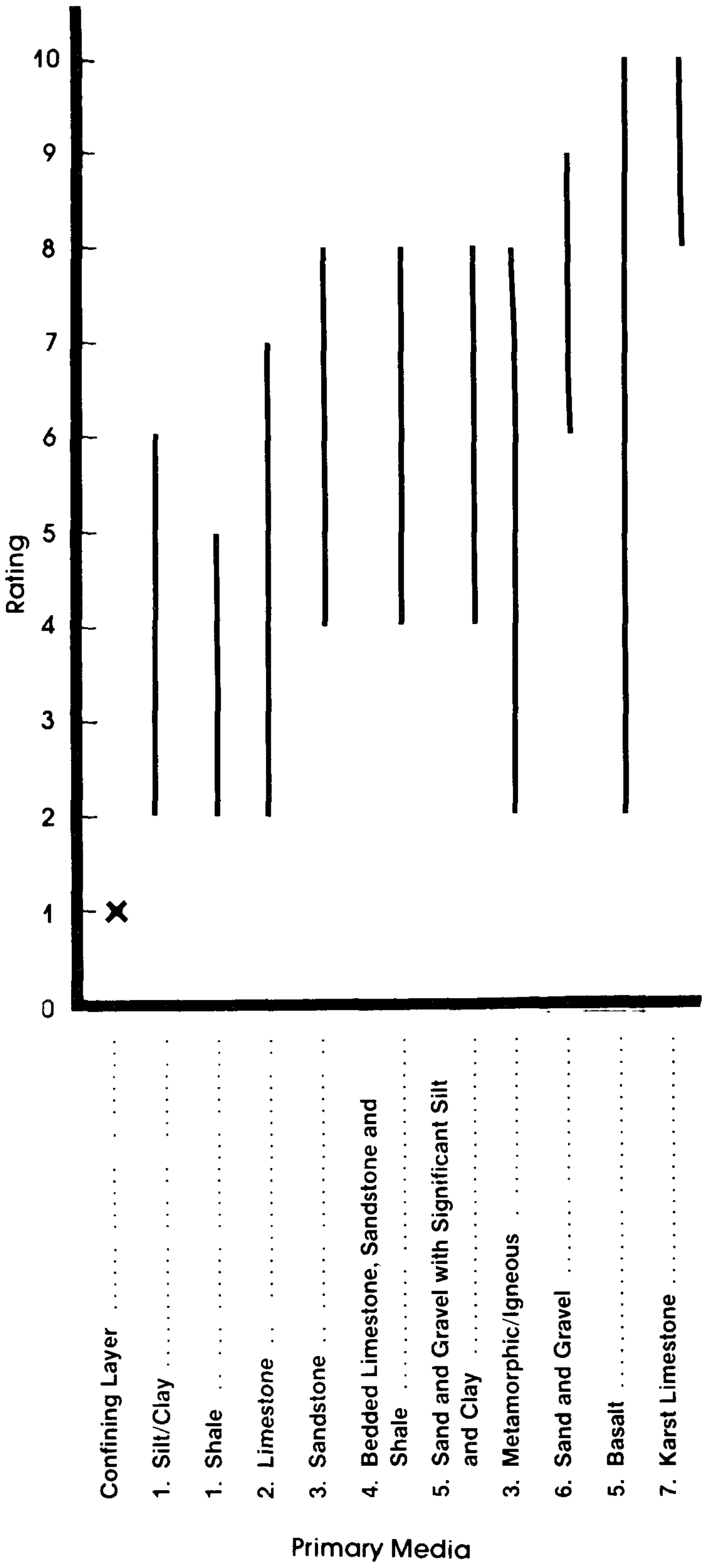


Figure 7. Graph of ranges and ratings for topography.



Relative impact of the principal Vadose Zone Media types. Range based upon:

a) path length and tortuosity,
b) potential for dispersion and consequent dilution,
c) reactivity (solubility),
d) consumptive sorption,
e) fracturing

Primary factors affecting rating:

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

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

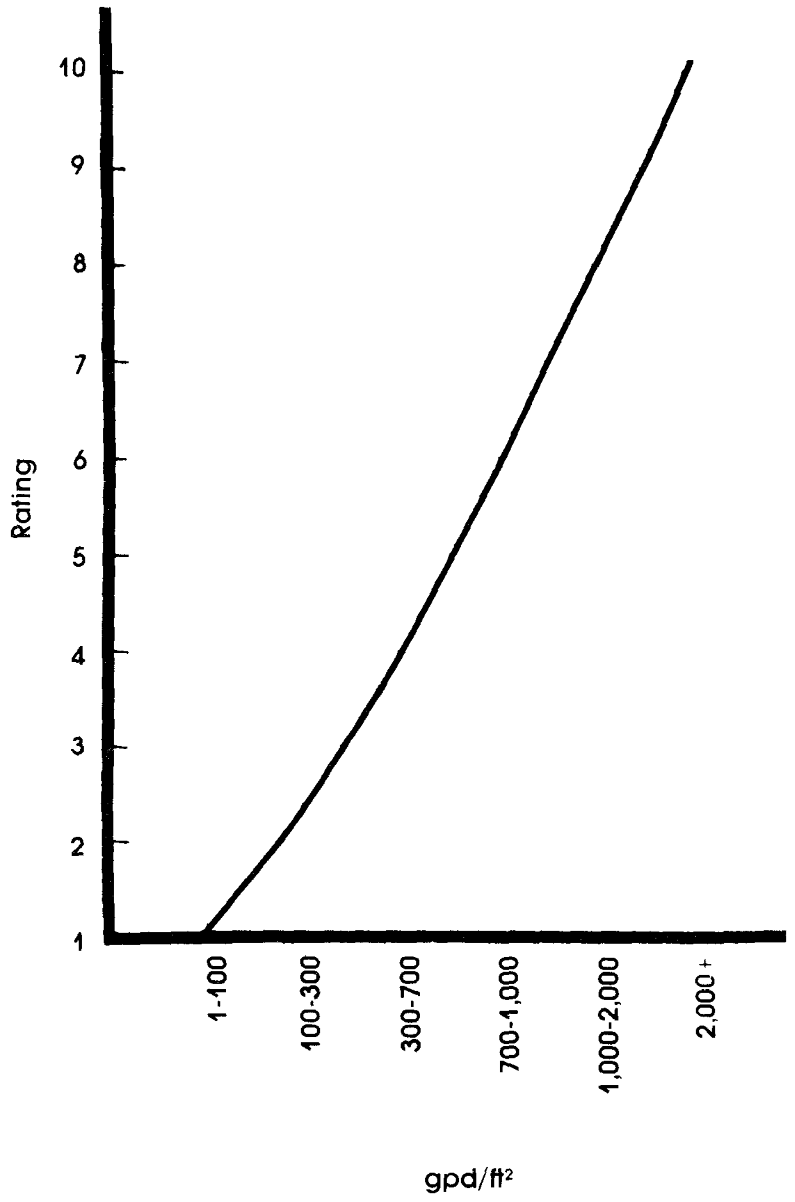


Figure 9. Graph of ranges and ratings for hydraulic conductivity.

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

INTEGRATION OF HYDROGEOLOGIC SETTINGS AND DRASTIC

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

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Heath, Ralph C., 1984. Ground-water regions of the United States; U.S. Geological Survey, Water Supply Paper 2242, 78 pp.

SECTION 3

DRASTIC: A DESCRIPTION OF THE FACTORS

GROUND-WATER CONTAMINATION AND DRASTIC

Ground-water pollution is caused by a variety of substances originating from many different activities. In general, man-influenced contaminants enter ground water through three pathways: 1) the placing or spreading of liquids or water soluble products on the land surface, 2) the burial of substances in the ground above the water table, or 3) the emplacement or injection of materials in the ground below the water table (Lehr et al., 1976). Table 11 lists the activities which cause contamination through one or more of these pathways. A description of each of these activities is included in Appendix C, Sources of Ground-Water Contamination.

After release at the land surface, the contaminant may infiltrate downward through the soil, vadose zone into saturated zone, thus finally reaching the aquifer. If the volume of contaminant is not great, the contaminant may be retained in the soil or vadose zone. If the contaminant is not completely attenuated, it may later be flushed toward the water table by infiltrating precipitation or additional amounts of contaminant. Once within the aquifer, the contaminant may: 1) travel at the velocity of and in the direction of ground water (Figure 10), 2) travel slower than the ground water (Figure 11), 3) float on the surface of the water table (Figure 12), 4) "sink" through the aquifer to the bottom (Figure 13) or 5) under some conditions, may actually move in a direction against the flow of the ground water (Figure 14). Generally, the majority of contaminants travel in the direction of ground-water flow at a velocity somewhat less than that of the ground water.

As the contaminant travels through this system, attenuation of the contaminant may take place. Attenuation includes mechanisms which reduce the velocity of the contaminant through processes such as dilution, dispersion, mechanical filtration, volatilization, biological assimilation and decomposition, precipitation, sorption, ion exchange, oxidation-reduction, and buffering and neutralization (Pye and Kelley, 1984; Fetter, 1980). The degree of attenuation which can occur is a function of 1) the time that the contaminant is in contact with the material through which it passes, 2) the grain size and physical and chemical characteristics of the material through which it passes, and 3) the distance which the contaminant has traveled. In general, for any given material the longer the time and greater the distance, the greater the effects of attenuation. In a similar manner, the greater the surface area of the material through which the contaminant passes, the greater the potential for sorption of the contaminant and hence for attenuation. The

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

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

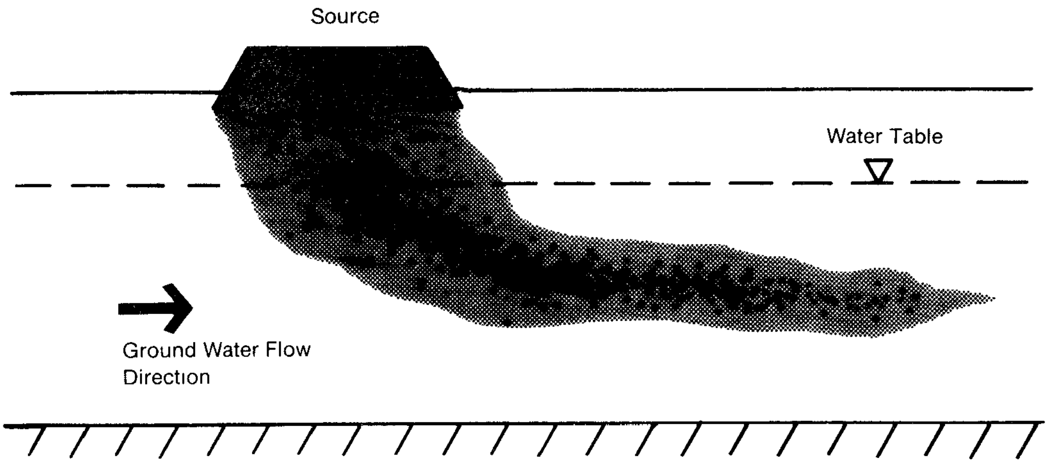


Figure 10. Travel of contaminant with same density as water in the aquifer.

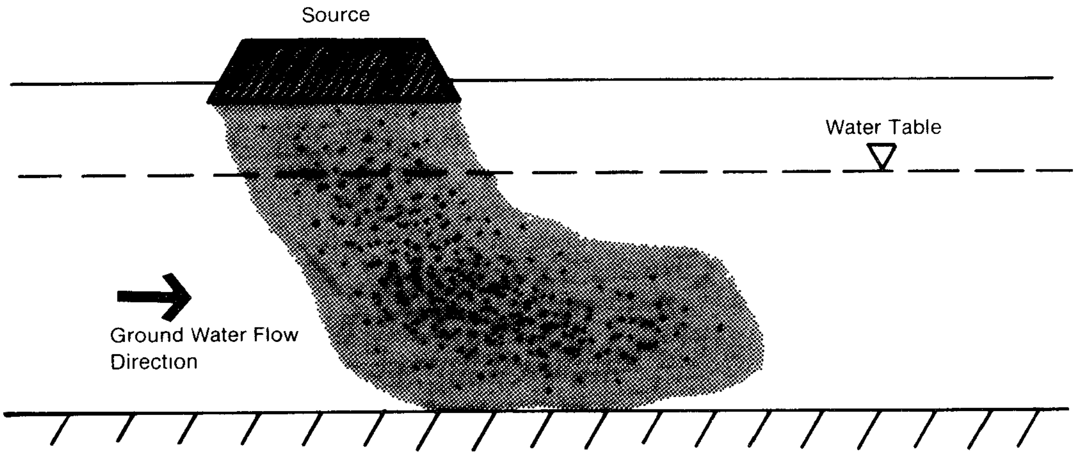


Figure 11. Travel of contaminant that is denser than water in the aquifer.

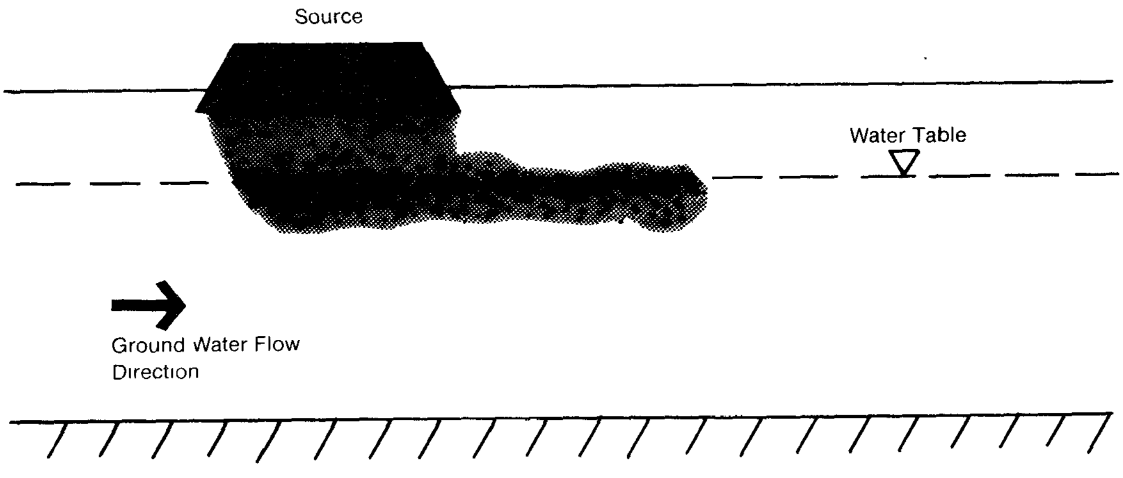


Figure 12. Travel of contaminant that is less dense than water in the aquifer.

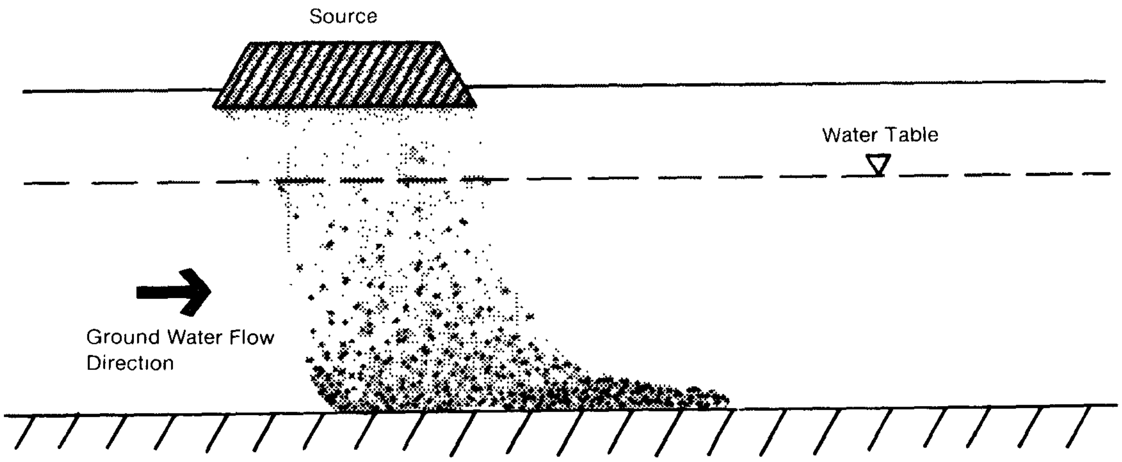


Figure 13. Travel of contaminant that is denser than water and sinks in the aquifer.

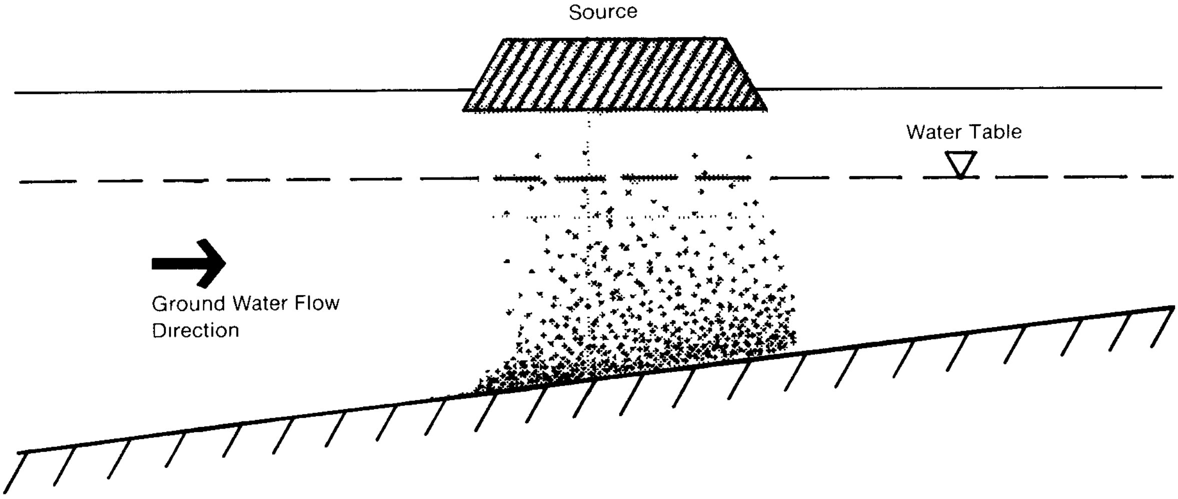


Figure 14. Travel of contaminant that is denser than water in the aquifer in a direction opposed to the water flow direction.

greater the reactivity of the material through which the contaminant passes, the greater the potential for attenuation. Any combination of these processes may be active depending on the hydrogeologic conditions and the contaminant. It is therefore necessary to have a general idea of these processes and whether they are active. A discussion of the mechanisms which control contaminant movement is included in Appendix A, Processes and Properties Affecting Contaminant Fate and Transport.

The effectiveness of dilution and attenuation processes is largely determined by 1) the rate and loading of the applied contaminant, 2) the characteristics of the contaminant and 3) the physical characteristics of the area. Ultimately, it is these factors which control the ground-water pollution potential of any area. The rate and loading factor which generally is of site specific character is discussed briefly in Section 6, IMPACT - Risk Factors. The characteristics of the contaminants are discussed in more detail in Appendix B, Characteristics of Ground-Water Contaminants. However, it is the physical properties characterized by the hydrogeologic setting of the area that determine the extent to which the attenuation mechanisms may have the potential to be active.

Because it is neither practical nor feasible to obtain quantitative evaluations of these intrinsic mechanisms from a regional perspective, it is necessary to look at the broader physical parameters which incorporate the many processes. Each of the DRASTIC parameters includes various mechanisms which will help to evaluate the vulnerability of ground water to pollution. When this is coupled with an understanding of the hydrogeology of the area, the result will be a clearer image of the potential for pollutant travel and attenuation. The following section provides a discussion of the possible movement and attenuation of contaminants in selected hydrogeologic settings.

GROUND-WATER CONTAMINATION AND HYDROGEOLOGIC SETTINGS

Figure 15 illustrates a typical hydrogeologic setting which provides the user with a feeling for the hydrologic cycle within the setting. This illustration further serves to depict anticipated flow patterns and reductions in contaminant concentrations during transport through the setting. This particular setting represents an unconsolidated sand, silt and clay deposit with a relatively shallow depth to water. A contaminant introduced at the surface is flushed by precipitation through the vadose zone into the ground water. Once within the ground-water system, a contaminant with an assumed mobility of water will be transported according to the flow patterns present within the aquifer. The concentration of the contaminant in the ground water will be influenced by dispersion, dilution and other natural attenuation processes. As the contaminant migrates through the aquifer, the various processes of attenuation that occur within this setting will typically cause reductions in contamination concentrations.

Similar flow and contaminant transport processes may be illustrated in different hydrogeologic settings. Figure 16 represents a hydrogeologic setting composed of bedded sandstones and shales. A contaminant introduced at the surface is flushed by precipitation through the soil and toward the sandstone

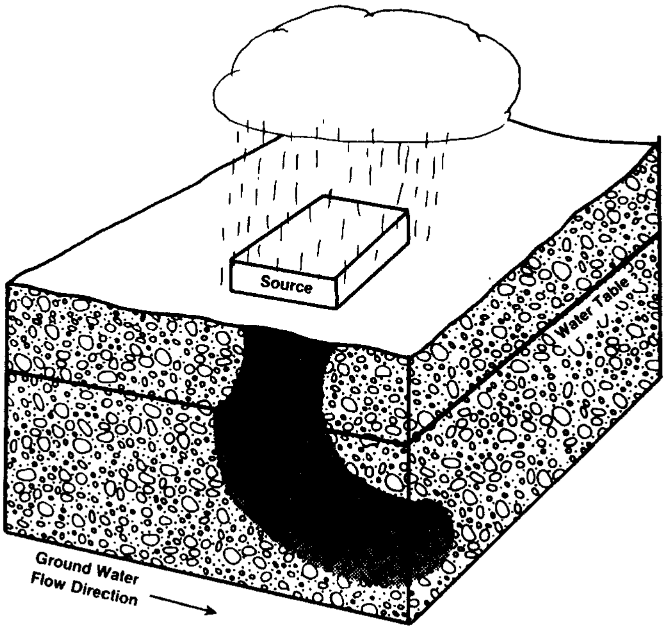


Figure 15. Hydrogeologic impact on a contaminant in an unconsolidated aquifer.

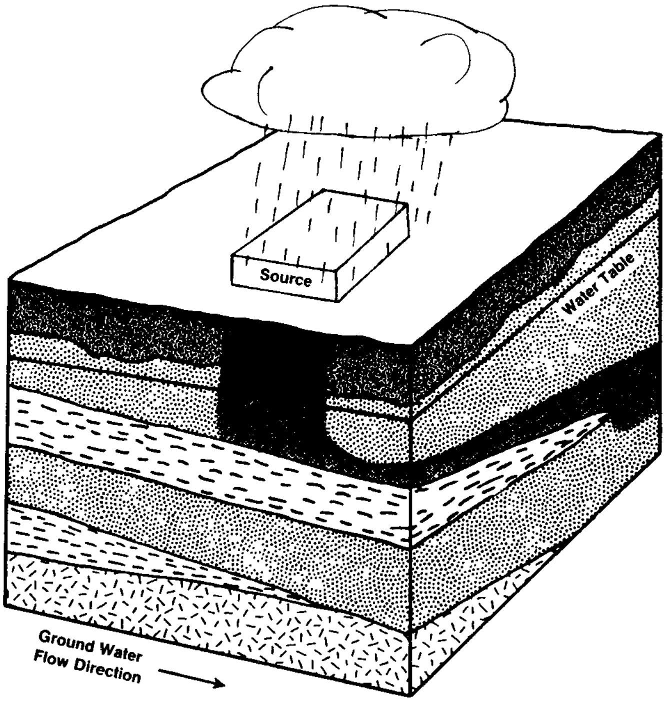


Figure 16. Hydrogeologic impact on a contaminant in a consolidated sedimentary aquifer containing a restrictive layer.

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

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

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

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

ASSUMPTIONS OF DRASTIC

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

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

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

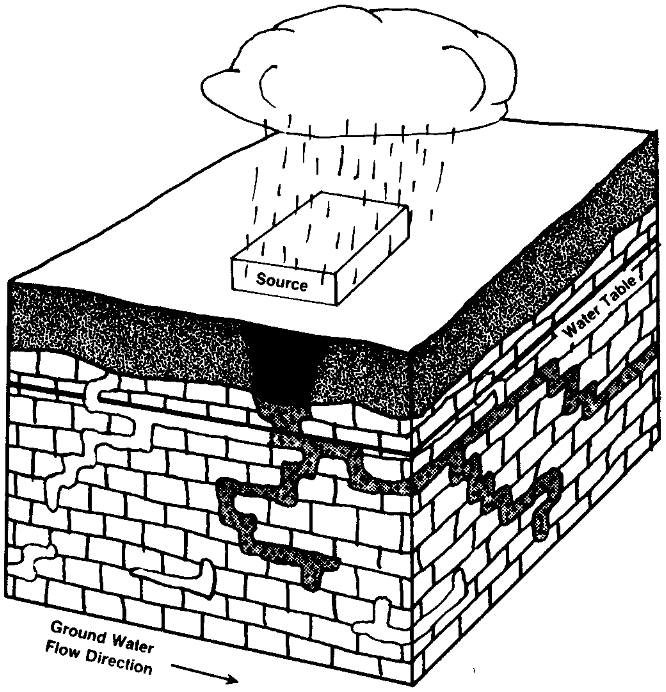


Figure 17. Hydrogeologic impact on a contaminant in a solutioned aquifer.

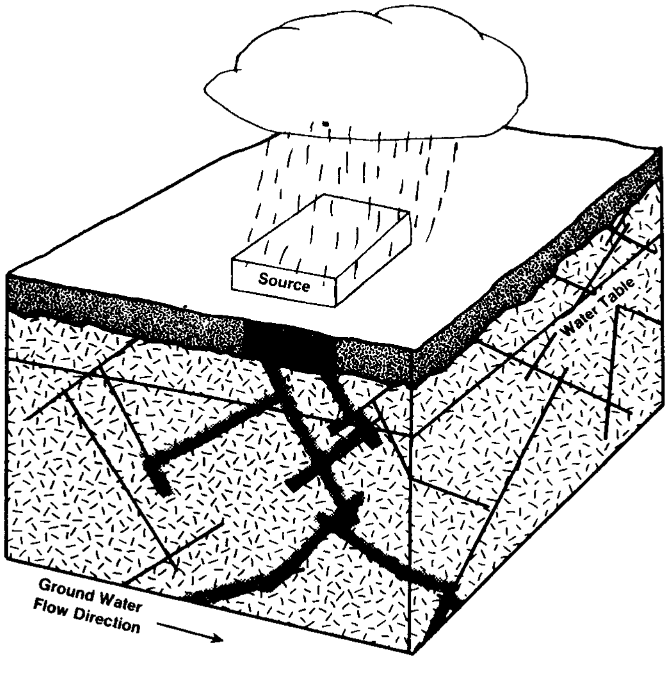


Figure 18. Hydrogeologic impact on a contaminant in a fractured aquifer.

would restrict movement into ground water. A contaminant may be denser than water and exhibit travel characteristics different from water. Further, a disposal method which injects contaminants directly into ground water negates many of the natural attenuation mechanisms assumed in the methodology. In this particular case, DRASTIC does not provide an accurate assessment of ground-water pollution potential.

In assuming areas of 100 acres or larger, DRASTIC attempts to evaluate ground-water pollution potential from a regional perspective rather than a site specific focus. An applicable analogy would be viewing an object with the naked eye versus a magnifying glass. For example, in an area of fractured rock, ground water generally flows in a regional direction. However, ground-water flow at any one site will be directly controlled by fracture orientation. In this scenario, exact direction of contaminant movement is controlled by a site specific characteristic. Generally, however, the contaminant would still flow in the regional direction.

In summary, DRASTIC can be a very useful tool when the assumptions of the methodology are met. However, the user needs to exercise caution and consider special conditions when deviations from the assumptions occur. To further assist the user in understanding the criteria upon which DRASTIC was created, a description of each DRASTIC feature is contained in the following sections. Processes of contaminant movement are also considered in the description of each feature.

DEPTH TO WATER

Depth to water is important primarily because it determines the depth of material through which a contaminant must travel before reaching the aquifer, and it may help to determine the contact time with the surrounding media. The depth to water is also important because it provides the maximum opportunity for oxidation by atmospheric oxygen. In general, there is a greater chance for attenuation to occur as the depth to water increases because deeper water levels imply longer travel times. The presence of low permeability layers which confine aquifers will also limit the travel of contaminants into an aquifer. Figure 3 shows the relative importance of depth to water. The ranges in depth to water as defined in the DRASTIC system have been determined based on what are considered to be depths where the potential for ground-water pollution significantly changes.

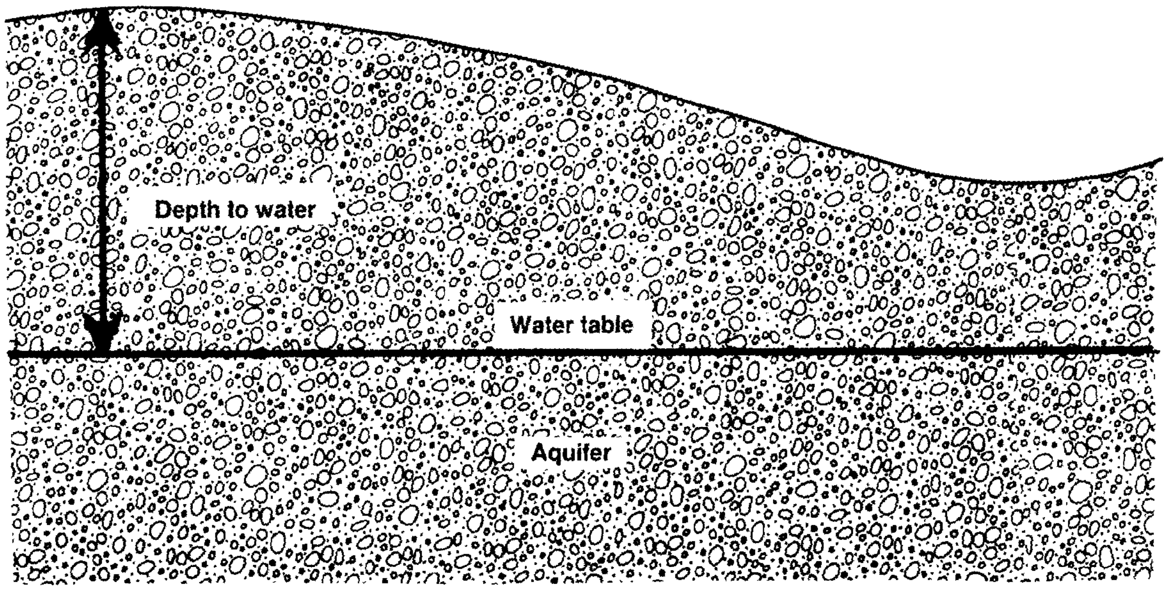
Ground water occurs in either unconfined, confined or semi-confined conditions. In an unconfined aquifer, the water table represents the uppermost elevation where the openings in the soil or rock material are filled with water. The water table is free to rise and fall under atmospheric pressure. Where present, unconfined aquifers are the uppermost aquifer near the ground surface, and as a result, these aquifers commonly are susceptible to ground-water pollution. The water in a confined aquifer is under pressure by the presence of a confining layer. By definition, the water level in a well penetrating a confined aquifer will rise above the base of the confining layer. Confined aquifers always underlie unconfined aquifers where unconfined aquifers are present. Confined aquifers have more natural protection from contaminants infiltrating from the ground surface and are less vulnerable to pollution. Semi-confined aquifers refer to aquifers overlain by confining layers which allow water to move through the layer. In this case, the aquifer is not truly confined and the confining bed is termed "leaky". Semi-confined aquifers exhibit characteristics ranging from unconfined to confined aquifers. Rate and direction of ground-water movement through the confining layer depends on the ground-water gradients and degree of confinement of the layer. Leaky confining layers may allow water to leak into the aquifer under downward gradients. In this case, the aquifer is more vulnerable to pollution than a confined aquifer. Conversely, where ground-water gradients are upward, leakage of water occurs away from the semi-confined aquifer. In this situation, the aquifer would be less vulnerable to pollution.

The unconfined or confined condition of the aquifer may have spatial variation. For example, the same aquifer may be unconfined in one area and change to confined conditions in another area. Varying degrees of confinement are not uncommon particularly when the aquifer is of large areal extent. All other variables equal, the pollution potential of the aquifer increases as the degree of confinement decreases.

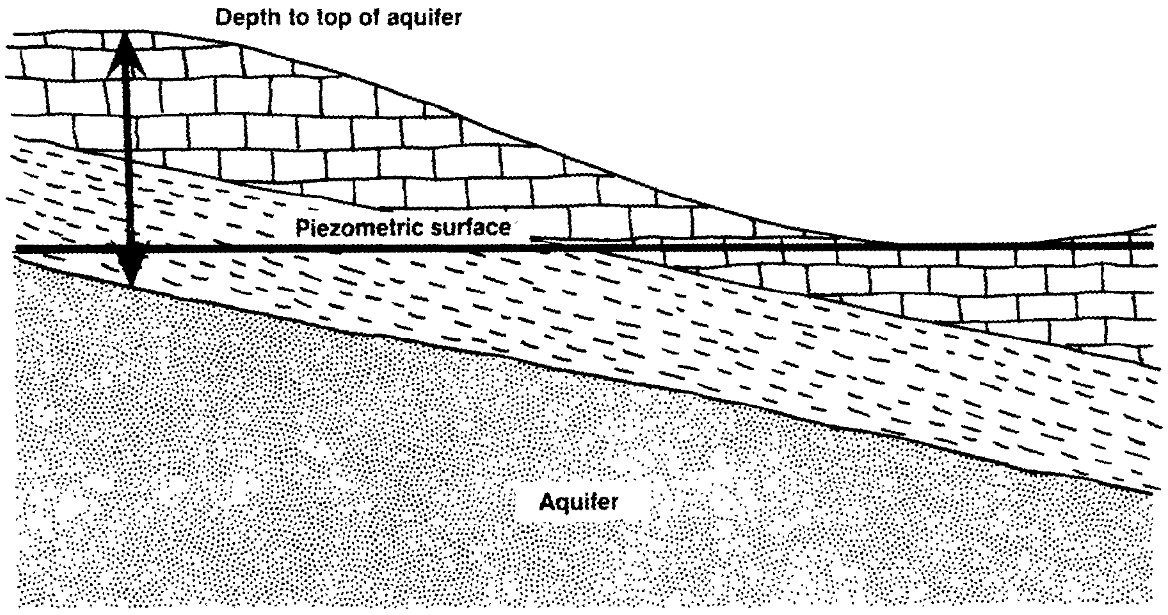
The methodology can be used to evaluate either confined or unconfined aquifers. In an unconfined aquifer, the user chooses depth to water as the depth from the ground surface to the water table (Figure 19). The water table is the expression of the surface below the ground level where all the pore spaces are filled with water. Above the water table, the pore spaces are partially filled with water and air. The water table may be present in any type of media and may be either permanent or seasonal. Depth to water does not include saturated zones which have insufficient permeability to yield significant enough quantities of water to be considered an aquifer. Water level data is available from a variety of sources including well logs and published water level maps contained in federal, state and local reports. A complete list of sources of potential information is contained in Table 1.

Because DRASTIC was originally designed for the evaluation of unconfined aquifers, special definitions must be assumed when evaluating depth to water for a confined aquifer. In the methodology, when an aquifer is confined, depth to water should be redefined as the depth to the top of the aquifer (Figure 19). This depth also corresponds to the base of the confining layer. When evaluating the depth to the top of the aquifer, the user does not refer to water level maps. The necessary information may be obtained in geologic reports containing cross sections or maps of the elevation of the bedrock surface. Well logs may also be a source of information.

Where semi-confined aquifer conditions exist, the user must choose to evaluate the aquifer as either unconfined or confined. DRASTIC does not permit the user to choose a semi-confined aquifer. The user must make a quantitative judgement of the degree of leakage with respect to pollution potential. If an aquifer is only slightly leaky, the user may evaluate the aquifer as confined and choose the depth to water as the depth from the ground surface to the top of the aquifer. Conversely, if the aquifer is significantly leaky, the user may wish to evaluate the aquifer as unconfined. In this case, the user must find information on water levels in wells penetrating the semi-confined aquifer for information on depth to water.



A. Determining depth to water in an unconfined aquifer.



B. Determining depth to water in a confined aquifer.

Figure 19. Diagrams showing how to determine depth to water.

Key words contained in published reports about ground-water levels may be of assistance in determining whether the aquifer is confined or unconfined. "Piezometric levels" are typically used when referring to water levels in confined aquifers. Piezometric comes from the Greek word for pressure. This implies that water in confined aquifers is under pressure and that pressure is the driving force. "Water Table" is generally used when referring to unconfined aquifers. In water table aquifers, the aquifer is open to the atmosphere and is not under pressure. In all cases, the user should gather as much information as possible about an aquifer in order to make an accurate and valid selection of the media rating. Knowledgeable individuals should be consulted where necessary.

NET RECHARGE

The primary source of ground water typically is precipitation which infiltrates through the surface of the ground and percolates to the water table. Net recharge represents the amount of water per unit area of land which penetrates the ground surface and reaches the water table. This recharge water is thus available to transport a contaminant vertically to the water table and horizontally within the aquifer. In addition, the quantity of water available for dispersion and dilution of the contaminant in the vadose zone and in the saturated zone is controlled by this parameter. Recharge water, therefore, is a principal vehicle for leaching and transporting solid or liquid contaminants to the water table. The greater the recharge, the greater the potential for ground-water pollution. This general statement is true until the amount of recharge is great enough to cause dilution of the contaminant, at which point the ground-water pollution potential ceases to increase and may actually decrease. For purposes of this document, this phenomena has been acknowledged but the ranges and associated ratings do not reflect the dilution factor.

As used in the methodology, net recharge is defined as the total quantity of water which is applied to the ground surface and infiltrates to reach the aquifer. Net recharge includes the average annual amount of infiltration and does not take into consideration distribution, intensity or duration of recharge events. Net recharge may be expressed in various units; DRASTIC uses inches per year.

Values for net recharge are often calculated for watershed or specific study areas, but rarely for a county. These values typically are found in published water resource or hydrologic reports and may need to be extrapolated to obtain representative recharge values for areas situated outside the study area of the published report. Where published values for net recharge are difficult to obtain, knowledgeable individuals may need to be consulted for estimates or confirmations of appropriate net recharge values. Because net recharge values are less precise and less easily obtained than values for other DRASTIC parameters, the ranges for net recharge are intentionally broad. These broad ranges afford the user "professional leeway" in choosing a range which is representative of the amount of recharge for the area.

Another potential source of recharge information is a water atlas which may contain general maps of average annual precipitation, evaporation and runoff. Where net recharge to an area principally occurs from precipitation, the user should be able to estimate the net recharge value as the amount of precipitation minus surface runoff, evaporation and transpiration. When using this method to determine the value for net recharge, it is necessary to ensure that the selected value is reasonable since net recharge is also influenced by other factors such as the amount of surface cover, slope and soil permeability. More accurate estimates of net recharge may be obtained by using more detailed water balance equations which account for these factors.

Net recharge values can be chosen to evaluate either unconfined or confined aquifers. A definition of unconfined and confined aquifers can be found in the section describing aquifer media. In areas where the aquifer is unconfined, recharge to the aquifer usually occurs more readily and the pollution potential is generally greater than in areas with confined aquifers. In unconfined conditions, net recharge values reflect typical water balance calculations. Confined aquifers are partially protected from contaminants introduced at the surface by layers of low permeability media which retard water movement to the confined aquifer. In portions of some confined aquifers, ground-water gradients are such that movement of water is through the confining bed from the confined aquifer into the unconfined aquifer. In this situation, there is little opportunity for local contamination of the confined aquifer and a low value for net recharge could be chosen. The principal recharge area for the confined aquifer is often many miles away. However, many confined aquifers are not truly confined and are partially recharged by migration of water through the confining layers. The more water that leaks through, the greater the potential for recharge to carry pollution into the aquifer. Values for net recharge can be chosen to reflect the amount of water which may actually recharge the aquifer.

In addition to infiltration from precipitation, sources of recharge including irrigation, artificial recharge and wastewater application must be considered. These sources of recharge may significantly affect the amount of water available to carry a pollutant into the aquifer. For example, irrigation has been estimated to provide as many as four inches per year to net recharge values. It is particularly important to account for irrigation water contribution when using Pesticide DRASTIC. The user should include all sources of recharge when choosing an appropriate net recharge range for DRASTIC.

Special consideration may need to be given to known recharge-discharge areas. Water flows from recharge to discharge areas. A recharge area occurs where there is a downward component of movement to the direction of ground-water flow; conversely, discharge areas have an upward component of flow near the surface. Discharge areas commonly form springs, rivers or other surface water expressions. Recharge and discharge areas may be influenced by changes in ground-water gradients. Changes in ground-water gradient commonly occur when nearby water wells are pumped. Where ground-water gradients are strongly upward, such as in areas with first order magnitude springs, pumpage has little effect on the recharge-discharge relationship. In this case, the user may wish to choose a lower value for net recharge because very little if any water is moving downward against such strong gradients. In areas where gradients are not as pronounced, pumpage may affect or reverse ground-water flow. In discharge areas where gradients may be easily reversed, the user may wish not to reduce net recharge values. Conversely, in known recharge areas which are environmentally sensitive, the user may wish to upwardly adjust the recharge values.

AQUIFER MEDIA

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

For purposes of this document, aquifer media have been designated by descriptive names. Each medium is listed in the order of increasing pollution potential. A discussion of each medium follows:

a) Massive Shale - Thick bedded shales, claystone or clays which typically yield only small quantities of water from fractures and which have a low pollution potential. Pollution potential is influenced by the degree of fracturing.

b) Metamorphic/Igneous Rock - Consolidated bedrock of metamorphic or igneous origin which contains little or no primary porosity and which yields water only from fractures within the rock. Typically well yields are low and the relative pollution potential is a function of the degree of fracturing.

c) Weathered Metamorphic/Igneous Rock - Unconsolidated material, commonly termed regolith or saprolite, which is derived by weathering of the underlying consolidated bedrock, and which contains primary porosity. The pollution potential is largely influenced by the amount of clay material present; the higher the clay content, the lower the pollution potential.

d) Glacial Till - Unconsolidated to semi-consolidated mixtures of gravel, sand, silt and clay-size particles which are poorly sorted and stratified. The low permeability of the till produces low yields to wells. Although glacial tills exhibit low permeabilities, wells completed in tills are typically shallow and may be more susceptible to contamination. Fracturing of tills may also influence pollution potential.

e) Bedded Sandstone, Limestone and Shale - Typically thin-bedded sequences of sedimentary rocks which contain primary porosity. The controlling factor in determining pollution potential is the degree of fracturing.

f) Massive Sandstone - Consolidated sandstone bedrock which contains both primary and secondary porosity and is typified by thicker deposits than the Bedded Sandstone Limestone and Shale sequences. Pollution potential is largely controlled by both the degree of fracturing and the primary porosity of the sandstone.

g) Massive Limestone - Consolidated limestone or dolomite bedrock which is characterized by thicker deposits than Bedded Sandstone, Limestone and Shale sequences. Pollution potential is largely affected by the degree of fracturing and the amount of solution cavities in the limestone.

h) Sand and Gravel - Unconsolidated mixtures of sand to gravel-sized particles which contain varying amounts of fine materials. Sands and/or gravels which have only small amounts of fine material are termed "clean." In general, the cleaner and more coarse-grained the aquifer, the greater the pollution potential.

i) Basalt - Consolidated extrusive igneous bedrock which contains bedding planes, fractures and vesicular porosity. The term is used herein in a generic sense, even though it is actually a rock type. Pollution potential is influenced by the amount of interconnected openings which are present in the lava flow materials.

j) Karst Limestone - Consolidated limestone bedrock which has been dissolved to the point where large, open, interconnected cavities and fractures are present. This is a special case of Massive Limestone.

A graphic display of the ratings which have been assigned to each media is contained in Figure 5. This graph also contains a more complete listing of the mechanisms which affect the pollution potential of that media. Because this DRASTIC parameter is less quantifiable than numerical parameters, the user will be instructed to choose a media type and rating based on the above discussion and available information on the geology of the area (Section 4, How to Use the Range in Media Ratings).

The user may choose to evaluate any aquifer within an area, however, only one aquifer may be evaluated at a time. In a multi-layer system, the user must decide which aquifer to choose as the appropriate media. Information on aquifers is typically available in published geologic or hydrologic reports, masters theses, well logs or other exploratory borings. A complete list of sources of potential information is contained in Table 1. Once the aquifer has been chosen, the aquifer media used for DRASTIC is selected by identifying the most significant media of the chosen aquifer. For example, if the aquifer is a limestone, the user would choose either massive or karst limestone as the aquifer media. Similarly, if the aquifer is a sand and gravel, the user would choose sand and gravel as the aquifer media.

DRASTIC provides the user with a range of ratings to choose from when evaluating the aquifer media. This allows the user to adjust the rating for the media based on specific information about the aquifer. If no specific information is available, or the user is uncertain, a typical rating for each media is provided. This typical rating has been chosen to depict a typical aquifer comprised of the associated aquifer media. The user may vary the rating based on degree of fracturing or presence of bedding planes in consolidated aquifers. For example, a moderately fractured metamorphic/igneous aquifer would receive a rating of 3. If however, the aquifer was highly fractured, the aquifer could be assigned a rating of 5 to indicate higher pollution potential. Conversely, if the metamorphic/igneous aquifer was only slightly fractured, the yields in the area would be low and the assigned rating would be a 2. In unconsolidated aquifers, the user may vary the rating based on the sorting and amount of fines within the aquifer. For example, a typical sand and gravel would receive a rating of 8. If the deposits are coarse and well-washed, the user could assign a rating of 9. Conversely, as the amount of fines increase and the deposits become more poorly sorted, the assigned rating can be lowered to 7 or 6.

SOIL MEDIA

Soil media refers to that uppermost portion of the vadose zone characterized by significant biological activity. For purposes of this document, soil is commonly considered the upper weathered zone of the earth which averages a depth of six feet or less from the ground surface. Soil has a significant impact on the amount of recharge which can infiltrate into the ground and hence on the ability of a contaminant to move vertically into the vadose zone. The presence of fine-textured materials such as silts and clays can decrease relative soil permeabilities and restrict contaminant migration. Moreover, where the soil zone is fairly thick, the attenuation processes of filtration, biodegradation, sorption and volatilization may be quite significant. Thus, for certain land surface practices, such as agricultural applications of pesticides, soil may have the primary influence on pollution potential. In general, the pollution potential of a soil is largely affected by the type of clay present, the shrink/swell potential of that clay and the grain size of the soil. In general, the less the clay shrinks and swells and the smaller the grain size, the less the pollution potential. The quantity of organic material present in the soil may also be an important factor particularly in the attenuation of pesticides. Organic matter is typically contained in the surface layer of the soil and composed of undecayed plant and animal tissue, charcoal and various humic compounds. The organic content of the soil generally decreases with depth from the surface. Humic compounds are principally responsible for the adsorption and complexation properties attributed to organic matter in the soil. Soil media are best described by referring to the basic soil types as classified by the Soil Conservation Service. A description of the soil media in order of increasing pollution potential follows:

a) Nonshrinking and Non-aggregated Clay - Illitic or Kaolinitic clays which do not expand and contract with the addition of water and therefore do not form vertical secondary permeability which increases the pollution potential.

b) Clay Loam - A soil textural classification which is characterized by 15-55 percent silt, 27-40 percent clay and 20-45 percent sand (Figure 20). Because of the high amounts of clay and restrictive permeabilities, it has a low pollution potential.

c) Muck - A soil consisting of fine, dark-colored, well decomposed organic material that typically contains a higher mineral or ash content than peat. Muck contains the least amount of plant fiber of the organic soils, thus limiting permeability. The organic matter content may be a significant factor for lowering the pollution potential.

d) Silty Loam - A soil textural classification characterized by 50-85 percent silt, 12-27 percent clay and 0-50 percent sand (Figure 20). The pollution potential is still low, but higher than a clay loam because of typically lower percentages of clay.

e) Loam - A soil textural classification characterized by 25-50 percent silt, 7-27 percent clay and 0-50 percent sand (Figure 20). The pollution potential is still low, but higher than a silty loam because of lower percentages of clay and silt.

f) Sandy Loam - A soil textural classification characterized by 0-50 percent silt, 0-20 percent clay and 15-50 percent sand (Figure 20). The pollution potential is greater than a loam due to the higher percentage of sand.

g) Shrinking and/or Aggregated Clay - Characterized by montmorillonitic clays or smectites which have an expanding lattice that swell and contract with alternating wetting and drying. Dessication cracks may form as the soil dries. These cracks may later be shut as the clay swells when hydrated. Pollutants, however, may move rapidly through the dessication cracks upon initial wetting of the soil. Although usually of low permeability, this medium can have a seemingly high pollution potential based on the secondary vertical permeability created by the cracking of the media upon drying.

h) Peat - A soil consisting of undecomposed to partially decomposed plant material that is fresh enough to be identified. Although peats contain organic matter which may be significant for contaminant attenuation, they are relatively permeable, thus pollution potential is high.

i) Sand - A size-based delineation of angular or rounded particles ranging in size from 1/16 mm to 2 mm. Sands are typically free of silts and clays and therefore have a high pollution potential.

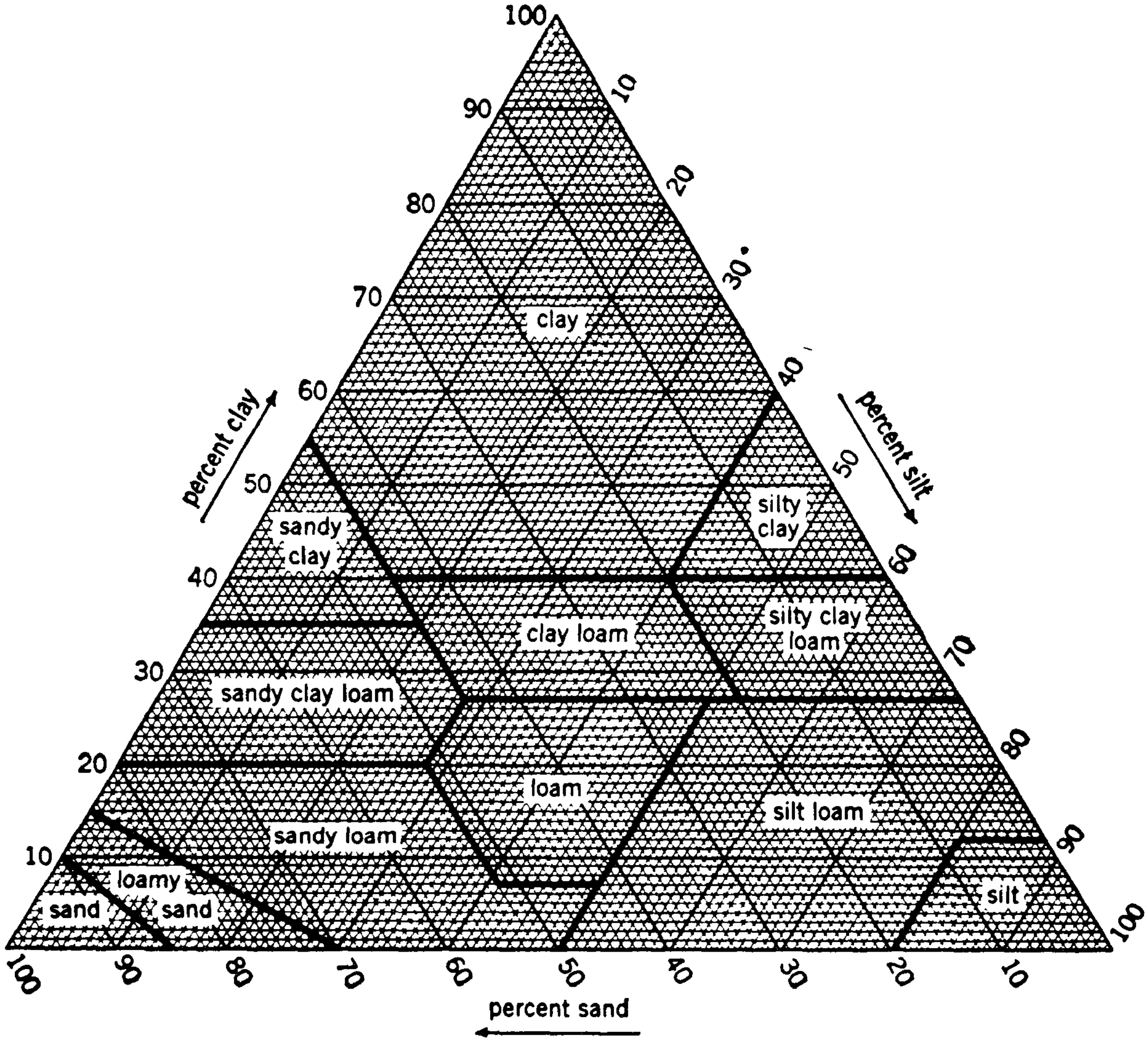


Figure 20. Soil textural classification chart (Soil Conservation Service, 1951).

j) Gravel - A particle-based size classification typified by particles larger than 2 mm in size. Gravel soils commonly include a mixture of sand, silt, clay and gravel particles, with a preponderance of large-sized particles. Permeability is rapid and pollution potential is high.

k) Thin or Absent - If a soil layer is not present or if the layer is so thin as to be considered ineffective for contaminant attenuation, the pollution potential is very high. Thin or absent should generally be chosen when the soil profile is 10 inches or less in thickness.

Figure 6 contains a graphic representation of the varying impacts which soil media may have on the ground-water pollution potential of an area. Soil surveys published by the Soil Conservation Service, United States Department of Agriculture, provide the information necessary for the evaluation of soils in DRASTIC. If published soil surveys are not available for a county, soil information may often be obtained from the local Soil and Water Conservation District. The county may be part of an active soil survey effort and portions or all of the county soils information may be available as field maps. If there is no on-going soil mapping project, portions of the county may have been previously evaluated for special projects. Regardless of the status of a mapping program, local soil scientists may be able to provide valuable soil information.

Published soil surveys provide information in three basic formats: 1) maps, 2) written descriptions and 3) descriptive charts. Soil survey maps are displayed as either general soil association maps or detailed soil maps which delineate individual soil series. The general soil association maps provide an overview of the major soil associations which have been identified in the county. These associations represent a geographically related group of soil series which are characterized by surface soil textures. The detailed soil maps are displayed as a series of fold-out sheets which detail specific soil series superimposed on aerial photographs. The soil series characteristics are described within the main text of the soil survey. A soil series is named for the geographic locality where the unique characteristics of the soil were first described. Soil series descriptions supply information on the soil drainage, texture and composition of the various horizons or layers within the series. This infomation is expanded into a group of charts which detail land capability usage and other important characteristics of each soil series. Of particular interest are the tables which detail the engineering properties and the physical and chemical properties of the soils.

The selection of an appropriate soil media in DRASTIC requires the user to consider the characteristics of the soils which influence ground-water pollution potential. This is accomplished by identifying the most significant soil textural layer which will influence water movement and contaminant transport. The user may take several approaches in this evaluation, however, the following approach is recommended until the user becomes familiar with the process.

1) Look at the general soil association map for the county.

2) Read the soil association descriptions in the text to identify major soil types.

3) Read the individual soil series descriptions for the major soil series in each soil association.

4) Review the depth and thickness of each soil texture in the soil profile by referring to the USDA texture category in the table of engineering properties.

5) Evaluate all horizons in the profile of a soil series and choose the most significant textural layers that will affect pollution potential based on consideration of the thickness and texture of the layers. Compare the chosen texture with the surface texture described in the general soil association description and map legend to determine what portions, if any, of the general soil association map may be used in DRASTIC. The selection of the most significant layer can be demonstrated in the following examples. The profile of a soil series is described as a sequential series of individual layers, starting from the ground surface. In the first example, the Astatula soil series has a profile of only one layer which is 0 to 86 inches of sand. The user would select sand as the appropriate soil media. In this case, the general soil association map would be usable for DRASTIC because sand also represents the surface texture of this soil series.

The next example represents a soil series with multiple soil layers. The Hiwassee soil has a profile of 0 to 7 inches of sandy loam, 7 to 62 inches of clay and 62 to 82 inches of sandy clay loam. In this example, the occurrence of 55 inches of clay would represent the most significant layer and would be selected as the appropriate soil media. The use of the general soils map or series name which denotes the surface texture as sandy loam would result in the incorrect choice of soil media without consideration of the entire soil profile. When clay is chosen as the significant soil texture, the user must evaluate the shrink-swell potential of each clay layer contained within the soil profile. The relative shrink-swell potential of a clay is important because of the possible transport of contaminants in fractures of shrinking and aggregated clays. The shrink-swell potential of the soil layers can be determined from the physical and chemical property table appearing in published soil surveys. If the shrink-swell potential is high, assign a DRASTIC range of shrinking and aggregated clay; where the shrink-swell potential is low, assign a DRASTIC range of non-shrinking and non-aggregated clay. If a soil has a moderate shrink-swell potential in the majority of the profile, a DRASTIC range of shrinking and aggregated clay should be assigned.

The next example illustrates the need to consider additional factors in the selection of soil media. The Matapeake soil series has a profile of 0 to 11 inches of silt loam, 11 to 26 inches of silt loam and silty clay loam, 26 to 32 inches of very fine sandy loam, and 32 to 50 inches of fine sandy loam. In this case, the user must evaluate the relative thicknesses of the horizons with respect to soil texture. In the event of a difficult decision, the user may wish to evaluate other information such as organic matter content or permeability in making a soil media selection. In this example, the appropriate soil media selection would be the silt loam; this media represents the most significant layer when considering pollution potential. The general soil association map would reflect this surface texture and could be used to help delineate DRASTIC ranges. Note that DRASTIC does not permit the incorporation of a petrocalcic layer (i.e. fragipan, durapan or caliche) within the numerical rating system. Since the presence of this layer may restrict vertical fluid movement within the soil horizon, the user may wish to supplement the DRASTIC evaluation with this information.

6) Where portions or all of the general soil association map cannot be used to delineate the soil media for DRASTIC, refer to the detailed soil maps. In essence, the user must formulate a general soil map of areas 100 acres or larger based on the most significant layer from a pollution potential standpoint. The user may find that the easiest approach is to choose the correct soil media for each soil series, and separate them into significant groups on the maps by colors. Because the maps are so detailed, the user may experience difficulty in making these generalizations because the process is time-consuming when evaluating large areas such as a county.

7) Where soils are thin or absent, little protection from pollution is offered. In this case, the user may use the DRASTIC designation of thin or absent. In general, this category should be used where the soil profile is less than 10 inches thick. This is particularly true for sands, however, the user may wish to consider even less thickness where the soil media is non-shrinking and non-aggregated clay. The decision of when to use this category is based on a point where the thickness of the soil media does not significantly contribute to contamination attenuation.

Additional information regarding various soil characteristics can be found in other parts of the soil survey should more specific information be desired. For example, the tables on engineering properties of soil series frequently contain information on grain size distribution, soil pH and soil permeability, liquid limit and plasticity index. Recent published soil surveys may also contain information on soil organic matter content which may be of particular interest in evaluating the ground-water pollution potential in areas where pesticides are applied. The current DRASTIC methodology does not permit the user to incorporate information on organic matter (other than what already appears in the soil media ranges) into the numerical system; however, the user can use this information to supplement the DRASTIC evaluation.

Although this discussion has centered around the use of soil series and associated textural layers within the soil, the Soil Conservation Service has developed a very detailed and descriptive system for naming and classifying soils. Soil taxonomic classifications can provide the user with additional information on soil genesis, particle size class, soil mineralogy and soil temperature. A complete discussion of soil classification and taxonomy may be found in Soil Conservation Service (1960; 1975).

TOPOGRAPHY

As used here, "topography" refers to the slope and slope variability of the land surface. Topography helps control the likelihood that a pollutant will run off or remain on the surface in one area long enough to infiltrate. Slopes which provide a greater opportunity for contaminants to infiltrate will be associated with a higher ground-water pollution potential. Topography influences soil development and therefore has an effect on contaminant attenuation. Topography is also significant because gradient and direction of flow often can be inferred for water table conditions from the general slope of the land. Typically, steeper slopes signify higher ground-water velocity.

Figure 7 contains the slope ranges which were chosen as significant relative to ground-water pollution potential. These ranges correspond to the typical ranges identified by the Soil Conservation Service for percent slope. The ranges are assigned ratings assuming that 0 to 2 percent slope provides the greatest opportunity for a pollutant to infiltrate because neither the pollutant nor much precipitation exits the area as runoff. Conversely, 18+ percent slope affords a high runoff capacity and therefore a lesser probability of contaminant infiltration and a subsequent lower ground-water pollution potential. Steep slopes, however, are more conducive to rapid erosion and contamination of surface water.

Percent slopes for topography may be determined from published soil surveys and U.S. Geological Survey 7 1/2 and 15 minute quadrangle topographic maps. Recently published soil surveys have letters on the detailed soil maps which represent percent slope ranges (i.e. A equals 0 to 2 percent, B equals 2 to 6 percent). The user may be able to identify soil and topography together since soil series frequently correspond to topographic breaks. Percent slope may also be calculated directly from 7 1/2 and 15 minute topographic maps. Percent slope is equal to the vertical "rise" divided by the horizontal "run". The user must measure the change in elevation over a measured distance on the topographic map. Distance may be calculated by using a ruler to measure a length on the map and then by comparing this length to the scale at the bottom of the map. The scale for 7 1/2 minute maps is 1 inch equals 2000 feet. Change in elevation is calculated by counting the number of contour lines crossed within the measured length, multiplied by the contour interval of the map. The user should always check the contour interval for each map; the contour interval can vary widely from one map to the next. Percent slope can be checked at intervals across the map and the most appropriate slope range for an area can then be selected.

IMPACT OF THE VADOSE ZONE MEDIA

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

Vadose zone media have been designated by descriptive names. Each medium, listed in order of increasing ground-water pollution potential is discussed as follows:

a) Confining layer - This media is chosen when evaluating a confined aquifer. A confining layer represents an impermeable layer which restricts the movement of water into an aquifer.

b) Silt/Clay - A deposit of silt and clay-sized particles which serves as a barrier to retard movement of liquids. The high clay content provides a low pollution potential. Shrinking clays and higher silt concentrations increase the pollution potential.

c) Metamorphic/Igneous Rock - Consolidated rock of metamorphic or igneous origin which contain no significant primary porosity and which permit movement of liquids through fractures. The relative pollution potential is a function of the degree of fracturing.

d) Shale - A consolidated thick-bedded clay rock which may be fractured. Pollution potential is low but increases with the degree of fracturing.

e) Limestone - Consolidated massive limestone or dolomite which typically contains fewer bedding planes than Bedded Limestone, Sandstone and Shale sequences (see "g" below). Pollution potential is influenced by the degree of fracturing, with a high density of fracturing increasing the chance for pollutant migration.

f) Sandstone - A consolidated sand rock which contains both primary and secondary porosity and is typified by thicker bedding, as opposed to Bedded Limestone, Sandstone, Shale sequences. Pollution potential is largely controlled by the degree of fracturing and the primary porosity of the sandstone.

g) Bedded Limestone, Sandstone, Shale - Typically thin-bedded sequences of sedimentary rocks which contain primary porosity, but where the controlling factor in determining pollution potential is the degree of fracturing.

h) Sand and Gravel with Significant Silt and Clay - Unconsolidated mixtures of sand and gravel which contain an appreciable amount of fine material. These deposits have a high concentration of clay, thereby reducing the permeability of the deposits. These deposits are commonly referred to as "dirty" and have a lower pollution potential than "clean" sands and gravels. In general, finer-grained and "dirtier" sands have a lower pollution potential than coarser-grained "dirtier" gravels.

i) Sand and Gravel - Unconsolidated mixtures of sand to gravel-sized particles which contain only small amounts of fine materials. The range in rating reflects principally a grain size distribution where unsorted smaller grained deposits have a lower pollution potential and larger grained, well-sorted deposits have a higher pollution potential.

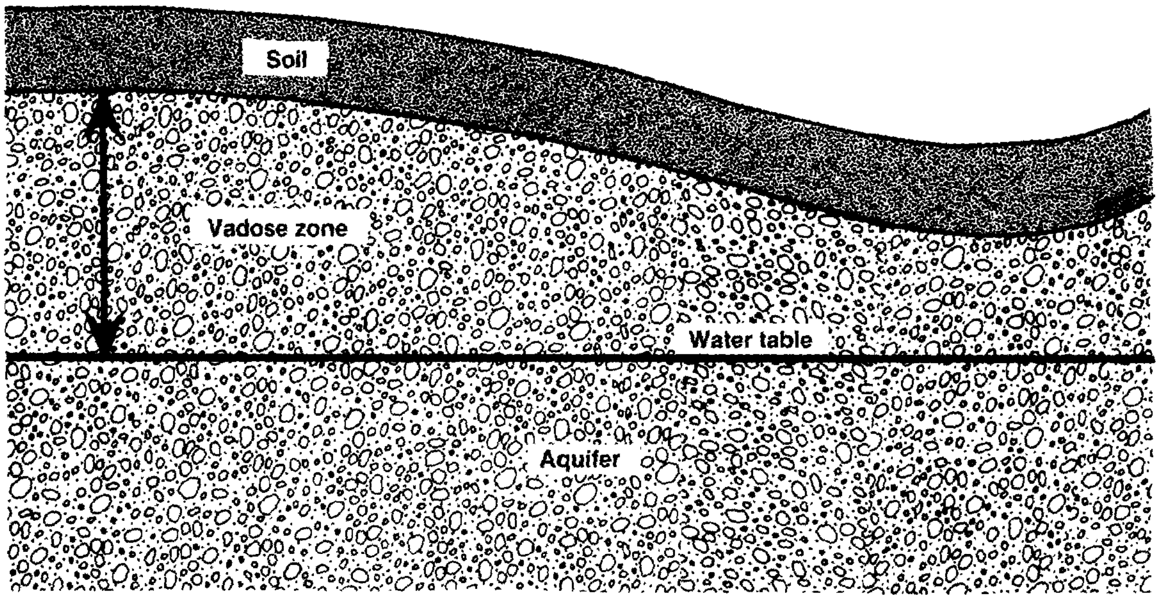
j) Basalt - Consolidated extrusive igneous bedrock which contains bedding planes, fractures and vesicular porosity. This is a special case of Metamorphic/Igneous. The term is used herein in a generic sense, even though it is actually a rock type. Pollution potential is influenced by the number and amount of interconnected openings present in the lava flow materials. Pollution potential is typically high because there is little chance for attenuation once a pollutant enters the fracture system.

k) Karst Limestone - Consolidated limestone bedrock which has been dissolved to the point where large open interconnected cavities and fractures are present. This is a special case of Limestone where pollution potential is high based on the amount of open area in the rock.

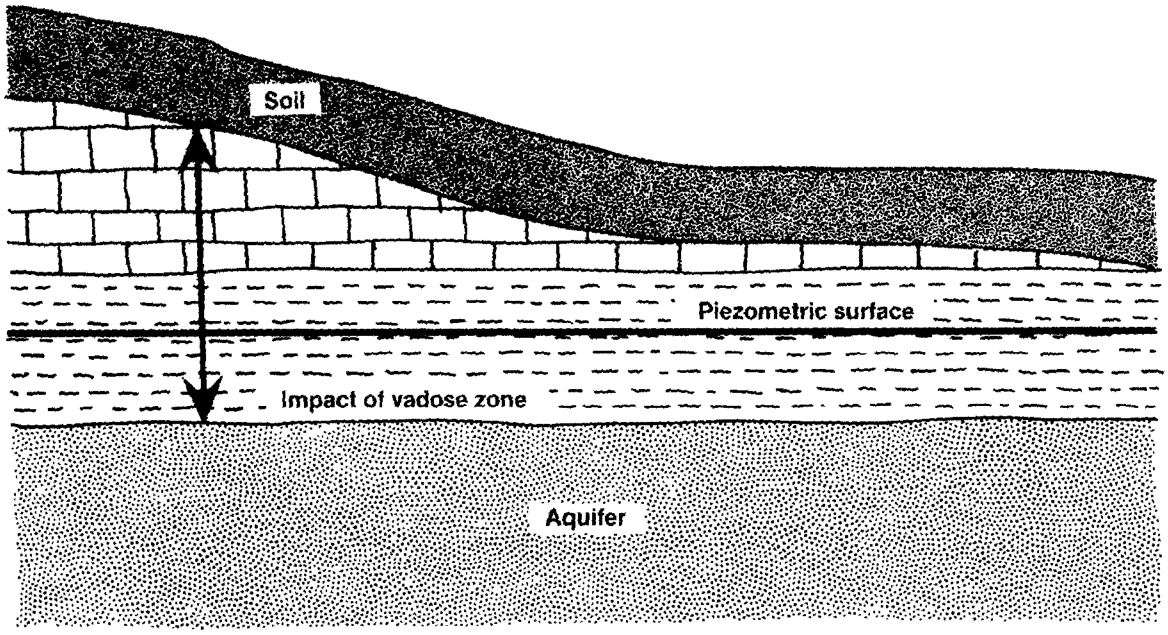
A graphic display of the ratings which have been assigned to each vadose zone medium is contained in Figure 8. This graph also contains a more complete listing of the mechanisms which affect the pollution potential of each medium.

The selection of the vadose zone media depends on whether the aquifer to be evaluated is unconfined or confined. A definition of unconfined and confined aquifers can be found in the discussion on depth to water. In the case of an unconfined or semi-confined aquifer that will be evaluated as unconfined, the user must select the most significant media which influences pollution potential. By definition, the vadose zone will include all the unsaturated media below the soil and above the water table (Figure 21). Information on vadose zone media is typically available in published geologic or hydrologic reports, masters theses, well logs or other exploratory borings. A complete list of potential sources of information is contained in Table 1. In a multi-layer system, relative thickness of the media is one parameter which influences the selection of the vadose zone media, however pollution potential must also be considered. For example, where a limestone aquifer is overlain by a significant thickness of sand and gravel and the water table is at the top of the limestone, the vadose zone media would be chosen as sand and gravel. However, if the sand and gravel were thinner and the water table was deep within the limestone, limestone might be chosen as the vadose zone media. Another example would be where a limestone aquifer is overlain by a silt/clay layer and a sand and gravel layer of equal or greater thickness. The silt/clay layer will be the most significant layer from a ground-water pollution potential standpoint because it would restrict the movement of contaminants into the limestone aquifer. The user would select silt/clay as the most appropriate vadose zone media. In the special case where the water table is very near or at the surface, the vadose zone media may be saturated. In this situation, the user still must choose a vadose zone media and assign an appropriate rating.

Where an aquifer is confined, the impact of the vadose zone includes all media below the soil and above the top of the aquifer (Figure 21). In many situations, the vadose zone will not be a true vadose zone, because part of the saturated zone may be treated as the vadose zone. When evaluating a confined



A. Determining the impact of the vadose zone media in an unconfined aquifer.



B. Determining the impact of the vadose zone media in a confined aquifer.

Figure 21. Diagrams showing how to determine the impact of the vadose zone media.

aquifer, the user must choose "confining layer" as the vadose zone media. Because the confining layer is the media which most significantly impacts pollution potential, the user is choosing the true impact of the vadose zone. Confining layer is used regardless of the other media composition in the area. For example, where a sandstone aquifer is overlain by a confining shale layer and a sand and gravel deposit of sufficient thickness, the impact of the vadose zone media is chosen as "confining layer" even though shale and sand and gravel would be listed in the table.

DRASTIC also provides a range of ratings for each media, with the exception of confining layer. Confining layer must always be assigned a value of 1. When evaluating an unconfined aquifer, the user may adjust the rating for each media to reflect information gained from published reports, well logs and knowledgeable individuals. Ratings are chosen similarly to the ratings for aquifer media. The user is referred to the discussion in the aquifer media section. Additional assistance in choosing ratings may also be found in the following discussion.

In consolidated media, ratings may be chosen to reflect the amount of secondary porosity by degree of fracturing, bedding or solution channels. A typical rating is provided for each media. The typical rating can be used in an aquifer with a moderate amount of fracturing or where data is not sufficient to change the media rating. For example, where a limestone vadose zone is present, the limestone may be highly solutioned allowing contaminants to infiltrate the vadose zone rapidly and without any attenuation. The vadose zone media would be chosen as a karst limestone and assigned a rating of 10. If however, less solution channels were present or the channels were not significantly interconnected, the vadose zone media would still be chosen as karst limestone, but the rating could be lowered to a 9 or 8 depending on the amount and interconnection of the channels. Still using the limestone as an example, assume the limestone was not karstic but rather a dolomite with few fractures. The user would choose a vadose zone media of limestone. A rating lower than the typical 6 would then be chosen based on the degree of fracturing.

In unconsolidated media, the user is provided with three descriptive media ranges for unconsolidated deposits. The user may choose sand and gravel, sand and gravel deposits with significant silt and clay or silt/clay depending on the relative proportion of the finer-grained materials. Ratings for each media are provided in parenthesis. Sand and gravel is used where the deposits consist mostly of sand and gravel with only small amounts of finer-grained materials (6-9). Sand and gravel with significant silt and clay is used where the predominant media is still sand and gravel (usually in lenses) but the matrix is finer grained deposits (4-8). Silt/clay is used to delineate deposits where the predominant material is fine-grained silt or clays, however small amounts of sand and gravel may still be present in the deposit (2-5). The three media ranges provide ratings which overlap the entire rating scale.

The user may choose ratings to reflect grain size, sorting, homogeneity and amount of fine material. For example, a well-sorted sand and gravel that is well washed may receive a rating of 9 while a sand and gravel with a larger fine fraction would receive a 7. Although no specific designation for glacial till is listed in the vadose zone media chart, glacial tills can be evaluated using the following discussion.

Depending on the characteristics of the till, the user may choose either silt/clay or sand and gravel with significant silt and clay as the appropriate media and adjust the ratings accordingly. For example, a sandy till may be called a sand and gravel with significant silt and clay and assigned a rating of 6. Conversely, a dense, unfractured, clayey till would be called silt/clay and assigned a rating of 3.

HYDRAULIC CONDUCTIVITY OF THE AQUIFER

Hydraulic conductivity refers to the ability of the aquifer materials to transmit water, which in turn, controls the rate at which ground water will flow under a given hydraulic gradient. The rate at which the ground water flows also controls the rate at which a contaminant moves away from the point at which it enters the aquifer. Hydraulic conductivity is controlled by the amount and interconnection of void spaces within the aquifer which may occur as a consequence of intergranular porosity, fracturing and bedding planes. For purposes of this document, hydraulic conductivity is divided into ranges where high hydraulic conductivities are associated with higher pollution potential. Figure 9 shows the relative importance of the ranges.

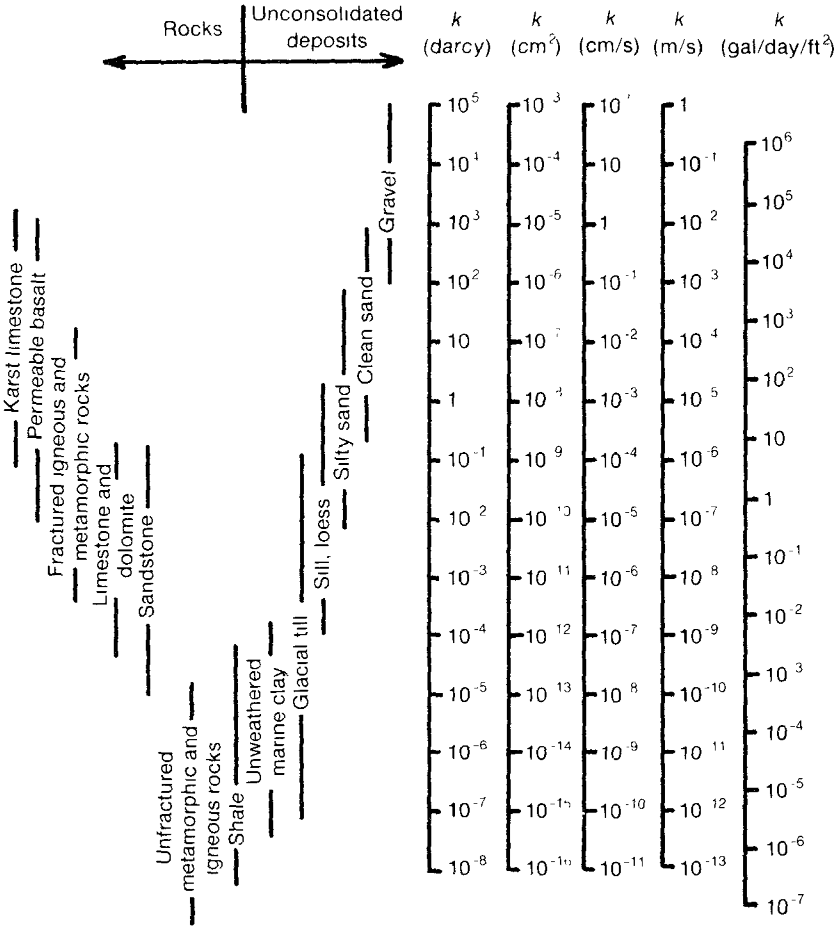
Values for hydraulic conductivity are calculated from aquifer pumping tests. Information on hydraulic conductivity typically is available in published hydrogeologic reports or masters theses. A complete list of potential sources of information is contained in Table 1. If this information is not available in published reports, values for hydraulic conductivity may be estimated from Table 12. Well yields may also provide assistance in estimating hydraulic conductivity. The user is advised to contact knowledgeable individuals such as consultants, federal, state and local government employees and drillers in the area which also may be able to provide or confirm reasonable estimates of hydraulic conductivity. The broad ranges for hydraulic conductivity provided in the DRASTIC charts were designed to provide flexibility in selecting appropriate values.

INTERACTION BETWEEN PARAMETERS

From the above discussion and in the application of the DRASTIC Index, it will be recognized that there is redundance between some of the parameters. The depth to the water, for example, affects the quantity of material that will be encountered by a pollutant moving downward toward an aquifer. The thicker the vadose zone in a given setting, the greater the effect may be upon the degradation, retardation or attenuation of the pollutant.

However, in considering the impact of the vadose zone, degradation, retardation and other significant attenuation processes are all varied according to the nature of the materials present, and their condition within the vadose zone. If, for instance, the vadose zone is moderately fractured granite, the materials within the vadose zone will have only a slight impact on

TABLE 12. RANGE OF VALUES OF HYDRAULIC CONDUCTIVITY AND PERMEABILITY (FREEZE AND CHERRY,1979)



most pollutants entering the vadose zone. The protection provided will be a function of depth and the failure of critical fractures to interconnect.

If, however, the vadose zone is comprised of unfractured glacial till, it can be anticipated that consumptive sorption will be moderately high; infiltration will be moderately low; retardation will be significant; and with any substantial thickness of till, considerable time will be required for most pollutants to penetrate the till. Thus it can be seen that the redundant consideration of degradation, retardation and attenuation within the context of both depth to water and impact of the vadose zone is useful in the comparative evaluation of sites.

Net recharge determines, on an annual basis, the quantity of water from precipitation that is available for vertical transport, dispersion, and dilution of a pollutant from a specific point of application. Net recharge exemplifies how some parameters can have both positive and negative effects. For example, greater recharge typically means more rapid transport of a pollutant and therefore less time for attenuation. However, in this situation, dilution is also greater thereby exerting a positive influence because the concentration of an introduced contaminant will be lessened. It is also evident that a thick unsaturated zone, with a layered sequence of bedded and fractured shales, sandstones and limestones, can have a profound impact on all three of the same factors (transport, dispersion, dilution) that are of primary importance to net recharge.

Topography and soil media also influence net recharge. Topography has site-specific influence which determines whether the capacity for recharge is high or low at a given point. The permeability of the surface soils has a similar impact. However, the nature of the surface soil materials has an additional impact upon potential pollutant attenuation, consumptive sorption, route length and direction, and time available for penetration.

In addition to its direct influence upon recharge, topography exerts a significant influence upon soil thickness, drainage characteristics, and profile development. These factors, in turn, influence soil media as well as the previously-mentioned factors. In addition, topography usually bears a predictable relationship to hydraulic gradient, and direction of probable pollutant movement under water table conditions, with a consequent impact on dispersion and dilution.

The upper portion of the vadose zone exerts influence on the type of soils developed on the surface. The vulnerability of an aquifer to a given pollution event varies in response to the nature of the materials in the vadose zone including but not limited to: grain size, sorting, reactivity, bedding, fracturing, thickness and sorptive character. In general, finer grain-size materials, i.e. clays and silt, have lower hydraulic conductivity and greater capacity for the temporary and long-term attenuation of pollutants. If expandable clay minerals are present, the sorptive capacity is further enhanced. If a material is even moderately cemented, then grain size and sorting may be less significant than the degree of cementation.

If the material in the vadose zone is reactive to the pollutant, or soluble in it, then there may be two different effects. First, the pollutant may be retarded (a positive effect) or second, the solution of the vadose zone material may actually increase permeability and allow subsequent introduction of pollutants to pass through more quickly with less retardation (a negative effect). In the case of reactive pollutants, the importance of secondary by-products must be considered. It is here that the risks associated with gaseous phase transport are most likely to have an impact on ground water.

The thickness of the vadose zone and the degree of fracturing and frequency of bedding planes in the vadose zone all impact upon the tortuosity, route length, dispersion and consequent travel time that is required for a pollutant to move through the vadose zone. This is not only of time-delay importance but also is important as the control of contact time for reactions to occur.

The vadose zone, including the surficial soil, is also of great importance as the zone where most of the biologic activity occurs. There are natural organisms found in this zone that break down many polluting substances into secondary by-products, both harmless and harmful. For many chemicals these reactions are very poorly understood, if at all, but it is known that with sufficient time the eventual results are generally beneficial. Among the best known of these processes at present are the bacterial fixation of iron and the bacterial breakdown of non-chlorinated hydrocarbons under natural conditions. Both of these processes occur in the vadose zone and in the aerobic portion of shallow aquifers.

The hydraulic conductivity, together with gradient and porosity of the aquifer beneath a site influences the rate of movement of an introduced pollutant away from the point of introduction. In conjunction with hydraulic gradient, conductivity also controls the direction of movement. These are, in turn, affected with regard to dispersion, by grain size, bedding, fracturing, and tortuosity.

It is evident that all of the DRASTIC parameters are interacting, dependent variables. Their selection is based not on available data quantitatively developed and rigorously applied, but on a subjective understanding of "real world" conditions at a given area. The value of the DRASTIC parameters is in the fact that they are based on information that is readily available for most portions of the United States, and which can be obtained and meaningfully mapped in a minimum of time and at minimum cost. The DRASTIC ranking scheme can then be applied by enlightened laymen for comparative evaluations.

If the vulnerability of a site, or sites, to ground-water pollution were to be evaluated with regard to travel time, flux, and concentration associated with the incidence of a pollutant introduced at the site, the DRASTIC parameters would be distributed as follows:

A. Travel Time

- Depth to Water
- Soil Media
- Impact of the Vadose Zone Media
- Net Recharge
- Hydraulic Conductivity of the Aquifer

B. Flux

- Aquifer Media
- Hydraulic Conductivity of the Aquifer (Existence of Gradient Assumed)

C. Concentration

- Depth to Water
- Net Recharge
- Aquifer Media
- Soil Media
- Topography
- Impact of the Vadose Zone Media
- Hydraulic Conductivity of the Aquifer

It should be noted that although the DRASTIC parameter of hydraulic conductivity of the aquifer is mapped as a function of the ability of a pollutant to be moved from a point of incidence, the direction of migration is a function of gradient and rate depends on both conductivity and gradient.

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SECTION 4

HOW TO USE HYDROGEOLOGIC SETTINGS AND DRASTIC

The system described in this document presents a simple and easy-to-use approach to assess the ground-water pollution potential of any area. Although the final system appears simplistic, the system actually includes many complex concepts and relationships. Before an attempt is made to make full use of this system, the user needs to develop an appreciation for the complexity of evaluating ground-water pollution potential. It is not necessary to understand every concept in detail, but the greater the depth of understanding, the more useful the system becomes. DRASTIC provides mappable results which can be used to provide a quick reference of relative pollution potential of different areas. DRASTIC is designed to be used as a planning, screening or prioritizing tool. DRASTIC and associated maps cannot be used in lieu of site specific evaluations because of local complexities in geologic conditions.

WHERE TO OBTAIN INFORMATION ON DRASTIC PARAMETERS

Before an area can be evaluated using the DRASTIC system, the basic information on each factor must be found. DRASTIC has been designed to use information which is available from a variety of sources. Table 1 contains a listing of possible sources of hydrogeologic information and the types of information which may be available from each. The most common source of information for each parameter is listed below:

1) Depth to Water - Well logs or hydrogeologic reports;
2) Net Recharge - Water resource reports combined with data on precipitation from the National Weather Service;
3) Aquifer Media - published geologic and hydrogeologic reports;
4) Soil Media - published soil survey reports or local mapping projects conducted by the Soil Conservation Service;
5) Topography - published U.S. Geological Survey topographic maps (various scales);
6) Impact of the Vadose Zone Media - published geologic reports;
7) Hydraulic Conductivity of the Aquifer - published hydrogeologic reports. (Of all the factors, this information may be the most difficult to find. Because it is related very closely to aquifer media, if necessary, hydraulic conductivity may be estimated using Table 12). Conversion factors for permeability and hydraulic conductivity are found in Table 13.

TABLE 13. CONVERSION FACTORS FOR PERMEABILITY AND HYDRAULIC CONDUCTIVITY UNITS (FREEZE AND CHERRY, 1979)

	Permeability, *k**			Hydraulic conductivity, *K*		
	cm^2	ft^2	darcy	m/s	ft/s	U S gal/day/ft^2
cm^2	1	$1\ 08 \times 10^{-3}$	1.01×10^{8}	9.80×10^{2}	3.22×10^{3}	$1\ 85 \times 10^{9}$
ft^2	9.29×10^{2}	1	$9\ 42 \times 10^{10}$	9.11×10^{5}	2.99×10^{6}	1.71×10^{12}
darcy	9.87×10^{9}	1.06×10^{11}	1	$9{,}66 \times 10^{-6}$	3.17×10^{-5}	1.82×10^{1}
m/s	1.02×10^{3}	$1\ 10 \times 10^{6}$	1.04×10^{5}	1	3.28	$2\ 12 \times 10^{6}$
ft/s	3.11×10^{4}	$3\ 35 \times 10^{7}$	3.15×10^{4}	3.05×10^{1}	1	6.46×10^{5}
U S. gal/day/ft^2	5.42×10^{10}	5.83×10^{13}	$5\ 49 \times 10^{7}$	4.72×10^{-7}	1.55×10^{-6}	1

*To obtain *k* in ft^2, multiply *k* in cm^2 by 1.08×10^{3}.

It should be noted that the more accurate the data used to compute the index, the more reliably the pollution potential can be assessed. There may be many gaps in the data, of course. These gaps can be filled with careful interpolation if such interpolation is reasonable.

STEPS FOR USE OF THE SYSTEM

In order to use the DRASTIC system, the user must follow a few simple steps. The following example illustrates how to use the system. The exact same steps are used when applying the modified Pesticide DRASTIC ratings. A decision-maker wishes to evaluate the pollution potential of two areas in a county. The county is located along the glacial boundary such that part of the county lies in the Glaciated Central Region and the other part lies in the Non-Glaciated Central Region. Precipitation in the area averages 42 inches per year. Area I is typified by 5 to 20 feet of glacial till deposits which overlie fractured sandstones and shales with hydraulic conductivities ranging from 100 to 300 gpd/ft2. The terrain is rolling, and depth to the water in the sandstones averages 30 feet below land surface. Typical soils have mixtures of sand, silt and clay with predominant clay fractions. Area II is typified by alternating sequences of sandstone, limestone and shale with moderate fracturing and hydraulic conductivity averaging 300 gpd/ft^2. Relief is low and slopes are commonly 2 percent. Depth to water averages 40 feet. Soil is thin but significant with soils reflecting equal mixtures of sand, silt and clay. Average net recharge is 8 inches per year.

1) Identify the Region in which the area is located. Become familiar with the hydrogeology of the region. Area I is in the Glaciated Central Region and Area II is in the Non-Glaciated Central Region.

2) Identify which hydrogeologic setting most closely approximates the conditions of the area. Area I most closely approximates Setting 7Aa - Glacial Till Over Bedded Sedimentary Rock; Area II, 6Da - Alternating Sandstone, Limestone and Shale - Thin Soil. For ease of reference, these setting descriptions are included as Figures 22 and 23 and Tables 14 and 15.

3) Evaluate available information for each DRASTIC parameter against the example ranges chosen for each DRASTIC parameter listed in the top table (Tables 14 and 15). These ranges represent example values for each hydrogeologic setting. In Area I (Table 14), the depth to water averages 30 feet; the example range of 30 to 50 feet would seem appropriate. Therefore, the associated rating of 5 (Table 4) does not need to be changed. No value for net recharge was available; however, precipitation in the region is 42 inches per year and recharge will typically be restricted due to the presence of clayey till; the example range of 4 to 7 inches per year seems appropriate. Therefore, the associated rating of 6 (Table 5) does not need to be changed. The aquifer media are fractured sandstones and shales; thin bedded sandstone, limestone and shale sequences are present, so the example media is appropriate. Therefore, the associated rating of 6 (Table 6) does not need to be changed. Soils have a

GLACIATED CENTRAL

(7Aa) Glacial Till Over Bedded Sedimentary Rocks

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

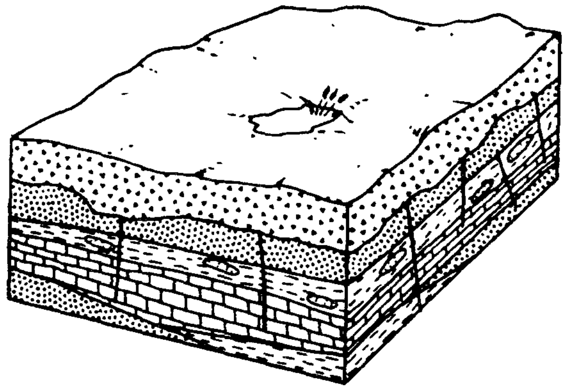

Figure 22. Description and illustration for setting 7Aa—glacial till over bedded sedimentary rocks.

NON-GLACIATED CENTRAL

(6Da) Alternating SS, LS, and SH - Thin Soil

This hydrogeologic setting is characterized by low to moderate topographic relief, relatively thin loamy soils overlying horizontal or slightly dipping alternating layers of fractured consolidated sedimentary rocks. Ground water is obtained primarily from fractures along bedding planes or intersecting vertical fractures. Precipitation varies widely in the region, but recharge is moderate where precipitation is adequate. Water levels are extremely variable but on the average moderately shallow. Shale or clayey layers often form aquitards, and where sufficient relief is present, perched ground water zones of local domestic importance are often developed.

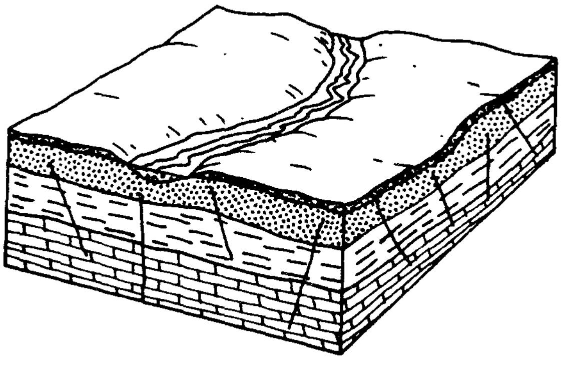

Figure 23. Description and illustration for setting 6Da—alternating sandstone, limestone and shale-thin soil.

TABLE 14. DRASTIC AND PESTICIDE DRASTIC CHARTS FOR SETTING 7Aa — GLACIAL TILL OVER BEDDED SEDIMENTARY ROCKS

Setting 7Aa Glacial Till Over Bedded Sedimentary Rock		General		
Feature	Range	Weight	Rating	Number
Depth to water	30-50	5	5	25
Net recharge	4-7	4	6	24
Aquifer media	Bedded SS, LS, SH sequences	3	6	18
Soil media	Clay loam	2	3	6
Topography	2-6%	1	9	9
Impact vadose zone	Silt/Clay	5	3	15
Hydraulic conductivity	100-300	3	2	6
		Drastic Index		103

Setting 7Aa Glacial Till Over Bedded Sedimentary Rock		Pesticide		
Feature	Range	Weight	Rating	Number
Depth to water	30-50	5	5	25
Net recharge	4-7	4	6	24
Aquifer media	Bedded SS, LS, SH sequences	3	6	18
Soil media	Clay loam	5	3	15
Topography	2-6%	3	9	27
Impact vadose zone	Silt/Clay	4	3	12
Hydraulic conductivity	100-300	2	2	4
		Pesticide Drastic Index		125

TABLE 15. DRASTIC AND PESTICIDE DRASTIC CHARTS FOR SETTING 6Da — ALTERNATING SANDSTONE, LIMESTONE AND SHALE — THIN SOIL

Setting 6Da Alternating Sandstone, Limestone and Shale — Thin Soil		General		
Feature	Range	Weight	Rating	Number
Depth to water table	15-30	5	7	35
Net recharge	4-7	4	6	24
Aquifer media	Thin bedded SS, LS, SH sequences	3	6	18
Soil media	Loam	2	5	10
Topography	2-6%	1	9	9
Impact vadose zone	Bedded LS, SS, SH	5	6	30
Hydraulic conductivity	1-100	3	1	3
			Drastic Index	129

Setting 6Da Alternating Sandstone, Limestone and Shale — Thin Soil		Pesticide		
Feature	Range	Weight	Rating	Number
Depth to water table	15-30	5	7	35
Net recharge	4-7	4	6	24
Aquifer media	Thin bedded SS, LS, SH sequences	3	6	18
Soil media	Loam	5	5	25
Topography	2-6%	3	9	27
Impact vadose zone	Bedded LS, SS, SH	4	6	24
Hydraulic conductivity	1-100	2	1	2
			Pesticide Drastic Index	155

predominant clay fraction but contain silt and sand; clay loam is the prevalent soil, so the example soil media would be appropriate. Therefore, the associated rating of 3 (Table 7) does not need to be changed. Terrain is rolling; 2 to 6 percent slopes are predominant. The example range is acceptable. Therefore, the associated rating of 9 (Table 8) does not need to be changed. The vadose zone is comprised of glacial till; silt and clay is the most significant portion of the glacial till. The example vadose zone media is the appropriate media. Therefore, the associated rating of 3 (Table 9) does not need to be changed. Hydraulic conductivity values for the bedrock average 100 to 300 gpd/ft^2 as listed on the example chart. Therefore, the associated rating of 2 (Table 10) does not need to be changed. Since all the example ranges in the hydrogeologic setting are identical to the example values for this setting, no values need to be modified for this area. The DRASTIC INDEX has already been computed for the user by multiplying each rating by the assigned weight to obtain the value listed in the "number" column. The sum of the "numbers" is the DRASTIC Index. In this instance, the DRASTIC Index of 103 is simply read from the chart. It should be noted here that weights are never changed. These were determined by the committee and are the essence of the system.

In Area II (Table 15), depth to water averages 40 feet. The example range on the chart indicates 15 to 30 feet. This range differs from the example values in this setting. The user should refer to Table 4 to find the correct range which most closely approximates the area. In this case 30 to 50 feet would be appropriate. Note the corresponding rating would now be 5 instead of 7 and the resultant weight of 5 multiplied by a rating of 5 is 25 instead of 35. Net recharge is 8 inches per year. The range on the chart differs from the example values in this setting. Seven to ten inches per year would be chosen as the appropriate range and the rating of 6 is then changed to an 8 by referring to Table 5. The aquifer media is alternating sequences of sandstone, limestone and shale with moderate fracturing; the media listed on the example chart is accurate and the associated rating of 6 does not need to be changed. Soils are typified by equal mixtures of sand, silt and clay; this is the definition of loam. The media on the example chart is adequate and the associated rating of 5 does not need to be changed. Topography is low; the range is listed as 2 to 6 percent. The user may, based on observation, choose 0 to 2 percent, and change the example rating as before, or may accept the example range of 2 to 6 percent if correct. For demonstration purposes, the user can refer to Table 8, choose a 0 to 2 percent range, change the rating from 9 to 10 and multiply by the weight of 1 to obtain an answer of 10 instead of 9. The vadose zone media in the area are fractured limestones, sandstones and shales; this is the same as the example media for this setting. Therefore, the associated rating of 6 does not need to be changed. Hydraulic conductivity averages 300 gpd/ft^2; the example range indicates 1 to 100 gpd/ft^2. Refer to Table 10 to choose the appropriate range. In this case, 100 to 300 gpd/ft^2 is chosen, the associated rating of 2 is substituted and multiplied by 3 to obtain 6. The DRASTIC Index cannot be read off the chart because all the ranges were not identical to those listed in the example setting. Calculate the correct DRASTIC Index by adding the numbers 25 + 32 + 18 + 10 + 10 + 30 + 6 = 131. The decision maker can then compare the two areas relative to one another.

From the above discussion, it is evident that the hydrogeologic settings serve as a guide to the user in evaluating the appropriate range for each DRASTIC factor. Each range has an associated rating which can then be integrated into DRASTIC by combining it with the weighting factor. The information to evaluate each DRASTIC factor and choose the appropriate range may not always be expressed in exactly the same terms which are used in this document. Section 3, DRASTIC: A Description of the Factors, contains a brief description of what is included in each of the media terms so that the most accurate DRASTIC range can be chosen. Section 5, Application of DRASTIC to maps discusses the step-by-step process for producing detailed DRASTIC maps with associated hydrogeologic settings and DRASTIC indexes.

HOW TO USE THE RANGE IN MEDIA RATINGS

Because geologic media are more highly variable than other more easily quantified DRASTIC factors, the system allows the user to make adjustments for the variability in aquifer and vadose zone media. Tables 6 and 9 provide the user with a typical rating and a variable rating which can vary based on the properties of the media. If no specific information is available to provide a rationale for making a change from a typical media, the typical rating should be used. The typical ratings for aquifer and vadose zone media were developed to represent the characteristics of a typical aquifer or vadose zone associated with a media type. The variable range in media ratings provide the user with a mechanism to adjust the ratings according to information that more accurately characterizes the nature of the media. The user may then use this information in conjunction with the pollution potential to choose a media rating which best represents the conditions of that media.

In consolidated rock, ratings may be adjusted to reflect degree of cementation, amount of primary porosity and presence of secondary porosity due to bedding planes, fractures, joints or solution openings. The relative presence or absence of these factors may significantly affect contaminant travel, attenuation and dilution within the aquifer. In unconsolidated deposits, the ratings may be adjusted to reflect the amount of fine-grained material and the size, shape and sorting of the entire deposit.

The first step in using the system is to choose an aquifer or vadose zone media. DRASTIC provides descriptive terms for both consolidated and unconsolidated media to characterize the aquifer and vadose zone media. The user must evaluate the geologic and hydrogeologic information about the area and choose an appropriate media. A complete discussion of the choices of media for aquifers and the vadose zone may be found in Section 3, DRASTIC: A Description of the Factors under Aquifer Media and Vadose Zone Media. Special consideration for aquifer and vadose zone media selection is necessary in the case of confined aquifers. The user is referred to Section 3 and Section 4, How to Evaluate Confined Aquifers for further information.

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

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

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

HOW TO EVALUATE CONFINED AQUIFERS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

SINGLE FACTOR OVERRIDES

In some instances, it will be found that the DRASTIC Index cannot adequately compensate for a single parameter that is so dominant that it overrides all other parameters. This may be a consideration that is glaringly apparent, as in a highly-fractured surficial karst area, or it may be a much more subtle consideration that involves design or policy decisions.

Tables 18 and 19 provide the DRASTIC ratings for two actual areas referenced as Maco I and Maco II. These areas are both located in the glacial till plain portion of the Glaciated Central Region approximately five miles apart. Based on the available data, both areas are underlain by 25 to 40 feet of dense glacial till containing a few discontinuous lenses of "dirty" sand and gravel that rarely exceed four inches in thickness. In the absence of fracturing or stratification, the horizontal and vertical permeabilities of the glacial tills average 10^{-6} to 10^{-7} gallons per day per square foot.

In area Maco I, the glacial till overlies fractured limestone which serves as a regional aquifer and has a hydraulic conductivity which averages 300 to 700 gallons per day per square foot. Water in the limestone is semi-confined and the regional water levels approximate 30 feet. The overlying glacial till is saturated only in association with the occasional discontinuous lenses of sand and gravel. These zones can be considered "perched."

In the Maco II area, the glacial till overlies dense, fractured shale. The hydraulic conductivity of the shale is less than 1 gallon per day per square foot. Because the shale is relatively impermeable, the overlying glacial till is saturated from a depth of approximately 5 feet, even though the elevation, topography and soils are similar in the two areas.

It can be seen by comparing Tables 18 and 19, that Maco II has a slightly more favorable rating than Maco I. The principal reason is because there is no significant aquifer at risk at Maco II. However, Maco II has a water table at a depth of approximately 5 feet. In the Maco I area, a landfill, for example, could be properly designed and operated at a maximum depth of fifteen feet. At this depth, the landfill would be located within the unsaturated zone and a substantial thickness of dense, low permeability material would be present at the base of the landfill to protect the regional aquifer. Construction of a landfill in the Maco II area (with the more favorable rating) would involve operating a saturation-zone landfill, which often would require a harder policy decision from the permitting agency.

With regard to the proper application of the DRASTIC Index in this situation, the question is, "Is the shallow, 5-foot depth to saturation of sufficient significance to 'override' all of the other, favorable aspects of the site?" This should be considered for all parameters that are very highly-rated (i.e., in the rating range of 8-10). Another single factor

TABLE 18. DRASTIC RATING FOR MACO I

MACO I		GENERAL		
Feature	Range	Weight	Rating	Number
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Massive Limestone	3	4	12
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	113

TABLE 19. DRASTIC RATING FOR MACO II

MACO II		GENERAL		
Feature	Range	Weight	Rating	Number
Depth to Water	5-15	5	9	45
Net Recharge	4-7	4	6	24
Aquifer Media	Massive Shale	3	2	6
Soil Media	Clay Loam	2	3	6
Topography	2-6	1	9	9
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	108

override would be exposed, highly-fractured or dissolved bedrock which would provide a direct conduit to an aquifer. Knowledge of the area being mapped is usually required in order to know when overrides must be applied.

BUILD-YOUR-OWN-SETTINGS

From the above discussion it should become obvious that for any given area in the United States, the ground-water pollution potential can be estimated by choosing appropriate ranges for each DRASTIC parameter without referring to any hydrogeologic setting described in Section 7, Hydrogeologic Settings of the United States by Ground-Water Regions. It becomes necessary to use both the hydrogeologic settings and the DRASTIC Index when producing a map which will clearly describe the conditions in an area. The individual DRASTIC ratings and hydrogeologic settings become important when DRASTIC will be used by other people in potentially different applications. The inclusion of both portions of the methodology will provide a clear and complete "picture" of the hydrogeologic and geologic conditions in the area. This information will enable other users to understand how and why the DRASTIC parameters were chosen and how setting conditions impact the pollution potential. The geographic relationship also helps the user evaluate the characteristics of an area more thoroughly thereby helping create sound judgement calls and a more realistic DRASTIC Index.

HOW TO INTERPRET A DRASTIC AND PESTICIDE DRASTIC INDEX

The culmination of the evaluation of any hydrogeologic setting is a numerical value termed the DRASTIC Index. The higher the DRASTIC Index, the greater the ground-water pollution potential. DRASTIC is designed to yield a relative numerical value which can readily be compared to a value obtained for another setting either in the same region or in a different region. A numerical value of 160, for example, has no intrinsic meaning. That number is of value only when compared to DRASTIC Indexes generated for other areas. DRASTIC Indexes range from 65 to 223 for all typical hydrogeologic settings.

It is also important to be able to reconstruct the ranges for each individual DRASTIC factor that comprise the DRASTIC Index. Frequently it becomes necessary to consider a specific parameter in addition to just knowing a number for ground-water pollution potential. The charts accompanying each hydrologic setting in Section 7, Ground-water Regions and Hydrogeologic Settings of the United States provide a format for quick and easy reference of the way the DRASTIC Index was derived.

DRASTIC Indexes provide discrete numbers which can be used to evaluate ground-water pollution potential. The numbers, however are not gradational between settings. For example, the line on a map which encloses the DRASTIC Index is not a contour line but rather a line depicting a setting boundary. A contour line infers that there is a gradational transition between two evaluated points. A setting boundary line allows the user to evaluate two points but only from a relative and not gradational perspective. Therefore, it is important to realize that DRASTIC Index values cannot be contoured.

This methodology also allows the user to apply a modified Pesticide DRASTIC to an area when the potential impact to ground-water quality from the application of pesticides is a concern. The weights assigned to each parameter have been modified to reflect the potential impacts of pesticide application on ground water. The assumptions have been modified to reflect a contaminant with the mobility of a generic pesticide. For this reason, it is not correct to compare a General DRASTIC Index with a Pesticide DRASTIC Index of the same area. Comparisons made between the two Indexes would be invalid. The user may only compare the Pesticide DRASTIC Indexes of two different settings evaluated using Pesticide DRASTIC to draw conclusions about the relative pollution potential of each area with respect to pesticide application. Pesticide DRASTIC Indexes range from 88 to 251 for all typical hydrogeologic settings.

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Section 5

APPLICATION OF DRASTIC TO MAPS

Complete evaluation of any area using DRASTIC involves not only producing a numerical score, but also delineating appropriate hydrogeologic settings. To fully demonstrate the use of the system and to better illustrate the steps in producing a DRASTIC map, ten widely varied counties were chosen for evaluation. This exercise also provided the opportunity to critique the methodology and make changes where necessary.

The selection process for the demonstration counties involved soliciting suggested counties from committee members and other interested individuals. The areas selected were to be representative of different hydrogeologic scenarios and be located in all parts of the United States. An attempt was made to select counties which had both an abundance and a scarcity of data and represented both urban and rural areas. The initial areas were further evaluated based on the level of interest at the state and county level. The ten counties which were finally selected include:

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

The evaluation approach for each county varied slightly but typically contained the following elements: 1) gathering of published data and maps, 2) eliminating data gaps through personal contacts, 3) preparing draft DRASTIC maps in the form of color-keyed overlays, 4) conducting a formal county presentation, 5) field checking of the draft maps with selected individuals intimately familiar with the county, 6) making changes where necessary on the maps and 7) printing a final map and legend. In all instances steps 1-4 and 7 were accomplished. Step 5 was not completed for Minidoka County, Idaho due to inclement weather; field checking New Castle County, Delaware was only cursorily performed because the reviewers did not deem an in-depth field visit necessary. Step 6 was not performed in many counties because modifications were not necessary.

HOW TO PERFORM A DRASTIC EVALUATION AND PRODUCE A DRASTIC MAP

This section contains a step-by-step discussion of the techniques which were used to evaluate each county and produce a map. Although each individual who uses DRASTIC will personalize the approach, these discussions will serve as a starting point for the user.

Drawing the Map Manually

1) Gather all the published or printed information available on the chosen county for each DRASTIC parameter. Sources of information are listed in Table 1.

2) Read and evaluate the data. Start to make preliminary choices about which aquifer or aquifers should be evaluated. DRASTIC permits the user to choose either a unconfined or confined aquifer for evaluation. This choice will determine the type of data needed for other key DRASTIC parameters. Depth to water and the impact of the vadose zone media are most significantly affected. Remember, if an aquifer is evaluated as confined, the depth to water is chosen as the depth to the top of the aquifer and the impact of the vadose zone is assigned the delineation.

The user may also choose to evaluate different aquifers on the same map. This may be necessary where an aquifer is not continuous across a county. Evaluation of different aquifers may be desirable where one aquifer does not have the same importance, either economically or usage-wise in the county. Care should be taken to document which aquifer is being evaluated so that users of the final map can understand the evaluations and relative pollution potential. DRASTIC does not permit the user to evaluate two separate aquifers at the same location on the same map; two separate maps must be produced.

3) Identify the pertinent hydrogeologic region (Western Mountain Ranges for example) and begin to formulate ideas about the appropriate hydrogeologic setting. The hydrogeologic settings can be located in Section 7, Hydrogeologic Settings of the United States by Ground-Water Regions.

4) Begin the mapping procedure by selecting a 7 1/2 minute USGS topographic quadrangle map (or a 15 minute map if a 7 1/2 minute map is not available). It is recommended that mapping proceed to an adjacent quadrangle to maintain continuity. Starting in one corner of the county is usually the best approach. Although many portions of the demonstration maps were produced using 15 minute topographic quadrangle maps, the 7 1/2 minute maps were easier to use.

5) Mapping is conducted by creating a series of overlays to represent the DRASTIC parameters. Theoretically an overlay is necessary for each parameter; however, it was discovered during the mapping process that

frequently DRASTIC factors would be closely associated. In some areas the vadose zone and aquifer media were the same. In other areas, soil and topography were intimately related. In these instances, it was not necessary to create seven separate overlays; frequently 2 or 3 were sufficient.

6) Once a 7 1/2 minute quadrangle is chosen, the first overlay can be constructed by placing a piece of matte acetate over the map and taping it down. The matte side should be placed toward the mapper. Choose a DRASTIC parameter to begin the map. It is typically easier to choose the aquifer media as the starting parameter because the values chosen for other parameters (i.e. depth to water) may depend on the choice of aquifer for mapping. So that consistency in creating the maps was maintained, a specified pencil color was assigned to each DRASTIC parameter. Table 20 shows the colors which were used during the demonstration project. The mapper need not use these colors, but may find standardization advantageous.

TABLE 20. PENCIL COLORS USED FOR DRASTIC MAPPING EXERCISE

DRASTIC Parameter	Color
Depth to Water	Black
Net Recharge	Green
Aquifer Media	Red
Soil Media	Blue
Typography	Violet
Impact of the Vadose Zone Media	Brown
Hydraulic Conductivity of the Aquifer	Orange

7) Referring to available information, draw boundary lines for the chosen DRASTIC parameter using the categories provided in Tables 4 through 10. Try to keep in mind that DRASTIC is best applied by recognizing the generalities and combining the unimportant specifics. This is best done by remembering that DRASTIC areas should represent areas that are 100 acres <u>or larger</u> in size. On a 7 1/2 minute quadrangle map this roughly corresponds to the size of a 50 cent piece. It is important to "lump" generalities and not to "split" unnecessarily. Frequently individuals experience the greatest difficulty in "lumping" where there is extremely detailed information available; where data is more generalized the temptation to "split" is reduced. For example, in an area of varying topographic relief, the mapper may see many areas on the topographic map which would lend themselves to producing a very detailed map. However, the mapper needs to remember the 50 cent piece and not create areas any smaller. Conversely, information about hydraulic conductivity of the aquifer is typically generalized and is easier to resist the temptation to draw a propensity of lines because the data is not available to support them.

It is during this mapping exercise that the mapper may become acutely aware of data gaps or data deficiencies. It is oftentimes necessary to supplement the printed information with professional expertise. A telephone call to knowledgeable individuals (consultant, government official, driller or other) may be both desirable and necessary.

It is also during the mapping exercise that the user will realize that the data used to generate a pollution potential map is produced at a variety of scales. For example, soils are commonly mapped at a level of detail representing 85 percent accuracy in a one or two-acre area. However, values for hydraulic conductivity are frequently extrapolated from only a few points of reference or simply are estimated by aquifer media. This can be likened to using significant figures to express research results. When adding numbers such as .038 and .1 the result is only properly expressed to the first decimal point. When creating the map it is therefore important to attempt to "justify" the scales by either making generalizations (in the case of soil media) or finding the most detailed available information (in the case of hydraulic conductivity). This process of trying to evaluate data at relatively equal scales produces a better pollution potential map.

8) Label the enclosed areas with the appropriate category. Record the corresponding weight and rating for the area and multiply the two numbers. Circle the number for easy reference. Figure 24 shows an example of a correctly drawn and labeled map of aquifer media.

9) Select the next factor to evaluate. Tape down an additional sheet of acetate or use the same sheet as before. Select a different colored pencil. Draw in the appropriate boundaries, label and circle the computed number. Figure 25 shows a correctly drawn and labeled map of depth to water superimposed on Figure 24.

10) Continue to map all seven DRASTIC parameters with a different colored pencil using as many sheets of acetate as necessary. By the time this portion of the exercise is complete, the mapper will have identified areas where additional information is needed. At this point, the mapper may wish to record those notations for future reference.

11) Overlay and align all the sheets of acetate. Add an additional clean acetate sheet to the top. Select a black (or other appropriate) pencil and retrace all the boundaries that are seen through the overlain sheets. Remember that the final map should have no areas smaller than a 50 cent piece (Figure 26). This may mean that the mapper may not be able to trace all the lines. In this instance, the mapper needs to employ the technique of "lumping." This is best done by reviewing the parameters that create this line. This process is made easier if a different color pencil was used for each parameter. The mapper should carefully look at boundaries which coincide between parameters. Where one or more parameter lines coincide the importance of keeping that particular line is enhanced. The reliability of the data which made the line should also be evaluated. For example, if the aquifer media was well-documented but professional

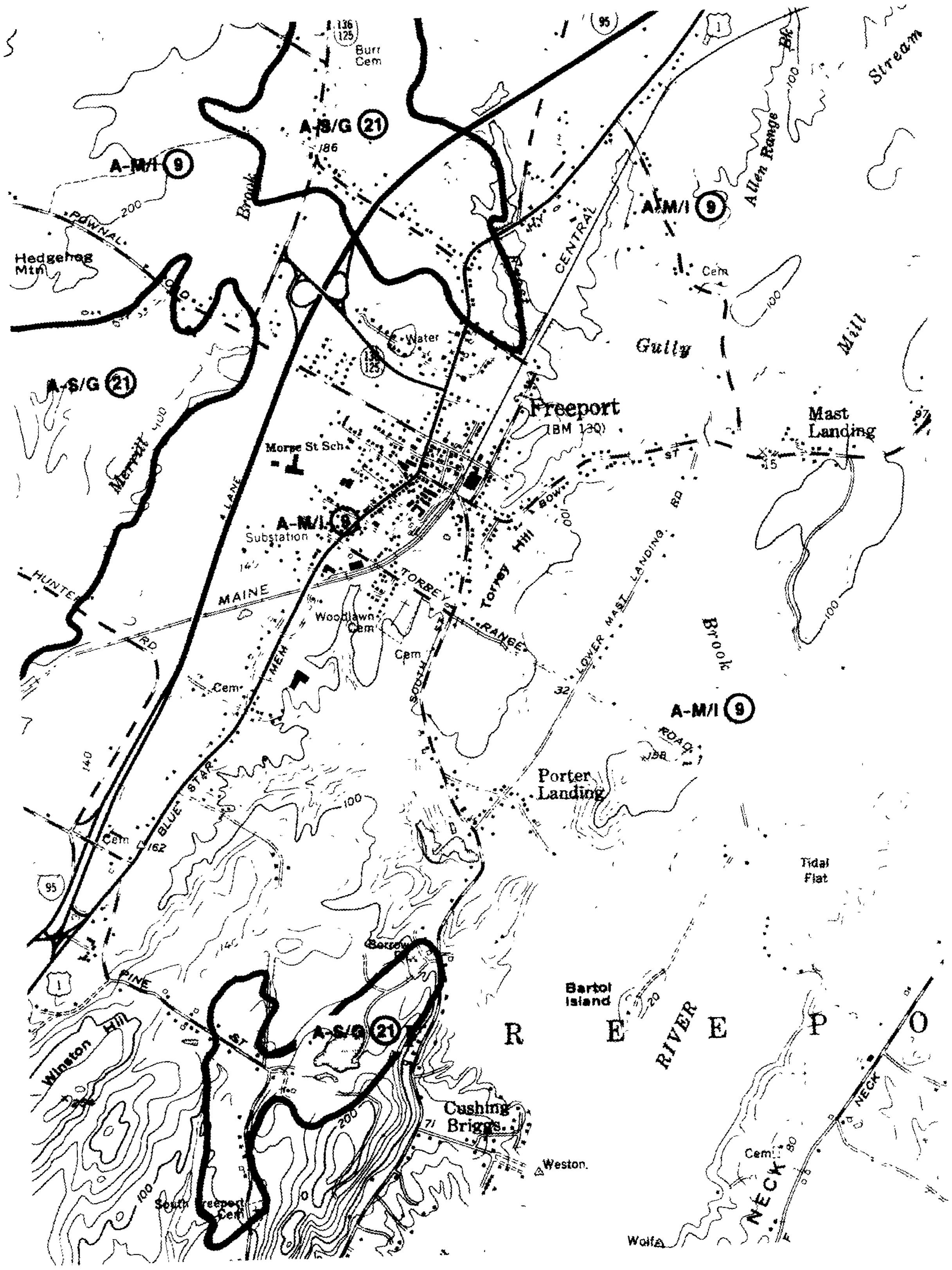


Figure 24. Hand-drawn map showing correct delineation and labeling of aquifer media.

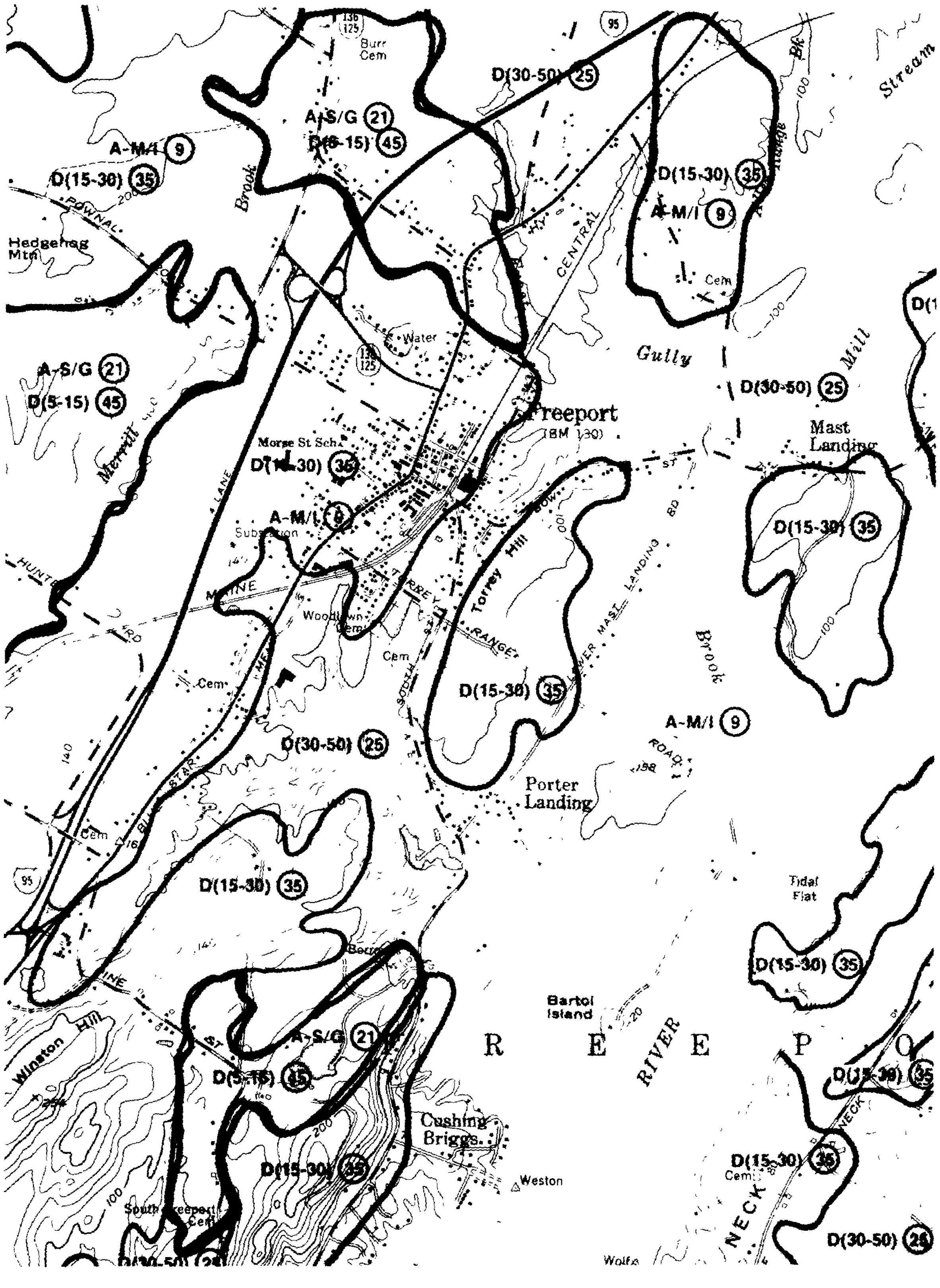


Figure 25. Hand-drawn map showing correct delineation and labeling of depth to water and aquifer media.

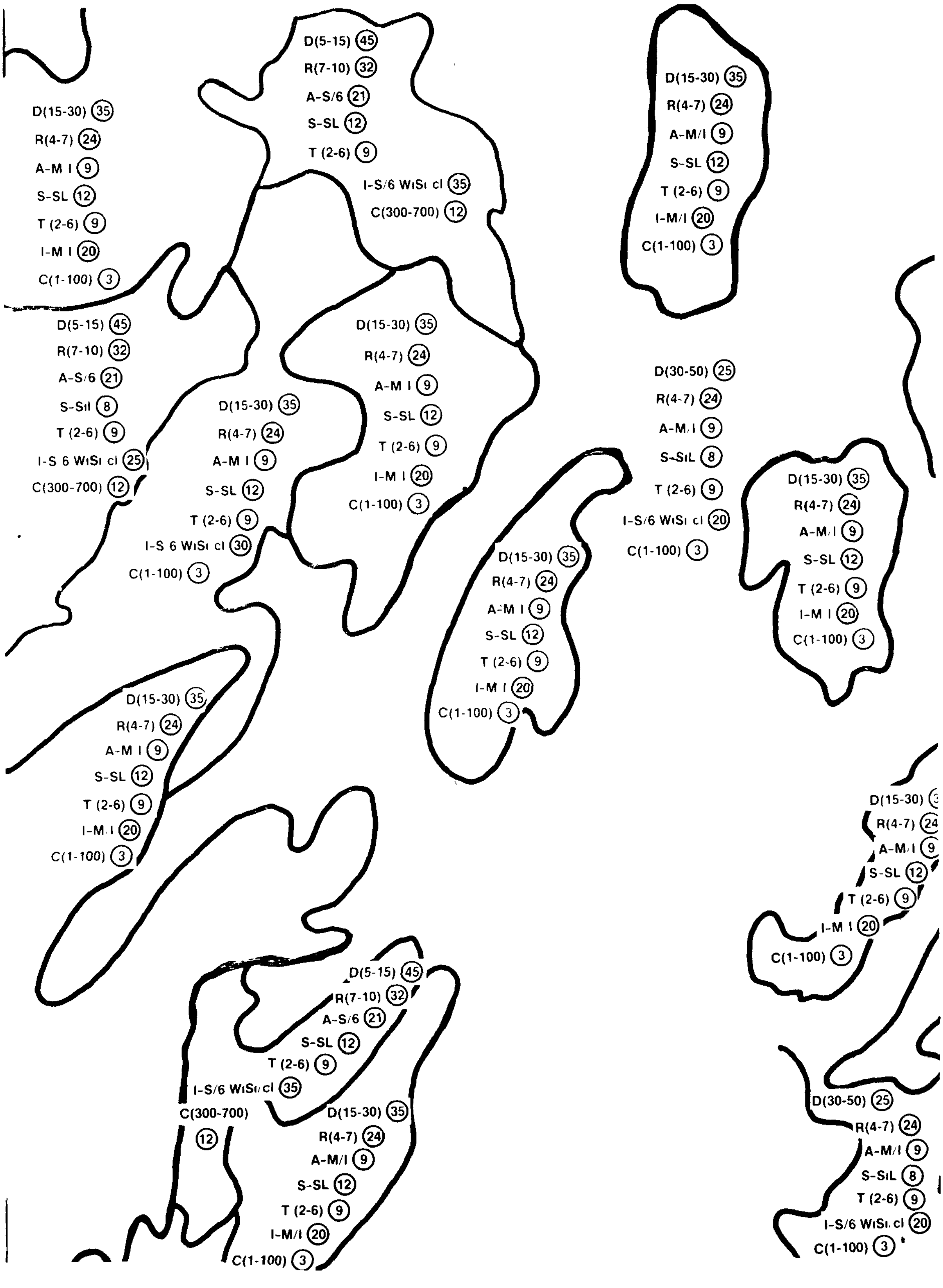


Figure 26. Hand-drawn map showing correct delineation and labeling of all DRASTIC parameters.

judgement has been used to draw the net recharge line, perhaps the net recharge boundary could share the aquifer media boundary. Finally, the importance of the DRASTIC parameter should be considered. For example, it is frequently very easy to make a detailed map using topography alone. However, since topography has only a weight of 1 in general DRASTIC, it may be possible to re-evaluate those boundaries with respect to soil, vadose zone or aquifer boundaries. By reasoning processes similar to this, the mapper is able to create a valid DRASTIC map delineating realistic areas of pollution potential.

12) At this point, the mapper needs to evaluate the hydrogeologic settings which are present on the map. This is done by reviewing the descriptions in the appropriate hydrogeologic region (Section 7). The descriptions and block diagrams provide generalized information about the important hydrogeologic parameters from a pollution potential standpoint. The block diagrams provide a "typical" range of values which might be present somewhere in the region. It is unlikely that the map which has been generated will duplicate the typical chart. Therefore, the mapper needs to create a lettering system for the map. This can be done by making a series of blank charts. Write the names of the hydrogeologic settings encountered during mapping on the top of the charts.

13) Next, label the areas on the final maps with the appropriate hydrogeologic settings (i.e., 2A, 7Da, 6K). Concurrently or later sum the DRASTIC numbers for a selected area. This number is the DRASTIC Index and a measure of relative pollution potential.

The user should note that the map produced using these steps is a map which outlines areas of hydrogeologic settings and variable DRASTIC Indexes. However, the user should also note that the numbers are not contoured. Contour lines imply a sequential progression between each line. The DRASTIC numbers are comparative and not sequential. This means that each individual Index value is not related to the adjacent value but only serves as a means of comparison.

14) Record the ranges and associated ratings on the blank chart with the appropriate hydrogeologic setting. Label the appropriate area on the map as below:

6K
101

where

6K denotes the ground-water region and hydrogeologic setting and

101 denotes the DRASTIC Index.

Figure 27 illustrates a correctly labeled map. Table 21 is an example of an accompanying chart.

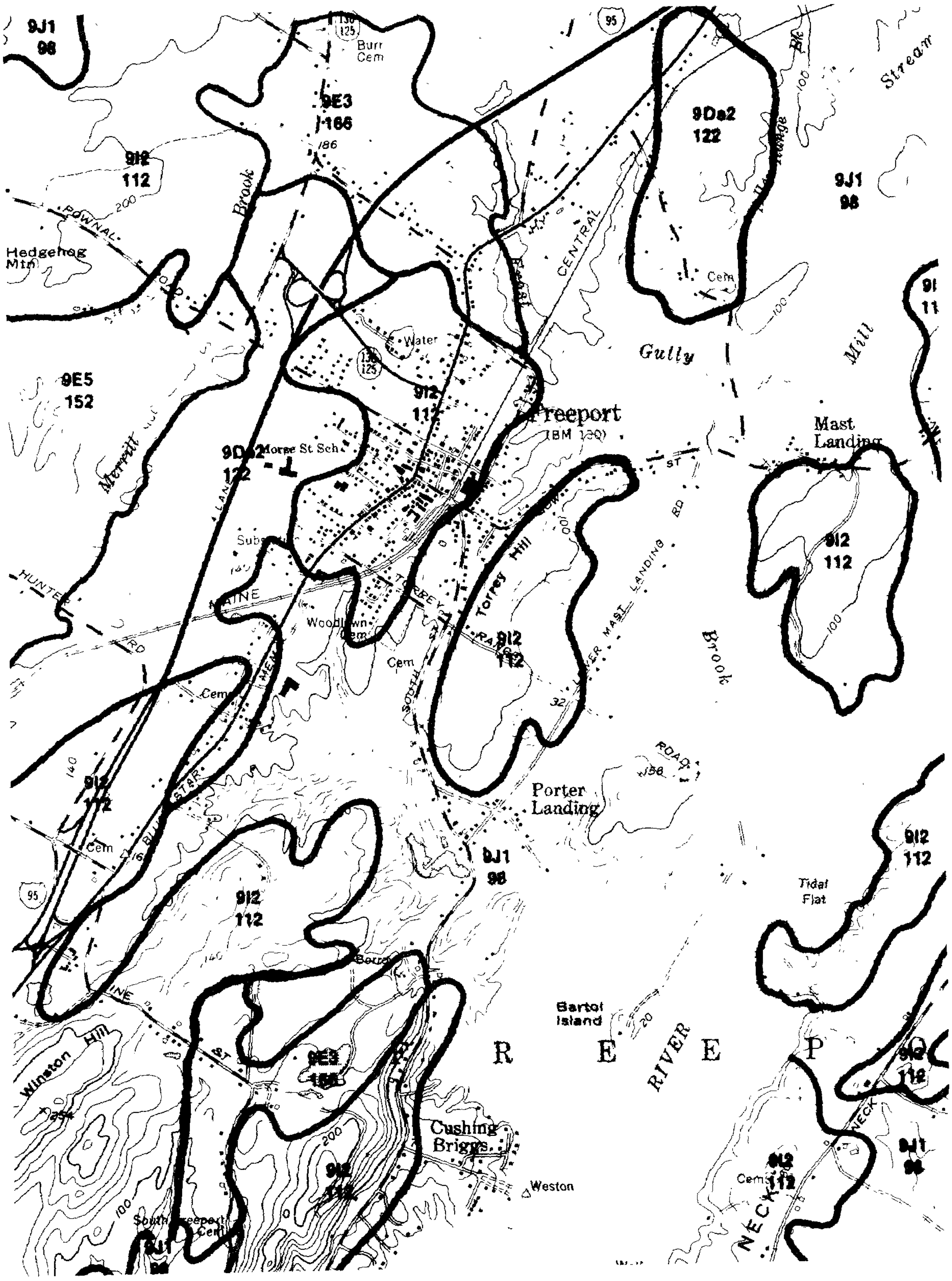


Figure 27. Hand-drawn map showing correctly labeled ground-water pollution potential map.

TABLE 21. CHART FOR SETTING 912 — BEDROCK UPLANDS

Setting	912 Bedrock Uplands	General		
Feature	Range	Weight	Rating	Number
Depth to water	15-30	5	7	35
Net recharge	4-7	4	6	24
Aquifer media	Metamorphic/igneous	3	3	9
Soil media	Sandy loam	2	6	12
Topography	2-6%	1	9	9
Impact vadose zone	Metamorphic/igneous	5	4	20
Hydraulic conductivity	1-100	3	1	3
		Drastic Index		112

15) Continue to sum the DRASTIC Index and label the hydrogeologic setting for each area. During this process, it will become obvious that there are many different variations within a hydrogeologic setting. For example, it is possible to be within the setting 6D but to have the depth to water be 15-30 feet in one area and 30-50 feet in another. This results in a different DRASTIC index. It is also possible to have changes in more than one parameter. For purposes of charts and labeling, it becomes desirable to delineate between the many variations. This is best done by labeling as follows:

6K1	6K2	6K3
96	103	113

where

6K1
96 is the first unique combination of DRASTIC parameters encountered

6K2
103 is the second set of unique DRASTIC parameters encountered, and

6K3
113 is the third variation encountered during mapping.

The mapper can thus continue to label ad infinitum. Probably no two mappers will label the variations (i.e., 1, 2, 3, etc.), in the same order, but the order is not really the important aspect. The unique combination of DRASTIC parameters and the ability of a reviewer or user to trace the way the mapper created the DRASTIC Index and hydrogeologic setting is the most significant milestone.

16) Continue to map each 7 1/2 minute quadrangle using the same technique until the county is completely mapped. Check all map boundaries to ensure that hydrogeologic setting lines continue from map to map. Continue to label the hydrogeologic setting variations sequentially.

Drawing the Map by Computer

A Geographic Information Systems (GIS) is designed to display and combine many layers of spatial data into differing formats so results may be more easily interpreted by the user. Since DRASTIC combines seven layers in the form of the seven DRASTIC parameters, an attempt was made to produce a map using a computerized GIS. Geographic Information Systems is a broad term for a variety of software packages capable of manipulating spatially-oriented data. The capabilities and output of the GIS varies with the software package.

New Castle County, Delaware was chosen to demonstrate the use of DRASTIC with a GIS. An Automated Environmental Resources Information System (AERI) was the computer assisted information system available in New Castle County. The information for the seven DRASTIC parameters resided in the existing computerized data base and needed only minor manipulation to fit the DRASTIC format. The software used in the demonstration was GRID II which was designed to overlay any combination of AERI data files and produce a map with a variety of scales. Data in the AERI files was previously entered in 5.74 acre grid cells with cell dimensions measuring 500 feet per side. The demonstration did not involve inputting additional data into the data files. The following steps were used in producing maps on the computer.

1) Existing data files were reviewed to verify the format content of the information to ensure relevance compatibility with DRASTIC.

A data file was chosen that represented each DRASTIC parameter. The data file was manipulated to correspond to the DRASTIC ranges. For example, soil was available in the data base by soil series name. Each soil series had to be coded to correspond to a soil texture as listed in Table 7. Where information already existed in ranges, it was not always possible to use the exact DRASTIC ranges. For example, hydraulic conductivity of the major unconsolidated aquifer existed in the computer by groups A, B, and C which corresponded to 748-1870 gpd/ft^2, 374-561 gpd/ft^2 and 1-150 gpd/ft^2 respectively. In this instance it was necessary to adapt the DRASTIC rating numbers to correspond to these ranges. Although, this practice is not recommended, the alternatives would have been to reenter all the data or abort the project.

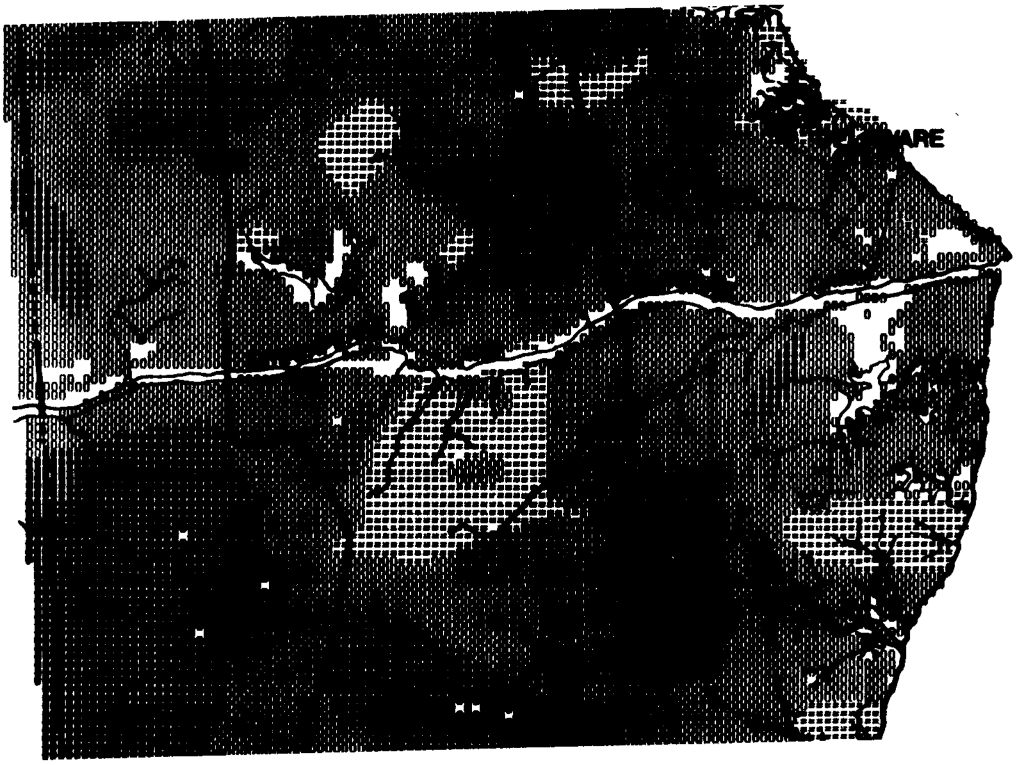
2) The ratings associated with the assigned ranges were entered into the computer.

3) A separate map was produced for each of the seven DRASTIC parameters at a scale of 1" = 6000" to allow review of each parameter. The output was in the format of symbols. The symbols were then chosen to represent ranges for the DRASTIC parameter. Figure 28 shows a part of a map for aquifer media in New Castle, County. Each symbol represented a 5.74 acre grid cell. An acetate overlay provided geographic reference points.

4) When necessary, the existing data files were reassigned DRASTIC ranges. For example, this was necessary in the category of soil media because the original data had been entered on such a fine scale. The resultant map produced a very detailed soil media map with an associated problem (Figure 29). Inasmuch as DRASTIC is designed to be used on areas 100 acres or larger, it would take approximately 14 consecutive grid cells to make an area of 100 acres. This would be the smallest area for which a symbol should be assigned (refer to Item number 7 in drawing the map manually). The GIS did not contain an algorithm to weight average each symbol and produce sets of symbols in aggregates of 14 grid cells or larger; therefore the only way to adjust the map was to reassign ranges and print additional maps by trial and error.

5) Once a tentatively acceptable map was produced for each DRASTIC Parameter, the weights for each DRASTIC parameter were entered into the computer. The program performed the calculations of the weight multiplied by the rating for each of the assigned DRASTIC parameters and combined the individual maps into a composite DRASTIC map. The output was displayed in the format of symbols. The symbols were chosen to represent ranges of DRASTIC values. For example, all values between 170-179 could be delineated by the symbol o. The computer could then re-group the values in chosen increments limited only by the number of available symbols necessary to map the output. Figure 30 shows a portion of a sample output. Once again the computer had produced DRASTIC Indices for areas smaller than 100 acres. By computer manipulation it was impossible to remove the small areas and retain any confidence in the output. Further, although the computer had produced a numeric map, it was not possible to detail at every point on the map the exact range chosen for each DRASTIC factor. It was also impossible to obtain an overview of the hydrogeology because no hydrogeologic settings could be delineated using this system.

6) To produce a valid final map for the county, it was necessary to resort to manual manipulation. Each separate DRASTIC factor map was used as a source of information to produce a more generalized overlay. For example, a piece of matte acetate was taped over the map generated for depth to water. Lines were hand drawn using professional judgement to make generalizations of parameters where necessary. For some of the parameters, the areas previously defined by the computer were simply outlined as an overlay. The entire process was very similar to producing a map by hand.



Frequency Distribution of Data Point Values in Each Level

	LOW VALUES							HIGH VALUES
LEVELS	0	1	2	3	4	5	6	7
SYMBOLS		:	|	=	0	█	█	
FREQUENCY	193	25	11646	4006	23061	8383	198	0

DRASTIC RATINGS FOR AQUIFER MEDIA
NEW CASTLE COUNTY, DELAWARE
SEPTEMBER 26, 1985

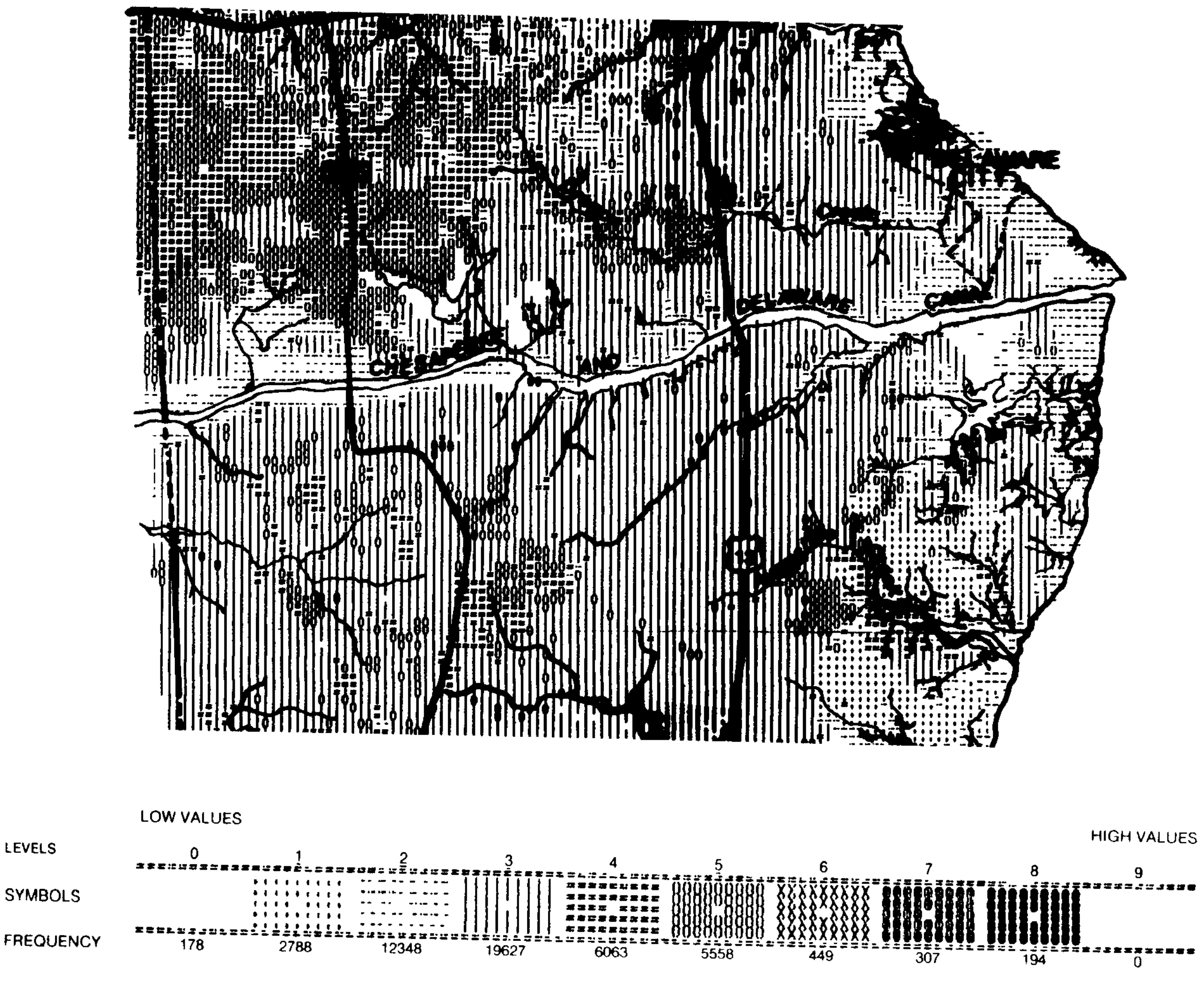
Ranges and Ratings for Aquifer Media

IMPACT OF AQUIFER MEDIA

Map Level	Range	Rating
1	Metamporphic/Igneous	2
2	Metamorphic/Igneous	3
2	Metamorphic/Igneous	3
3	Sand and Gravel	5
3	Sand and Gravel	5
4	Sand and Gravel	6
4	Sand and Gravel	6
5	Sand and Gravel	8
6.	Karst Limestone	9

Blank = Water as Primary Land Cover
Map Scale. 1" = 6,000'

Figure 28. Computer-drawn map showing representation of aquifer media by symbols.

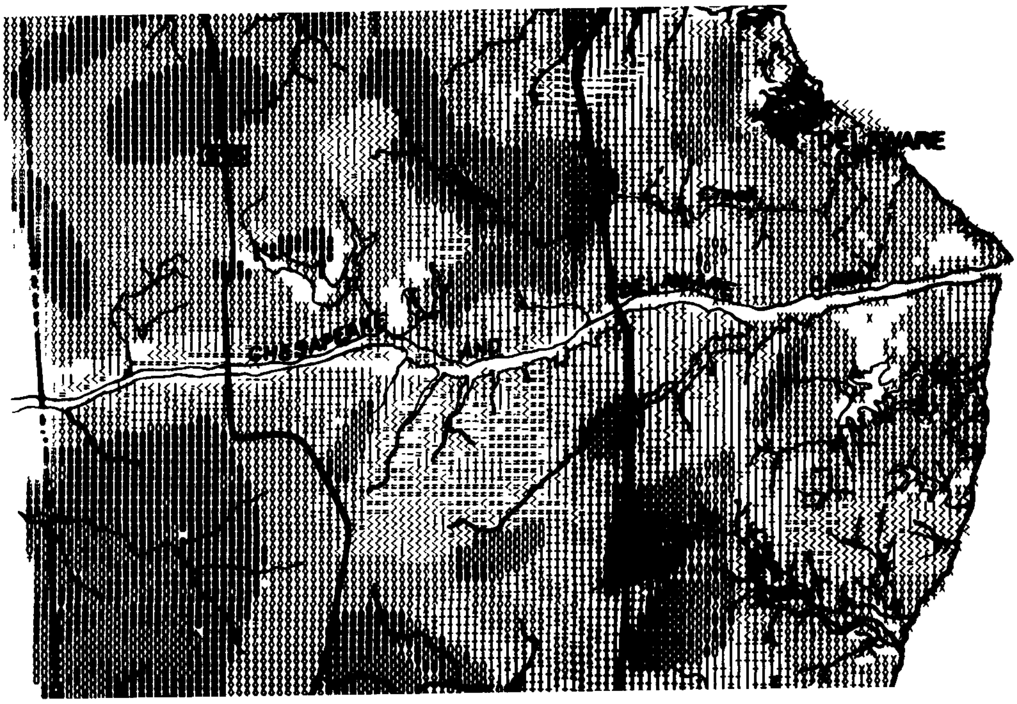


DRASTIC RATINGS FOR SOIL MEDIA
NEW CASTLE COUNTY, DELAWARE
SEPTEMBER 24, 1985
Ranges and Ratings for Soil Media
SOIL MEDIA

Map Level	Range	Rating
1	Nonshrinking and Nonaggregated Clay	1
2	Clay Loam	3
3	Silty Loam	4
4	Loam	5
5	Sandy Loam	6
6	Shrinking and/or Aggregated Clay	7
7	Sand	8
8	Gravel, Quarries, Thin or Absent	9
		10

Blank Cells = Water as Primary Land Cover
Map Scale 1" = 6,000'

Figure 29. Computer-drawn map showing an unacceptable detailed soils map.



Frequency Distribution of Data Point Values in Each Level

LOW VALUES

LEVELS	0	1	2	3	4	5
SYMBOLS		:	-	=	<	|
FREQUENCY	130	493	2608	7186	5376	2599

HIGH VALUES

LEVELS	6	7	8	9	10	11
SYMBOLS	+	X	0	▓	█	
FREQUENCY	6817	14410	2304	4392	1326	0

DRASTIC INDEX VALUES MAPPED IN RANGES
NEW CASTLE COUNTY, DELAWARE
DECEMBER 5, 1985

	DRASTIC Index Ranges
1	94 - 109
2	110 - 119
3	120 - 129
4	130 - 139
5.	140 - 149
6.	150 - 159
7	151 - 169
8	170 - 179
9	180 - 189
10	190 - 204

Scale. 1" = 6,000'
Blank = Water as Primary Land Cover

Figure 30. Computer-drawn map showing a final DRASTIC Index value map.

Once overlays had been produced for the seven factors, a final hydrogeologic setting map was produced from the overlays as per the explanation in the previous hand mapping section. The mapper was able to evaluate shared lines and the importance of parameters when delineating the final hydrogeologic setting. The software used in this demonstration project was not capable of incorporating this less tangible function. In retrospect, any software coupled with a GIS system should be able to produce not only a numeric or symbolic map, but also be capable of determining how best to draw final hydrogeologic setting lines with corresponding labels. Labeling and charts for New Castle County, Delaware were accomplished using the step previously described in the hand mapping section.

Final Map Production

Map Reduction

Once the final hydrogeologic setting map has been created for each topographic map, it is frequently desirable to display the results within a political boundary such as a county. However, a county is comprised of many 7 1/2 or 15 minute quadrangles such that the resultant map would typically cover the floor of a large room. To more concisely display the finished product, the overlays need to be reduced to a scale which can be displayed on one map. The following steps detail the process used in the demonstration counties.

1) A county highway map or other suitable political base map was selected. The base map was reduced to fit a 20 inch by 24 inch image area when necessary. This size was chosen for production purposes.

2) Each topographic map-sized overlay was final drafted using a rapidograph and labeled with a template. The rapidograph line width and letter size was chosen so that camera reduction would yield readable letters and significant lines.

3) Each topographic sized overlay was professionally camera reduced to fit the base map and printed on drafting applique film. A typical county contained all or part of approximately 24 topographic maps; therefore 24 individual camera reductions were necessary.

4) The maps on the drafting applique film were peeled and placed on a sheet of matte acetate to form a composite overlay. An image deletion pen and rapidograph were used to clean the overlay and perform boundary adjustments due to parallax.

5) The pasted up overlay was photoghraphically processed into a positive film overlay.

6) The hydrogeologic setting map with associated DRASTIC Indexes were superimposed on the county highway map to provide geographic reference. Since the counties varied in size from 437 square miles to 1302 square miles, the resultant maps were produced at varying scales.

National Color Code

Although each hydrogeologic setting map imparted a significant amount of information when coupled with the computed DRASTIC Index for each setting, it was difficult to perceive a general assessment of relative pollution potential within the county. For example, Figure 31 demonstrates a portion of the pollution potential map for Yolo County, California. To assist in map readability, each demonstration map was subsequently color-coded using the DRASTIC Index. Colors were chosen based on a simplified statistical evaluation of frequency of Index occurrence. Table 22 shows the DRASTIC Index ranges and associated colors used in the development of a National Color Code. The colors of the spectrum were chosen to show the levels of relative vulnerability to pollution. The warm colors -- red, orange and yellow -- indicate areas with the potentially greatest problems; the cool colors -- blue, indigo and violet -- indicate areas of lower susceptibility to ground water pollution. Two varying shades of green delineate the middle ranges. Figure 32 illustrates the superposition of the National Color Code on a portion of the hydrogeologic setting map for Yolo County, California. Various screens have been chosen to simulate the color variations on the map.

Each draft hydrogeologic setting map was color-coded to aid in the review process. The color overlays were created by delineating the appropriate DRASTIC Indexes on the map according to the ranges in Table 22. For each color range, it was necessary to cut a piece of rubylith or amberlith with an exacto knife along the appropriate hydrogeologic setting lines. Once the rubylith or amberlith was cut for each color range, the colors were photographically shot onto separate acetate overlays. The result was a series of overlays containing each color. These overlays were taped onto the base map and the hydrogeologic setting overlay was placed on top.

TABLE 22. NATIONAL COLOR CODE FOR DRASTIC INDEX RANGES

DRASTIC Index Range	Color	Printing Specification Color
<79	Violet	Pantone Purple C
80 - 99	Indigo	Pantone Reflex Blue
100 - 119	Blue	Pantone Process Blue C
120 - 139	Dark Green	Pantone 347C
140 - 159	Light Green	Pantone 375 C
160 - 179	Yellow	Pantone Yellow C
180 - 199	Orange	Pantone 151C
>200	Red	Pantone 485C

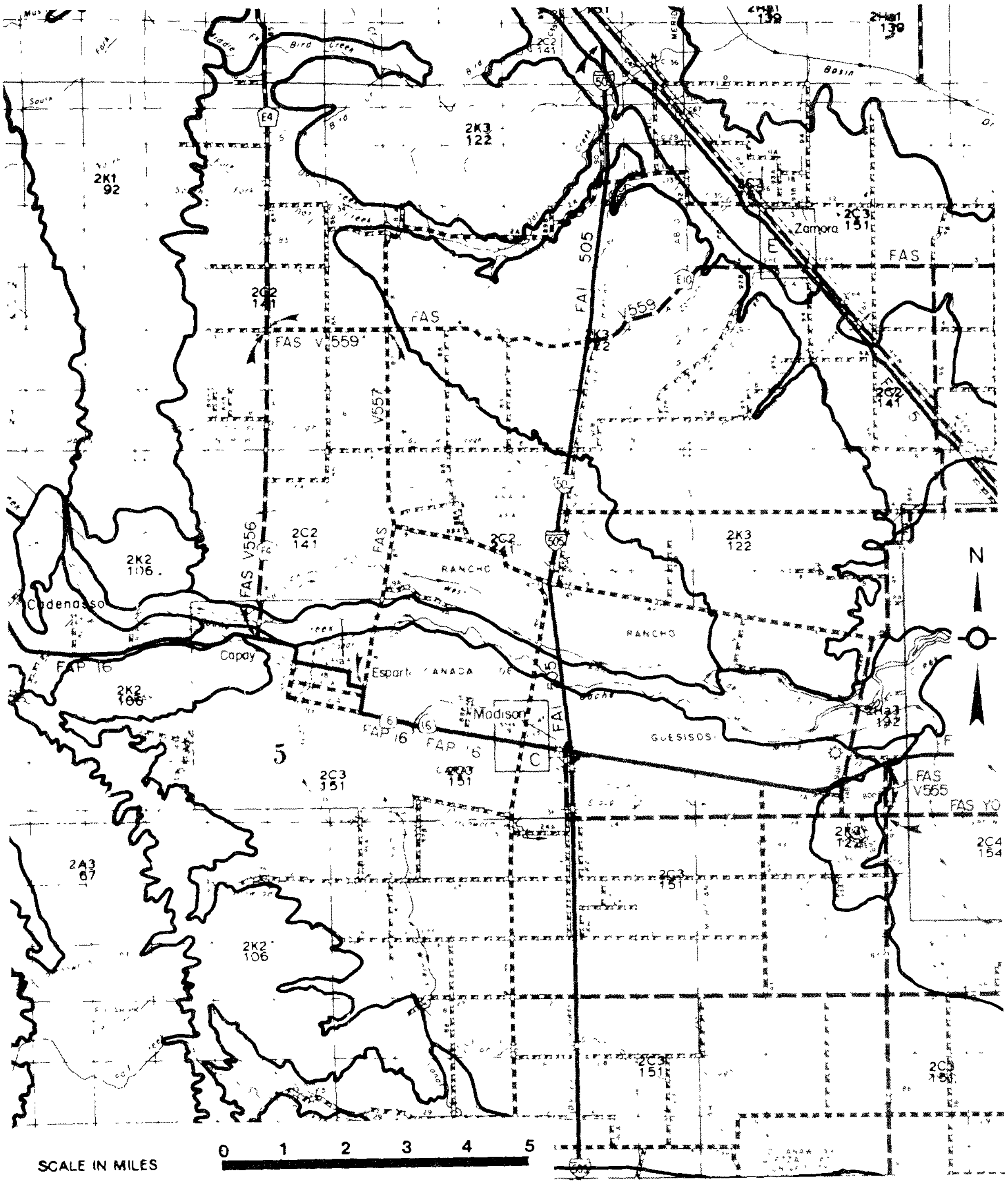


Figure 31. Pollution potential map for a portion of Yolo County, California, showing hydrogeologic settings.

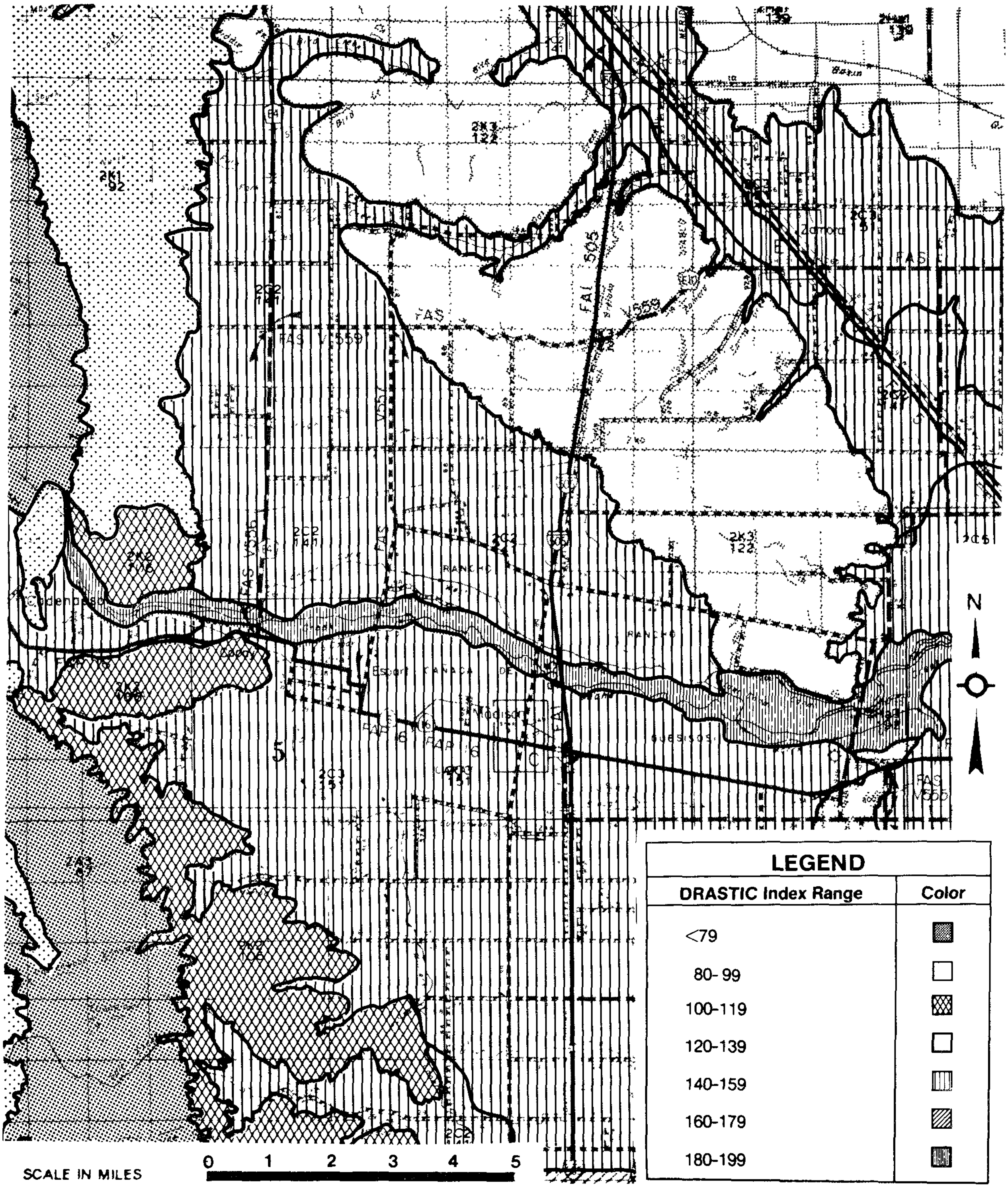


Figure 32. Pollution potential map for a portion of Yolo County, California, showing the superposition of the national color code.

Presentation and Field Check

The draft pollution potential maps accentuated using the National Color Code were used as the focus of a presentation which was given to interested individuals. The presentations were held within the mapped county or in a convenient location within the state. The purpose of the meeting was to familiarize people with the DRASTIC methodology, explain the efforts conducted to date in the county, solicit critical review on the maps and educate individuals about the importance of protecting ground-water resources. The audience at the meetings included a cross-section of individuals ranging from state geologists, city planners, mayors, and county commissioners.

The draft color-keyed maps and the full size topographic-based overlays were also used to field check the maps. Individuals particularly knowledgeable about the seven DRASTIC parameters were asked to critically review the maps. The review consisted of an office and field component. The reviewers represented drillers, universities, geologists, soil scientists, and other technical experts. Typically, five individuals spent a very long field day verifying the ranges chosen for the DRASTIC parameters.

Final Map and Legend

Once the review was complete, suggested modifications to the draft maps were made. The final DRASTIC maps were professionally printed in 21 inch by 27 inch sheets. A four-color printing process was used to color code the appropriate DRASTIC Index ranges. A fifty percent screened county highway map formed the base map. All maps contained a scale, title, legend, and location map.

An accompanying legend was created using a folio style. The legend contains a written description and block diagram for every hydrogeologic setting encountered in the county. The block diagram precedes DRASTIC charts with appropriate ranges and DRASTIC Indexes for every variation delineated in the county. This allows the user to recreate the decision-making process for assessing pollution potential for every area on the map.

The legend also contains a section designed to assist the user in reading the map by presenting a general county description and information on DRASTIC. Figure 33 shows the format of a horizontally arranged legend. A similar format was used for vertically oriented maps. The general county description was adapted for each county. The text for the other explanatory sections needed very slight modification between counties. The text for Portage County, Wisconsin has been reproduced below for reference by the system user:

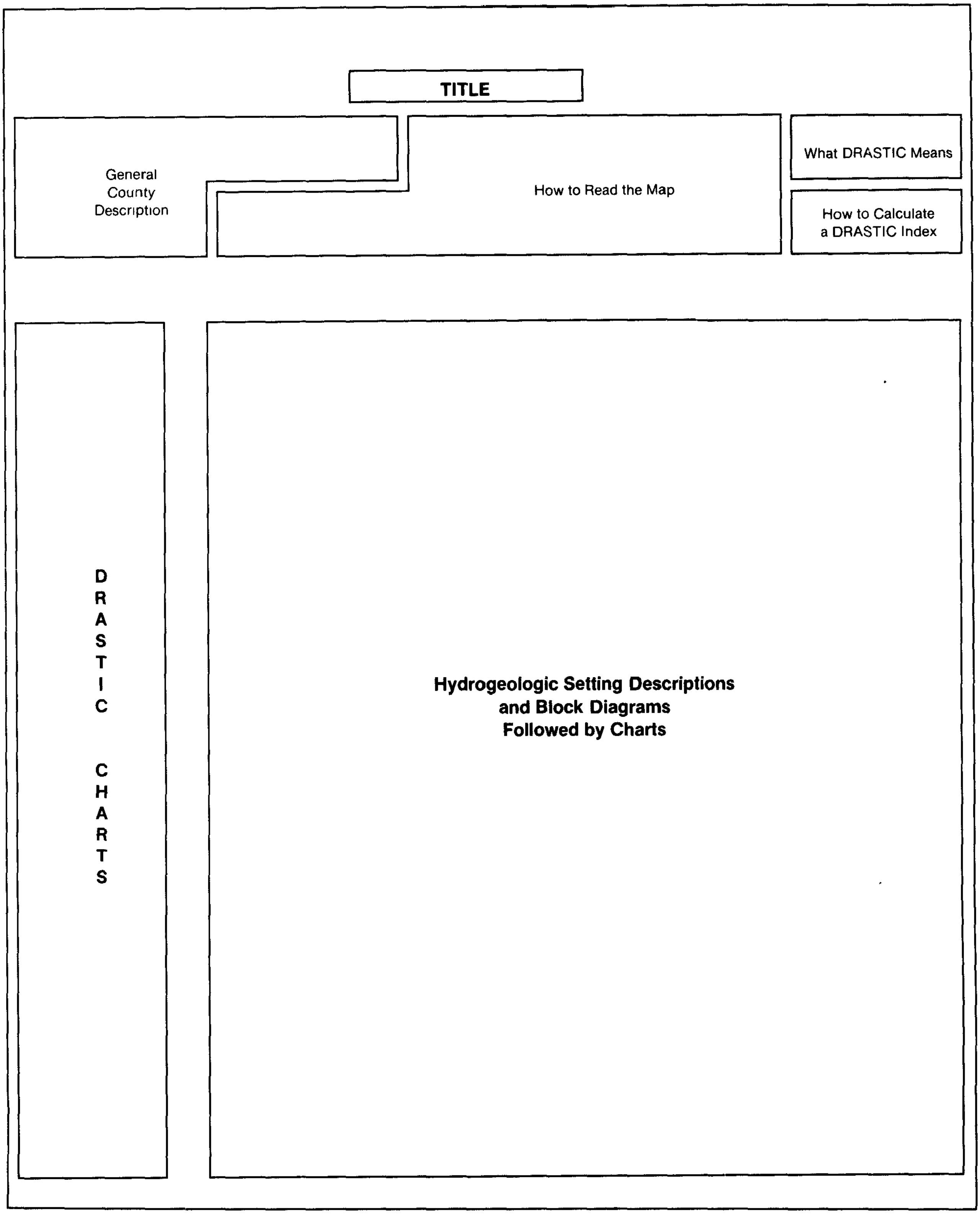


Figure 33. Sample format of a legend for a ground-water pollution potential map.

"How to Read the Map

The DRASTIC System provides the user with information about the hydrogeologic setting of an area and the pollution potential. The symbols found on the map look like this:

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

A. Hydrogeologic Setting

1. The first number (7) refers to the major ground-water region in which the hydrogeologic setting is located.
2. The letter or letters (Ba) define the hydrogeologic setting in more detail.
3. The number (1) describes a certain set of DRASTIC parameters which are unique to this setting. When parameters, such as depth to water, change enough to warrant a different DRASTIC Index but not significantly to change hydrogeologic settings, a new set of unique characteristics is generated and another number (2) is assigned. See charts below.

B. DRASTIC Index

This number represents a relative measure of ground water pollution potential. The map has been color-coded using ranges developed on the map legend. These colors are part of a national color code which has been developed to assist the user in gaining a general insight into the vulnerability of ground water to pollution. DRASTIC Index values range from 99 to 200 in Portage County.

What DRASTIC Means

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

How to Calculate a DRASTIC Index

1. Each DRASTIC parameter has been weighted with respect to each other and assigned a number from 1 to 5 (Table 2).
2. Each DRASTIC parameter has been divided into ranges or descriptive terms and assigned associated ratings (Tables 4-10).
3. A DRASTIC Index is calculated by multiplying: Weight X Rating for each parameter
4. Add the results to obtain the DRASTIC Index."

The legend was printed on 21 inch by 27 inch sheets to correspond to the finished map size. Where necessary, the lengends were printed double-sided to allow for display of all the hydrogeologic setting descriptions and accompanying charts.

COUNTY MAPPING EFFORTS

The level of effort required to produce a map depends on the size of the area to be evaluated, the amount of available information and the degree of prior knowledge of the user about the area. In addition, the level of hydrogeologic expertise and familiarity with the methodology will also influence the ability of the user to quickly produce an accurate and reliable map.

This section is designed to familiarize the user with the application of DRASTIC in each of the ten demonstration counties. Each discussion contains a generalized description of the county, significant references used to determine DRASTIC ranges, and a description of the major assumptions used in producing the maps. Notations of some of the significant changes to DRASTIC based on this testing phase of the system are also made.

Each county section also contains a generalized pollution potential map screened to show DRASTIC Index ranges corresponding to the National Color Code. The full-scale maps delineating hydrogeologic settings overlayed on a county highway map are displayed in Appendices D through M. A location map and charts corresponding to the maps are also contained in these Appendices. The full-scale map of Yolo County in Appendix M has been screened to correspond to the DRASTIC Index ranges used in the National Color Code. By comparing the full-scale map of Yolo County with the unscreened maps in the other appendices, the user can evaluate the advantages of displaying the information in a variety of formats.

Cumberland County, Maine

Cumberland County, Maine, lies within the Northeast and Superior Uplands hydrogeologic region. Sand and gravel aquifers are the major ground-water resource for the county and are capable of supplying significant yields to domestic and municipal wells. These aquifers consist of glacial ice-contact and outwash deposits, which occur primarily in the valleys of major rivers and along their tributaries. These deposits are typically very permeable with shallow water depths. Where sand and gravel deposits are not present, the igneous/metamorphic aquifers are used for water supplies. These aquifers are typically in hydraulic connection with overlying glacial till; however, well yields are low.

In mapping Cumberland County, eight hydrogeologic settings were identified and included. Computed DRASTIC Index values range from 84 to 184. Table 23 details the settings and ranges of associated DRASTIC Indexes. Also noted in the table are the number of unique DRASTIC Index calculations which were made during the mapping effort. The DRASTIC Index numbers reflect evaluation of water table aquifers only.

TABLE 23. HYDROGEOLOGIC SETTINGS MAPPED IN CUMBERLAND COUNTY, MAINE

Hydrogeologic Setting	Range of DRASTIC Indexes	Number of DRASTIC Index Calculations
(9A) Mountain Slopes	84	1
(9Da) Glacial Till Over Crystalline Bedrock	118-122	2
(9E) Outwash	152-184	7
(9F) Moraine	151	1
(9H) Swamp/Marsh	153	1
(9I) Bedrock Uplands	98-112	2
(9J) Glacial Lake/Glacial Marine Deposits	98-112	2
(9K) Beaches, Beach Ridges and Sand Dunes	160	1

Figure 34 shows a general pollution potential map for Cumberland County. The DRASTIC Indexes have been grouped in accordance with the National Color Code (Table 22). Selected screens have been used to illustrate the variability. The pollution potential map has been superimposed on a base map for geographic reference. No hydrogeologic setting lines have been delineated on the map.

Appendix D contains the full-size pollution potential map for Cumberland County complete with hydrogeologic setting designations and individual DRASTIC Index computations. The map has been superimposed on a base map for geographic reference. The DRASTIC Index values have not been grouped on the full-size map. The map has been divided into separate sheets which permit it to be incorporated into the document. An Index to the map sheets is provided for ease of geographic sheet location. The corresponding charts which detail the ranges of the seven DRASTIC parameters chosen for each area and the computation of the DRASTIC Index immediately follows the maps.

Computation of the DRASTIC Indexes and identification of hydrogeologic settings relied on detailed information of the seven DRASTIC parameters. Specific descriptions and sources used to obtain this information are outlined in the following discussion centering around each DRASTIC parameter. A complete list of references is contained at the end of Section 5. The rating associated with the chosen range for each DRASTIC parameter appears in parenthesis for ease of reference.

Depth to Water

Water level information was primarily obtained from Ground Water Resource Maps of Cumberland County (Caswell and Lanctot, 1978); published maps of the Sand and Gravel Aquifer Map Series including Caswell (1979b, c, d, e, f and g) and Tepper et al. (1985); and unpublished maps of the Sand

Figure 34. Generalized pollution potential map of Cumberland County, Maine.

and Gravel Aquifer Map Series at the Maine Geological Survey. Supplemental information was obtained from maps and well logs within Maine Basic Data Reports Nos. 3 and 9 (Prescott, 1967; 1976a). According to geologic reports, water occurs in the fractures of the igneous/metamorphic bedrock aquifers under semi-confined conditions. Since DRASTIC does not effectively evaluate semi-confined aquifers, the metamorphic/igneous aquifers must be designated as either confined or unconfined. After consultation with Andrews Tolman (personal communication, Maine Geological Survey, 1985), the metamorphic/igneous aquifers were treated as unconfined. Water levels ranged from 15 to 30 feet (7) and 30 to 50 feet (5). Sand and gravel aquifers were also unconfined and exhibited water level depths 5 to 15 feet (9) and 15 to 30 feet (7). Water level data in some areas were scarce; personal communications with Andrews Tolman were helpful in establishing reasonable ranges for depth to water.

Net Recharge

Published references for net recharge were not located during reference-searching in this country. Therefore, net recharge values were estimated based on precipitation rates and types of surficial materials. Estimates were provided by Andrews Tolman (personal communication, Maine Geological Survey, 1985). Estimates were classified according to aquifers. Sand and gravel aquifers yielding 50 gallons per minute or greater were assigned the range of 10+ inches per year (9) while those yielding 10 to 50 gallons per minute were assigned 7 to 10 inches per year (8). The metamorphic/igneous aquifers were assigned a range of 4 to 7 inches per year (6) regardless of the characteristics of the overlying deposits.

Aquifer Media

Information on aquifer media was derived from a variety of sources including: Hussey and Westerman (1979); Caswell (1979a); Caswell and Lanctot (1979); Prescott (1963; 1967; 1968; 1976); published maps from the Sand and Gravel Aquifer Map Series including: Caswell (1979b, c, d, e, f and g) and Tepper et al. (1985); unpublished maps from the Sand and Gravel Aquifer Map Series; and the Surficial Geology Series including: Prescott (1976b; 1977); Prescott et al. (1976); Prescott and Thompson (1976a and b; 1977a, b and c); Smith (1976a and b; 1977a, b, c and d); Smith and Thompson (1976; 1980); Thompson (1976a, b, c, d, e and f; 1977); and Thompson and Prescott (1977). The distribution of the sand and gravel aquifers was determined primarily from the Sand and Gravel Aquifer Maps and the Surficial Geology series. The sand and gravel aquifers producing 50 gallons per minute or greater were assigned a typical rating of (8); those producing 10 to 50 gallons per minute were assigned the lower rating of (7). The metamorphic/igneous aquifers were primarily evaluated using Prescott (1963; 1968; 1976a). These aquifers were assigned a typical rating of (3) due to the fracture characteristics and known and anticipated yields.

Soil Media

Soils were mapped based on the Soil Survey of Cumberland County, Maine (Hedstrom, 1974). Because the soil complexes were particularly detailed, it was necessary to generalize the soils into a workable distribution. In areas of glacial till, sand and gravel outwash and the sandy occurrences of the Presumpscott Formation, the designation of sandy loam (6) was used. In less sandy areas of the Presumpscott Formation, the designation of silt loam (4) was used.

Topography

Percent slope was estimated by using 7 1/2 minute USGS topographic quadrangle maps where available and 15 minute USGS topographic quadrangle maps in other areas. Only 15 minute maps were available for the northern and northwestern portions of the county. Contour intervals on the 7 1/2 and 15 minute maps were 20 feet. Areas of mountain slopes, bedrock uplands and some glacial tills averaged 6 to 12 percent (5); areas of outwash, swamps and the remaining glacial tills averaged 2 to 6 percent (9).

Impact of the Vadose Zone Media

Information on the vadose zone media was obtained from well logs and discussions in Prescott (1963; 1968; 1976; and 1977) and Tepper et al. (1985). Surficial geology was also reviewed. Areas underlain by sand and gravel aquifers yielding 50 gallons per minute or greater were assigned a sand and gravel vadose zone with a rating of (8) because the stratigraphy was typically consistent. Areas underlain by sand and gravel aquifers yielding 10 to 50 gallons per minute were called a sand and gravel with significant silt and clay and assigned a value of (7). This media could possibly have been called a sand and gravel; the determination was based on the significance of the silt and clay in the deposits. The media was still relatively "clean" and thus received a rating of (7). Areas of glacial till overlying metamorphic/igneous aquifers were designated as sand and gravel with significant silt and clay and assigned a rating of (6). The lower range was chosen based on the relative degree of fine material within the deposits when compared to the previously discussed deposits. The Presumpscott formation, which is a glacial marine deposit, was termed a sand and gravel with significant silt and clay (5) regardless of the aquifer which it overlay. The formation did not receive a (4) rating because of the extensive fracturing of the fine-grained clay. [The Presumpscott formation would be delineated as a silt/clay in this updated version of DRASTIC. The rating would still remain a (5).] The metamorphic/igneous vadose zone was assigned the typical rating of (4). The ratings assigned to each of the vadose zone media were reviewed during the selection process by Andrews Tolman (personal communication, Maine Geological Survey, 1985).

Hydraulic Conductivity of the Aquifer

Hydraulic conductivity values for the various aquifer media were estimated from the aquifer properties and through discussion with Andrews Tolman (personal communication, Maine Geological Survey, 1985). Very few published values were available. Sand and gravel aquifers yielding 50 gallons per minute or greater were assigned a range of 700 to 1000 gallons per day per square foot (6); those yielding 10 to 50 gallons per minute were assigned a range of 300 to 700 gallons per day per square foot (4). The metamorphic/igneous aquifers were assigned a range of 1 to 100 gallons per day per square foot (1) based on the generally low yields from wells within the county.

Finney County, Kansas

Finney County, Kansas, is situated within two ground-water regions; the western half of the county is located in the High Plains region and the eastern half of the county is predominantly in the Non-Glaciated Central region. Ground-water resources in the High Plains region of the county are derived primarily from the poorly-sorted, unconsolidated sands and gravels of the Ogallala Formation which has been extensively developed for irrigation. This usage has resulted in historicaly declining ground-water levels. In the northwestern corner of the county, the Ogallala is dewatered and small domestic ground-water yields are supplied from the underlying consolidated chalky limestone. A shallow, unconfined river alluvium aquifer also occurs in the Arkansas River valley. This alluvium aquifer is in hydraulic connection with the underlying poorly sorted clay, silt, sand and gravel deposits south of the river.

Within the Non-Glaciated Central ground-water region in Finney County, ground water is primarily available in the deep confined Dakota Sandstone. Because the aquifer is confined and deep, ground-water pollution potential is relatively low. The area of the Pawnee River is underlain by a river alluvium aquifer which typically yields supplies for domestic purposes. This river alluvium serves as the only available shallow ground-water resource in the Pawnee River drainage basin.

In mapping Finney County, seven hydrogeologic settings were identified and included. Computed DRASTIC Index values range from 50 to 166. Table 24 details the settings and ranges of associated DRASTIC Indexes. Also noted in the table are the number of unique DRASTIC Index calculations which were made during the mapping effort. Ground-water pollution potential was computed using both confined and unconfined aquifers as described above.

TABLE 24. HYDROGEOLOGIC SETTINGS MAPPED IN FINNEY COUNTY, KANSAS

Hydrogeologic Setting	Range of DRASTIC Indexes	Number of DRASTIC Calculations
(5A) Ogallala	93-121	19
(5C) Sand Dunes	113-151	9
(5D) Playa Lakes	102-122	3
(5Ga) River Alluvium with Overbank Deposits	154-166	3
(5H) Alternating Sandstone, Limestone Shale Sequences	76	1
(6Da) Alternating Sandstone, Limestone and Shale Thin Soil	51-59	5
(6Fa) River Alluvium with Overbank Deposits	126	1

Figure 35 shows a general pollution potential map for Finney County. The DRASTIC Indexes have been grouped in accordance with the National Color Code (Table 22). Selected screens have been used to illustrate the variability. The pollution potential map has been superimposed on a county highway map for geographic reference. No hydrogeologic setting lines have been delineated on the map.

Appendix E contains the full-size pollution potential map for Finney County complete with hydrogeologic setting designations and individual DRASTIC Index computations. The map has been superimposed on a county highway map for geographic reference. The DRASTIC Index values have not been grouped on the full-size map. The map has been divided into separate sheets which permit it to be incorporated into the document. An Index to the map sheets is provided for ease of geographic sheet location. The corresponding charts which detail the ranges of the seven DRASTIC parameters chosen for each area and the computation of the DRASTIC Index immediately follows the maps.

Computation of the DRASTIC Indexes and identification of hydrogeologic settings relied on detailed information of the seven DRASTIC parameters. Specific descriptions and sources used to obtain this information are outlined in the following discussion centering around each DRASTIC parameter. A complete list of references is contained at the end of Section 5. The rating associated with the chosen range for each DRASTIC parameter appears in parenthesis for ease of reference.

Depth to Water

Depth to water in the Ogallala aquifer, the chalky limestone (Fort Hays Member of the Niobrara Formation) and in the Arkansas and Pawnee River alluvium aquifers was mapped based on 1984 water level data reported by Pabst and Dague (1984). Trends in water level changes were also noted from Pabst and Gutentag (1979).

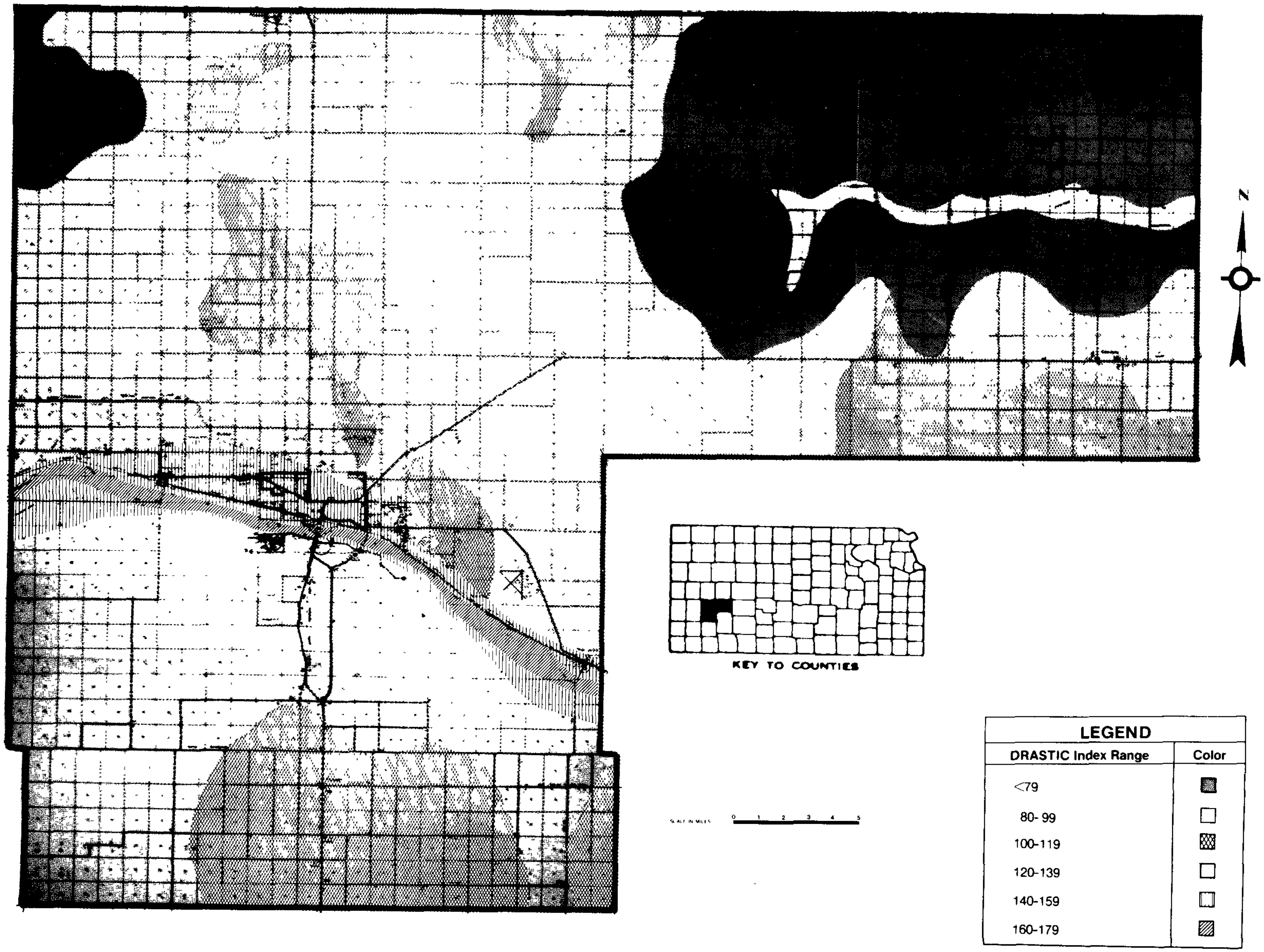


Figure 35. Generalized pollution potential map of Finney County, Kansas.

According to geologic reports, the deposits which are collectively referred to as the Ogallala aquifer have been extensively dewatered. North of the Arkansas River Valley, this dewatering has lowered water levels below the confining layer making the aquifer unconfined. Water levels in the area ranged from 75 to 100 feet (2) and 100+ feet (1). In the northwestern portion of the county, the Fort Hays Limestone of the Niobrara Formation serves as a localized unconfined aquifer. Water levels in this area were 100+ feet (1). In the north central portion of the county, a small section of undifferentiated deposits had shallower water levels which averaged 30-50 feet (5). South of the Arkansas River Valley, the Ogallala is semi-confined with the thickness of the confining layer decreasing southward. Since DRASTIC does not effectively evaluate semi-confined aquifers, the aquifer must be considered either confined or unconfined. Because the aquifer is in direct hydraulic connection with the overlying river alluvium where present and the aquifer has a high vertical hydraulic conductivity, the aquifer was treated as unconfined. Water levels ranged from 100+ feet (1) and 75 to 100 feet (2) in the majority of the area with levels decreasing to 50 to 75 feet (3) and 30 to 50 feet (5) close to the Arkansas River Valley. Water levels in the Arkansas River Valley Alluvium and the Pawnee River alluvium were 15 to 30 feet (7).

Depth to water in the confined Dakota aquifer was mapped as the depth to the top of the sandstone as reported by Gutentag, Lobmeyer, McGovern and Long (1972). Depth to the top of the aquifer was 100+ feet (1).

Net Recharge

Values for net recharge were based on information found in Meyer et al. (1970), Latta (1944) and Dunlap et al. (1985). Additional guidance was obtained from Lloyd Stullken (personal communication, U.S. Geological Survey, 1985). The non-glaciated central ground-water region in the northeasten part of the county was assigned a range of 0 to 2 inches (1). The High Plains ground-water region north of the Arkansas River was also assigned a value of 0 to 2 inches (1). A value of 2 to 4 inches (3) was selected for the Arkansas River Valley and High Plains area south of the Arkansas River. These higher recharge rates took into consideration recharge from irrigation return flows in addition to nominal recharge from precipitation (less than 1/2 inch per year). The higher infiltration rates of precipitation and irrigation return flows occurred through the dune sands and river alluvium.

Aquifer Media

Aquifer media information for the High Plains region (which includes the hydrogeologic settings of Ogallala, Playa Lakes and Sand Dunes) was obtained from Meyer et al. (1970), Latta (1944) and Dunlap et al. (1985). North of the Arkansas River, the lower unit of Miocene and Pleistocene age undifferentiated sand, gravel, silt and clay deposits was selected as the aquifer to map. The deposits were called sand and gravel and were assigned a rating of (7) due to the presence of preferential sorting and presence of fines. South of the Arkansas River, the upper unit of undifferentiated

Miocene and Pleistocene deposits was chosen as the aquifer. Because this upper unit does not have the caliche layers and finer silt and clay deposits, the aquifer media was selected as sand and gravel with a value of (8).

Information on aquifer media for the Fort Hays Limestone Member of the Niobrara Formation was obtained from Gutentag et al. (1981), Meyers et al. (1970) and Latta (1944). The aquifer media was selected as massive limestone and assigned a value of (6) because the fractures and solution openings in the rock are limited both in thickness and areal extent.

Aquifer media information in the river alluvium of the Arkansas and Pawnee Rivers was obtained from Meyer et al. (1970), Latta (1944) and Dunlap et al. (1985). The Arkansas River alluvium is a well-washed sand and gravel which was assigned a rating of (9). The Pawnee River alluvium is also a sand and gravel, but contains a higher percentage of fines. This alluvium was assigned a typical rating of (8).

Information on aquifer media for the Dakota aquifer in the non-glacial central ground-water region was found in Gutentag et al. (1981), Meyer et al. (1970), Latta (1944), Gutentag et al. (1972) and Dealy et al. (1984). Based on this data, the aquifer media was selected as massive sandstone and assigned a value of (6) due to the fine to medium grain calcareous composition of the sandstone.

Soil Media

Soils were mapped based on the Soil Survey of Finney County, Kansas (Horner et al., 1965). Soil media was selected by referring to the general soil association map and choosing a different soil media where more detailed soil series information supported the choice. Sand (9) was used as the soil media in the hydrogeologic setting, Sand Dunes. The Arkansas River Valley contained three different soil medias. Sand (9) and sandy loam (6) media were designated adjacent to the river channel and clay loam (3) was selected for areas not adjacent to the river channel. The clay loam provided the basis for designating the river as having overbank deposits. This county was evaluated using only 3 feet instead of 6 feet of soil profile thickness. In this updated version of DRASTIC, the soil media choice for clay loam (3) would have been sand (9) in most areas because the clay loam typically represented less than 20 inches of the soil profile and was underlain by significant deposits of sand. The hydrogeologic setting designation would be river alluvium without overbank deposits. Silt loam (4), typified by Ulysses silt loam, was chosen in the bluff area immediately north of the Arkansas River Valley in the western to central part of the county. Clay loam (3) was chosen as the predominant soil media in the high plains region north of the Arkansas River. Shrinking and aggregated clay (7) was chosen as the principal soil media in the playa lake settings and in the east-central section of the high plains region. Soils selected as shrinking and aggregated clays were characterized by clayey subsoils with a high shrink-swell potential. Soils in the Pawnee river basin were designated as clay loam (3). Clay loam was also selected as the predominant soil throughout the non-glaciated central region; sandy loam (6) and shrinking and aggregated clay (7) occur in minor areas. Another minor area of shrinking and aggregated clay (1) was also identified in the western edge of the county, north of the Arkansas River. Areas of sandy loam (6) were designated in the high plains area, both north and south of the Arkansas River. These sandy loam soils commonly occurred in geographical proximity to sand deposits. Major areas of clay loam (3) also occurred in the south-central section of the county, where they interfaced with adjacent sandy loam soils. One isolated section of loam (5) was identified in the north-central section of the county. The loam comprised part of a sand-sandy loam-loam-clay loam soil sequence.

Topography

Percent slope was estimated by using 7 1/2 minute USGS topographic quadrangle maps. Contour intervals on the maps were either 5 foot or 10 foot intervals. The entire county is relatively flat. North of the Arkansas River slopes were 0 to 2 percent (1) while south of the Arkansas River slopes averaged 2 to 4 percent (3).

Impact of the Vadose Zone Media

Information for selecting values for the vadose zone media was obtained from the same sources listed in the aquifer media section. For the high plains area north of the Arkansas River, the vadose zone media above the lower unit of the undifferentiated Miocene and Pleistocene deposits was called sand and gravel with significant silt and clay and assigned a value of (6). The deposits overlying the Niobrara Formation were also assigned this designation. In the high plains area south of the Arkansas River, the upper unit of undifferentiated Miocene and Pleistocene deposits was selected as sand and gravel with significant silt and clay and assigned a value of (7). The higher value was assigned based on the presence of the sandy deposits in the dune areas.

In the Arkansas River alluvium, the deposits beneath the thin overbank are described as coarse sand and gravel. The vadose media was chosen as "sand and gravel" and assigned a typical value of (8). In the Pawnee River alluvium, the sands and gravels are interbedded with large amounts of silts and clays. This area was designated as sand and gravel with significant silt and clay and assigned a value of (7). The typical rating of (6) was not chosen due to the large fraction of coarser-grained materials within the alluvium.

The Dakota sandstone aquifer is confined by overlying sequences of shales, siltstones and limestones. The impact of the vadose zone media was chosen as "confining layer" (1). The charts accompanying the full-size pollution potential map detail the impact of the vadose zone media as silt/clay (1) instead of confining layer (1). The vadose zone would be delineated as confining layer in this updated version of DRASTIC. The rating would still remain a (1). This change was made to help clarify the use of confining layer in the methodology.

Hydraulic Conductivity of the Aquifer

Information on hydraulic conductivity of the aquifer in the High Plains region was obtained from Meyer et al. (1970) and Dunlap et al. (1985). According to these published reports, hydraulic conductivity values for the undifferentiated Miocene and Pleistocene deposits ranged from 600 to 1500 gallons per day per square foot. Because it was not possible to differentiate specific areas with representative hydraulic conductivities, a range of 700-1000 gallons per day per square foot (6) was chosen.

A hydraulic conductivity range for the Fort Hays Limestone Member of the Niobrara Formation was selected based on an aquifer description by Latta (1944). A range of 1-100 (1) gallons per day per square foot was selected.

Hydraulic conductivity values for the river alluvium aquifers in the Arkansas River and Pawnee River valleys were selected based on information found in Meyer et al. (1970) and Dunlap et al. (1985). This information indicated conductivity values in the Arkansas River alluvium ranged from 1000 to 2000 gallons per day per square foot (8). Values in the Pawnee River alluvium ranged from 300 to 700 gallons per day per square foot (4). Hydraulic conductivity values for the Dakota Aquifer were obtained from Dealey et al. (1984). A range of 1 to 100 gallons per day per square foot (1) was assigned.

Gillespie County, Texas

Gillespie County, Texas, lies within the Nonglaciated Central Hydrogeologic Region. Several different aquifers occur within the county which provide adequate municipal and domestic supplies of ground water. The western portion of the county is covered by a thick sequence of bedded dolomitic limestones, which contain water in solution cavities and fractures. The central area of the county is covered by unconsolidated sands and silts, which provide moderate well yields from lenses of sand and gravel. Where these deposits are locally non-water bearing or absent, ground water is supplied from deeper, more permeable sandstones and limestones. Igneous and metamorphic rocks, which outcrop in the northeastern part of the county, contain ground water in fractures and faults and only provide small quantities of water to domestic wells.

In mapping Gillespie County, five hydrogeologic settings were identified and included. Computed DRASTIC Index values range from 63 to 126. Table 25 details the settings and ranges of associated DRASTIC Indexes. Also noted in the table are the number of unique DRASTIC Index calculations which were made during the mapping effort. The DRASTIC Index numbers reflect evaluation of water table aquifers only.

TABLE 25. HYDROGEOLOGIC SETTINGS MAPPED IN GILLESPIE COUNTY, TEXAS

Hydrogeologic Setting	Range of DRASTIC Indexes	Number of DRASTIC Calculations
(6B) Alluvial Mountain Valleys	94	1
(6Da) Alternating Sandstone, Limestone and Shale Thin Soil	93-126	9
(6Fb) River Alluvium without Overbank Deposits	112-116	2
(6J) Metamorphic/Igneous Domes and Fault Blocks	63-65	2
(6K) Unconsolidated and Semiconsolidated Aquifers	96-113	3

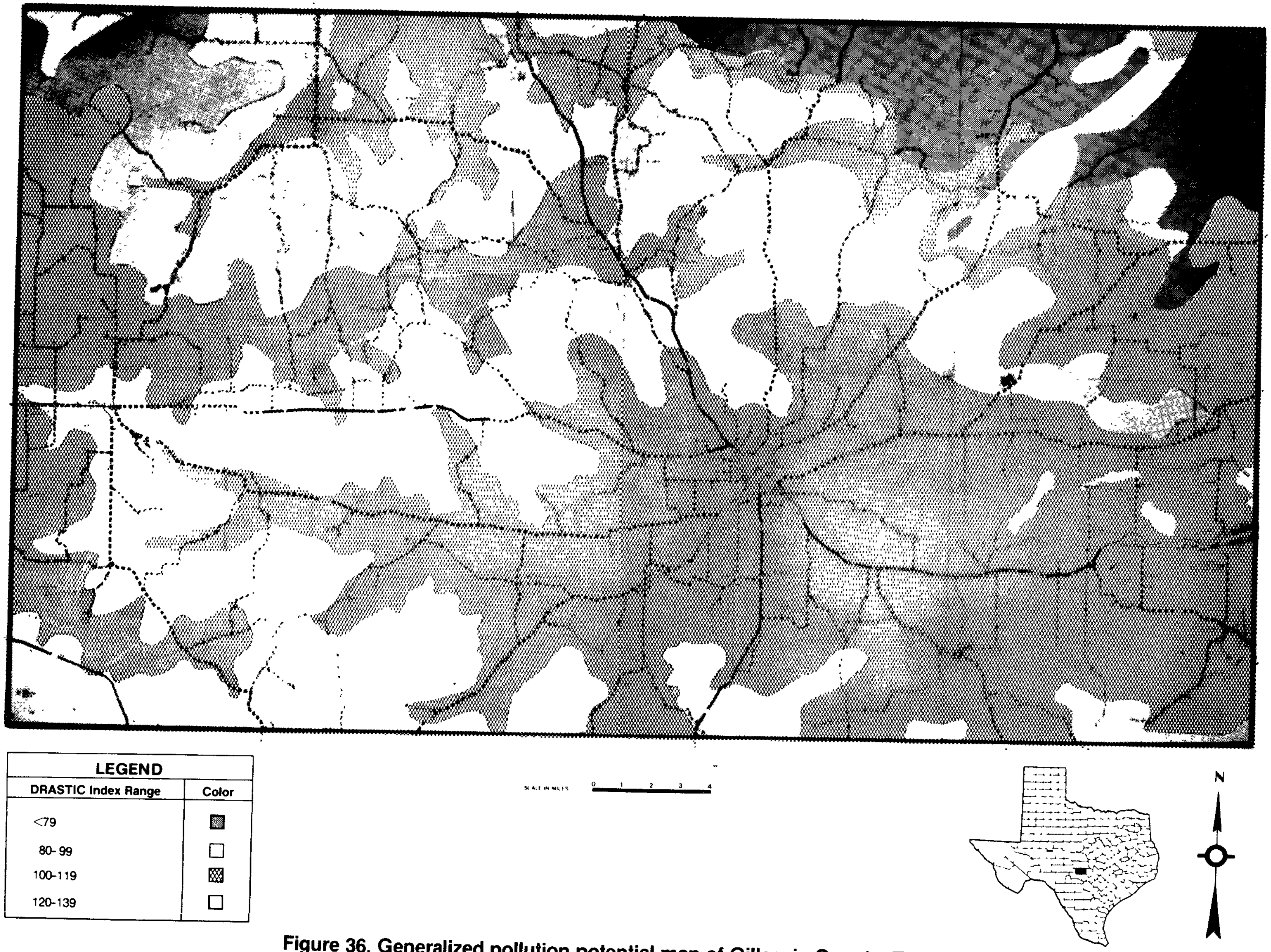
Figure 36 shows a general pollution potential map for Gillespie County. The DRASTIC Indexes have been grouped in accordance with the National Color Code (Table 22). Selected screens have been used to illustrate the variability. The pollution potential map has been superimposed on a county highway map for geographic reference. No hydrogeologic setting lines have been delineated on the map.

Appendix F contains the full-size pollution potential map for Gillespie County complete with hydrogeologic setting designations and individual DRASTIC Index computations. The map has been superimposed on a county highway map for geographic reference. The DRASTIC Index values have not been grouped on the full-size map. The map has been divided into separate sheets which permit it to be incorporated into the document. An Index to the map sheets is provided for ease of geographic sheet location. The corresponding charts which detail the ranges of the seven DRASTIC parameters chosen for each area and the computation of the DRASTIC Index immediately follows the maps.

Computation of the DRASTIC Indexes and identification of hydrogeologic settings relied on detailed information of the seven DRASTIC parameters. Specific descriptions and sources used to obtain this information are outlined in the following discussion centering around each DRASTIC parameter. A complete list of references is contained at the end of Section 6. The rating associated with the chosen range for each DRASTIC parameter appears in parenthesis for ease of reference.

Depth to Water

Information on the depth to water was derived from the Texas Department of Water Resources computer printouts of well logs. These files contain information regarding the location, depth, producing aquifer and the static water level of each well. Additional water-depth information



LEGEND	
DRASTIC Index Range	Color
<79	■
80- 99	□
100-119	▩
120-139	□

Figure 36. Generalized pollution potential map of Gillespie County, Texas.

was obtained from well logs of Virdell Drilling Company in Fredricksburg, Texas (personal communication, Taylor Virdell, Sr. and Taylor Virdell, Jr., 1985). All water levels were plotted on a base map and corrected for topography. All aquifers were unconfined. Water levels in the alternating sandstone, limestone and shale sequences were assigned based on aquifer type and elevation. The Edwards Limestone is the major aquifer in the Edwards Plateau region in the western portion of the county. Where mean sea elevations were 2100 feet or greater, water levels in the aquifer were assigned a range of 100+ feet (1). Where elevations were 2000 to 2100 feet, the depth to water was assigned as 75 to 100 feet (2). Water levels in elevations less than 2000 feet averaged 50 to 75 feet (3). The Edwards Limestone is the aquifer used in settings 6Da1 through 6Da5. Other formations also serve as aquifers in the alternating sandstone, limestone and shale sequences. The Glen Rose Limestone is in the southern and eastern portions of the county. The Glen Rose is depicted as the aquifer in setting 6Da6 and has average water-level depths of 30 to 50 feet (5). The Ellenberger-San Saba group occurs in the northern and eastern portions of the county. The Ellenberger-San Saba as exemplified in settings 6Da7 and 6Da8 have water levels averaging 50 to 75 feet (3). The Hickory Sandstone serves as the aquifer in the northeastern portion of the county. Setting 6Da9 delineates the Hickory Sandstone aquifer and has water levels averaging 75 to 100 feet (2). The Hensell sand is depicted in the unconsolidated and semi-consolidated aquifer setting which occurs throughout the county. Water levels in the Hensell sand averaged 75 to 100 feet (2) in the northwest, 50 to 75 feet (3) in the northeast and 30 to 50 feet (5) in the central and southern portions of the county. Water levels in the unconsolidated deposits of the alluvial mountain valleys averaged 75 to 100 feet (2). Depth to water in the river alluvium ranged from 30 to 50 feet (5). Water levels in the metamorphic and igneous bedrock in the northeastern portion of the county averaged 75 to 100 feet (2).

Net Recharge

Values for net recharge were obtained from Ashworth (1983) and Muller and Price (1979). Recharge rates were published in units of acre feet per year and had to be converted to inches per year. Values for recharge were less than two inches per year throughout the county. The range of 0 to 2 inches per year (1) was used.

Aquifer Media

Information on aquifer media was derived from a variety of sources including: Muller and Price (1970); Rose (1972); Ashworth (1983); Walker (1979); Mount (1963); Texas Department of Water Resources (1983) and published maps from the Geologic Quadrangle Map Series including:

Barnes (1952 a, b, c, d, e and f; 1954a, b, c and d; 1956a, b, c, d, e, f and g; 1965a and b; and 1967). The Edwards Limestone group (settings 6Da1 through 6Da5) contains a basal, extremely burrowed and solutioned limestone unit approximately 50 feet above the base of the section. This marly unit is the principle water-bearing unit and may form springs where the aquifer outcrops. Other water-bearing zones occur higher in the section but little information was available about their water-bearing characteristics. The aquifer media was chosen as massive limestone and assigned a rating of (8). The Glen Rose Limestone (setting 6Da6) is a massive limestone with moderate solutioning along faults and joints in the lower fossiliferous member. The aquifer media was chosen as massive limestone and the typical rating of (6) was assigned. The Ellenberger-San Saba (settings 6Da7 and 6Da8) is also a massive, fossiliferous limestone. Water occurs in the joints and solution cavities. The aquifer was called massive limestone and assigned a rating of (8) because the aquifer is more prolific than the Glen Rose. The Hickory Sandstone (setting 6Da9) is a coarse to fine-grained moderately-sorted sandstone with a conglomerate and coarse sandstone in the lower portion of the aquifer. The aquifer media was chosen as massive sandstone and assigned a typical value of (6). The Hensell Sand (settings 6K1 through 6K3) is a semi-consolidated deposit of sand, silt and clay. The aquifer media was chosen as sand and gravel and assigned a rating of (7) based on the variability of the deposit. Unconsolidated materials in the alluvial mountain valleys (setting 6B1) and the river alluvium (settings 6Fb1 and 6Fb2) were called sand and gravel and assigned a rating of (7) based on the presence of fine materials. The metamorphic igneous aquifers have low yields and were assigned the typical rating of (3) due to a lack of information about the degree of fracturing.

Soil Media

Soils were mapped based on the Soil Survey of Gillespie County, Texas (Allison et al., 1975). Soils were grouped based on the underlying major aquifer. Soils overlying the Edwards Limestone (settings 6Da1 through 6Da5) were very thin. The soil media was chosen as thin or absent (10). Soils overlying the Glen Rose (setting 6Da6) are typically silt loams (4). Soils formed in the Ellenberger-San Saba area (settings 6Da7 and 6Da8) and the Hickory Sandstone area (setting 6Da9) are typically loams (5). In some high relief areas, the soils are thin or absent (10). Soils overlying the Hensell Sand (setting 6K1 through 6K3) are typically loam (5) in the northwest portion of the county and sandy loam (6) in the remainder of the county. Soils formed in the alluvial mountain valleys (setting 6B1) are silty loam (4). River alluvium soils (settings 6Fb1 and 6Fb2) are clay loam (3) in the northwestern portion of the county and loam (5) in the remainder of the county. Soils overlying the metamorphic/igneous aquifer area (settings 6J1 and 6J2) are loam (5) and sandy loam (6).

Topography

Percent slope was estimated by using 7 1/2 minute USGS topographic quadrangle maps. Contour intervals on the 7 1/2 minute maps are 20 feet. Topography was influenced by the formation exposed at the surface. Areas of the Edwards group (settings 6Da1 through 6Da5) are 2 to 6 percent (9) on the top of the plateau; slopes at the plateau boundary ranged from 2 to 6 percent (9) to 6 to 12 percent (5). Typically the northern slopes are steeper than the southern slopes. Slopes in other areas are relatively uniform throughout the county at 2 to 6 percent (9). Slopes of 6 to 12 percent (5) are present in portions of the metamorphic/igneous area where extensive faulting has occurred. Slopes of 6 to 12 percent (5) also occur in portions of the areas underlain by the Ellenberger-San Saba group (setting 6Da8).

Impact of the Vadose Zone Media

Information on the vadose zone media was obtained from Mount (1963), Ashworth (1983), Walker (1979) and Rose (1972). The Edwards Limestone area (settings 6Da1 through 6Da5) was called a limestone and assigned a typical rating of (6) based on the solutioning and jointing of the formation. The Glen Rose (setting 6Da6) was called limestone and assigned a rating of (5) because the limestone is more massive than the Edwards and marly in the upper layers. The Ellenberger-San Saba (settings 6Da7 and 6Da8) vadose zone media was designated as limestone and assigned a typical rating of (6). The Hickory Sandstone (setting 6Da9) is overlain by a limestone. The vadose zone media was called limestone and assigned a typical value of (6). The Hensell Sand (settings 6K1 through 6K3) vadose zone media contains silts and clays. The media was designated as a sand and gravel with significant silts and clays and assigned a typical value of (6). The alluvial deposits in the alluvial mountain valleys (setting 6B1) were called sand and gravel with significant silts and clays and assigned a typical value of (6). The river alluvium (settings 6Fb1 and 6Fb2) is better sorted than in the alluvial valleys. A vadose zone media of sand and gravel with significant silts and clays was chosen and assigned a rating of (7). The vadose zone media in the metamorphic/igneous areas (settings 6J1 and 6J2) was called metamorphic/igneous and assigned a typical value of (4).

Hydraulic Conductivity of the Aquifer

Hydraulic conductivity values for the various aquifer media were contained in Walker (1979), Muller and Price (1979) and Mount (1963). Where no values were given, estimates were based on discussions contained within the reports. Hydraulic conductivities for the Edwards Limestone (settings 6Da1 through 6Da5) are 1000 to 2000 gallons per day per square foot (8). Glen Rose values (setting 6Da6) were estimated to be 300 to 700 gallons per day per square foot (4). Ellenberger-San Saba values (settings 6Da7 and 6Da8) were given as 700 to 1000 gallons per day per square foot (6). Hydraulic conductivity values for the Hickory Sandstone (setting 6Da9) were stated as 300 to 700 gallons per day per square foot (4). Values for the Hensell Sand (settings 6K1 through 6K3) were listed as ranging between 300 to 700 gallons per day per square foot (4). The alluvial aquifers (settings 6B1, 6Fb1 and 6Fb2) were estimated to range between 300 to 700 gallons per day per square foot (4) based on the presence of fines and the hydraulic connection to the underlying Hensell sand in the river alluvium settings. The metamorphic/igneous aquifers were estimated to be 1 to 100 gallons per day per square foot (1) based on low yields. Little information is available on the metamorphic/igneous aquifers.

Greenville County, South Carolina

Greenville County, South Carolina, lies within the Piedmont and Blue Ridge ground-water region. The primary ground-water resources of the county are derived from igneous and metamorphic rocks covered by variable thicknesses of saprolite. Ground water in the igneous/metamorphic aquifer system provides moderate yields from fractures and faults. Unconfined ground water accumulates in the saprolite overlying the parent rock and often serves as a recharge source for these aquifers. Although saprolite is an easily developed source of ground water, low yields and seasonal fluctuations typically limit the development of this resource. Although limited in aerial extent, alluvial deposits of sand and gravel adjacent to rivers and overlying the saprolite may also constitute a source of ground water.

In mapping Greenville County, five hydrogeologic settings were identified and included. Computed DRASTIC Index values range from 87 to 152. Table 26 details the settings and ranges of associated DRASTIC Indexes. Also noted in the table are the number of unique DRASTIC Index calculations which were made during the mapping effort. The DRASTIC Index numbers reflect evaluation of water table aquifers only.

TABLE 26. HYDROGEOLOGIC SETTINGS MAPPED IN GREENVILLE COUNTY, SOUTH CAROLINA

Hydrogeologic Setting	Range of DRASTIC Indexes	Number of DRASTIC Index Calculations
(8A) Mountain Slopes	87-113	7
(8B) Alluvial Mountain Valleys	143	1
(8D) Regolith	105-125	3
(8E) River Alluvium	152	1
(8F) Mountain Crests	90-99	3

Figure 37 shows a general pollution potential map for Greenville County. The DRASTIC Indexes have been grouped in accordance with the National Color Code (Table 22). Selected screens have been used to illustrate the variability. The pollution potential map has been superimposed on a county highway map for geographic reference. No hydrogeologic setting lines have been delineated on the map.

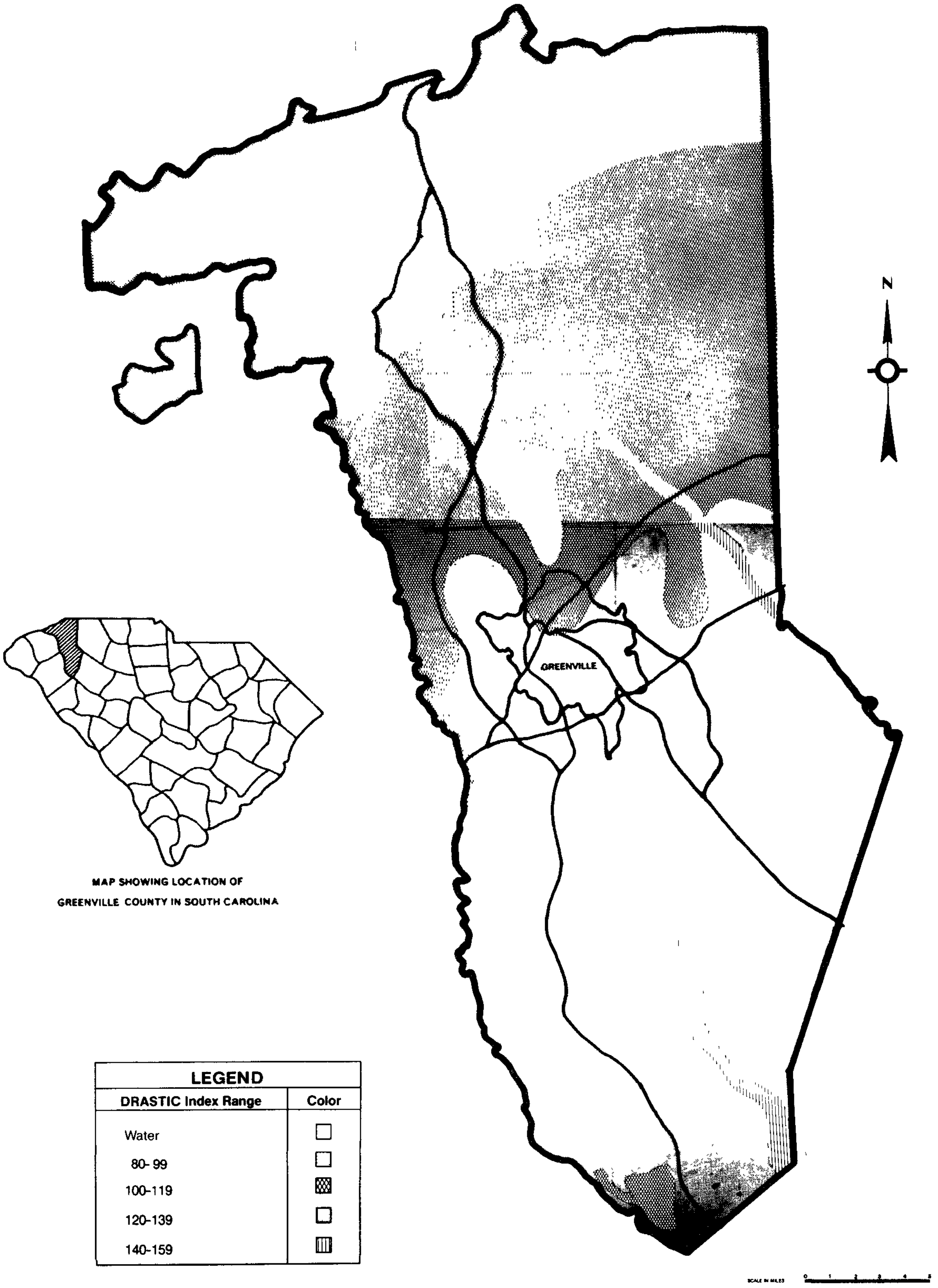


Figure 37. Generalized pollution potential map of Greenville County, South Carolina.

Appendix G contains the full-size pollution potential map for Greenville County complete with hydrogeologic setting designations and individual DRASTIC Index computations. The map has been superimposed on a county highway map for geographic reference. The DRASTIC Index values have not been grouped on the full-size map. The map has been divided into separate sheets which permit it to be incorporated into the document. An Index to the map sheets is provided for ease of geographic sheet location. The corresponding charts which detail the ranges of the seven DRASTIC parameters chosen for each area and the computation of the DRASTIC Index immediately follows the maps.

Computation of the DRASTIC Indexes and identification of hydrogeologic settings relied on detailed information of the seven DRASTIC parameters. Specific descriptions and sources used to obtain this information are outlined in the following discussion centering around each DRASTIC parameter. A complete list of references is contained at the end of Section 6. The rating associated with the chosen range for each DRASTIC parameter appears in parenthesis for ease of reference.

Depth to Water

Water level information was primarily obtained based on well logs and information contained in Koch (1968). Supplemental values were estimated based on topography and personal communication with Don Duncan (South Carolina Department of Health and Environmental Control, 1985). Water-level data was generally sparse. All aquifers were treated as unconfined. In general, water levels averaged 5 to 15 feet (9) in the river valleys and and alluvial mountain valleys. Depth to water in the regolith in the central and southern portion of the county averaged 15 to 30 feet (7) due to the presence of thin saprolite deposits. Water levels in the central and northern portion of the county averaged 30 to 50 feet (5) due to the formation of thicker saprolite deposits on the biotite-gneiss bedrock. Water levels on mountain slopes averaged 75 to 100 feet (2) except on slopes adjacent to the Saluda River where water levels were shallower and averaged 30 to 50 feet (5). Water levels on mountain crests ranged from 75 to 100 feet (2) and 100+ feet (1).

Net Recharge

Published references for net recharge were not located during reference-searching in this county. Net recharge rates were estimated based on precipitation and predicted infiltration due to rock type, cover and topography. The estimates were supplemented by referring to other similar areas in the Piedmont and Blue Ridge for which net recharge values were available. Values of 7 to 10 inches per year (8) were assigned for areas of high relief and 10+ inches per year (9) was used in the remainder of the county.

Aquifer Media

Information on aquifer media was obtained from Koch (1968) and Padgett and Hardee (1982). Metamorphic/igneous bedrock was chosen as the aquifer in the alluvial mountain valleys due to the shallow thickness of the overlying alluvial deposits. This area was assigned a typical rating of (4). In the river alluvium areas, the alluvium is sand and gravel interbedded with lenticular clay layers. A rating of (5) was assigned based on the presence of the high clay content. In the updated version of DRASTIC, these deposits would receive a rating of (6) which is the lowest rating for sand and gravel. The areas as drawn on the map depicting river alluvium were generously broad along minor tributaries and may be thinner than depicted. The saprolite was chosen as the aquifer in the majority of the county. Wells may be developed in either the underlying metamorphic/igneous bedrock or in the overlying saprolite. In all areas where the saprolite is present, it serves as a holding reservoir for the underlying bedrock. Based on the hydraulic interconnection of the two medias, the saprolite was mapped as the aquifer. An aquifer media of weathered metamorphic/igneous rock was chosen for the saprolite. A typical rating of (3) was assigned in the northern portion of the county; a value of (5) was assigned in the southern portion of the county based on increased fracturing and higher well yields. Bedrock type which influenced the development of the overlying saprolite was used as the differentiation between the two values.

Soil Media

Soils were mapped based on the Soil Survey of Greenville County, South Carolina (Camp, 1975). Soils on mountain crests or soils in the northern portion of the county which developed on mica-granite gneiss bedrock were called loam (5). Soils in the river alluvium and alluvial mountain valleys were also designated as loam (5). Soil media in the thicker regolith area in the southern two thirds of the county were called non-shrinking and non-aggregated clay (1).

Topography

Percent slope was estimated by using 7 1/2 minute USGS topographic quadrangle maps where available and 15 minute USGS topographic quadrangle maps in other areas. Contour intervals on the 7 1/2 minute maps were 10 feet and 40 feet; intervals for the 15 minute maps were 20 feet and 40 feet. Areas of alluvial mountain valleys and river alluvium averaged 2 to 6 percent (9). Slopes in the regolith areas ranged from 2 to 6 percent (9) in wider well-developed valleys to 6 to 12 percent (5) in other areas. Mountain slopes averaged 12 to 18 percent (3) or 18+ percent (1). Mountain crests ranged from 6 to 12 percent (5), 12 to 18 percent (3) and 18+ percent (1).

Impact of the Vadose Zone Media

Information on the vadose zone media was obtained from Koch (1968) and Padgett and Hardee (1982). The river alluvium and alluvial mountain valley deposits were called sand and gravel with significant silt and clay and assigned a rating of (5). This value is less than the typical value due to the presence of interbedded clays and silts in the deposits. The regolith was well-developed and contained a significant fraction of fine materials. The media was called sand and gravel with significant silt and clay and assigned a rating of (5). The vadose zone media in the mountain slope and mountain crest areas consisted of more poorly weathered coarser deposits. The media was still chosen as sand and gravel with significant silt and clay, but was assigned a typical rating of (6).

Hydraulic Conductivity of the Aquifer

Values for hydraulic conductivity of the various aquifer media were not available in published reports. Estimates were based on well yields and aquifer characteristics as described in Koch (1968) and Padgett and Hardee (1982). The river alluvium was assigned a value of 300 to 700 gallons per day per square foot (4) based on the description of sand and gravel interbedded with clay lenses. The alluvial mountain valley areas were assigned a range of 100 to 300 (2) gallons per day per square foot based on the occurrence of significant fractures in the bedrock valleys. The weathered metamorphic/igneous aquifers in the central to northern portion of the county principally consisting of biotite and mica granite gneiss were assigned a range of 1 to 100 gallons per day per square foot (1). In the central to southern portion of the county where the bedrock consisted primarily of granite gneiss the value of 100 to 300 gallons per day per square foot (2) was chosen due to an increased amount of fracturing.

Lake County, Florida

Lake County, Florida, lies within the Southeast Coastal Plain ground-water region. The county is characterized by low to moderate relief with karst topography and numerous sinkholes, lakes and swampy areas. Water depths are typically shallow and soils are highly permeable. Ground-water resources within Lake County are derived from either a near-surface sand aquifer or an underlying carbonate rock aquifer, which is in hydraulic connection with the overlying sand deposits. The aquifers are separated by a confining bed comprised of an interbedded mixture of clayey sand and clay. This confining layer is extensive throughout the county, although variable in thickness and discontinuous in local sections. Yields from the surficial sand aquifer are usually sufficient for domestic purposes. Because of the highly permeable overlying soils and shallow water table, the surficial aquifer is vulnerable to pollution from the surface. The carbonate rock aquifer is referred to as the "Floridan" aquifer and is the major ground-water resource in the county. The susceptibility of this aquifer to pollution from the surface depends on the degree or confinement of the limestone aquifer and the amount of recharge received from the more vulnerable surficial sand aquifer.

In mapping Lake County, Florida, two separate evaluations were performed: one for the surficial aquifer and another for the confined aquifer. Two hydrogeologic settings were identified and included for the surficial aquifer. Computed DRASTIC indexes range from 134 to 190. Two hydrogeologic settings were also identified and included for the confined aquifer. Computed DRASTIC indexes range from 93 to 214. Table 27 details the settings and ranges of associated DRASTIC Indexes. Also noted in the table are the number of unique DRASTIC Index calculations which were made during both mapping efforts.

TABLE 27. HYDROGEOLOGIC SETTINGS MAPPED IN LAKE COUNTY, FLORIDA

Hydrogeologic Setting	Range of DRASTIC Indexes	Number of DRASTIC Index Calculations
Surficial		
(11A) Solution Limestone and Shallow Surficial Aquifers	134-190	35
(11C) Swamp	166-190	17
Confined		
(11A) Solution Limestone and Shallow Surficial Aquifers	102-155	36
(11C) Swamp	93-145	9

Figure 38 shows the general pollution potential map for the surficial aquifer in Lake County; figure 39 shows the general pollution potential for the confined aquifer. Selected screens have been used to illustrate the variability. The pollution potential maps have been superimposed on county highway maps for geographic reference. No hydrogeologic setting lines have been delineated on the map.

Appendix H contains the full-size pollution potential map for both the surficial and confined aquifers in Lake County complete with hydrogeologic setting designations and individual DRASTIC Index computations. The maps have been superimposed on county highway maps for geographic reference. The DRASTIC Index values have not been grouped on the full-size maps. The maps have been divided into separate sheets which permit incorporating into the document. Two Indexes to the map sheets are provided for ease of geographic sheet location. The corresponding charts which detail the ranges of the seven DRASTIC parameters chosen for each area and the computation of the DRASTIC Index immediately follows the maps.

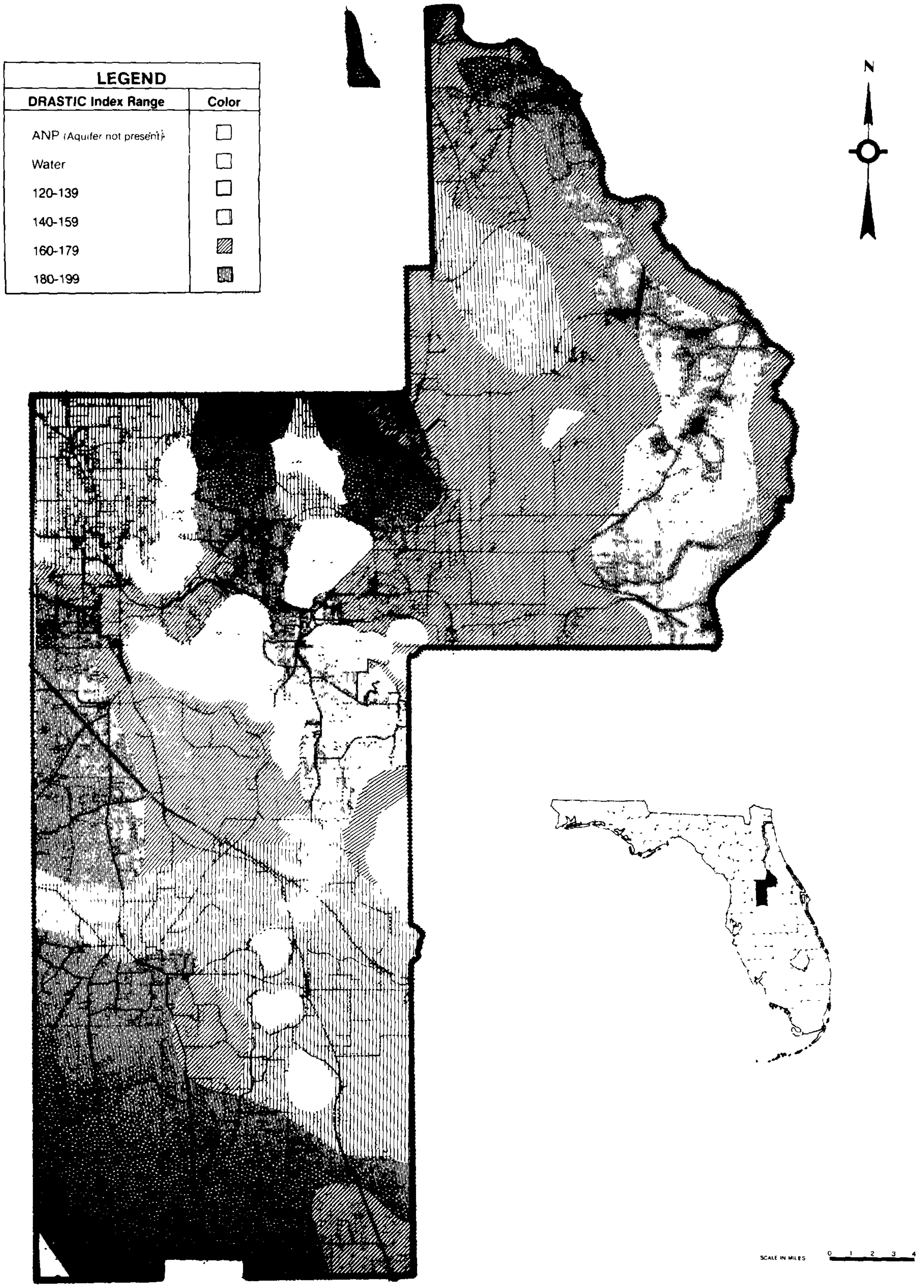


Figure 38. Generalized pollution potential map of the surficial aquifer, Lake County, Florida.

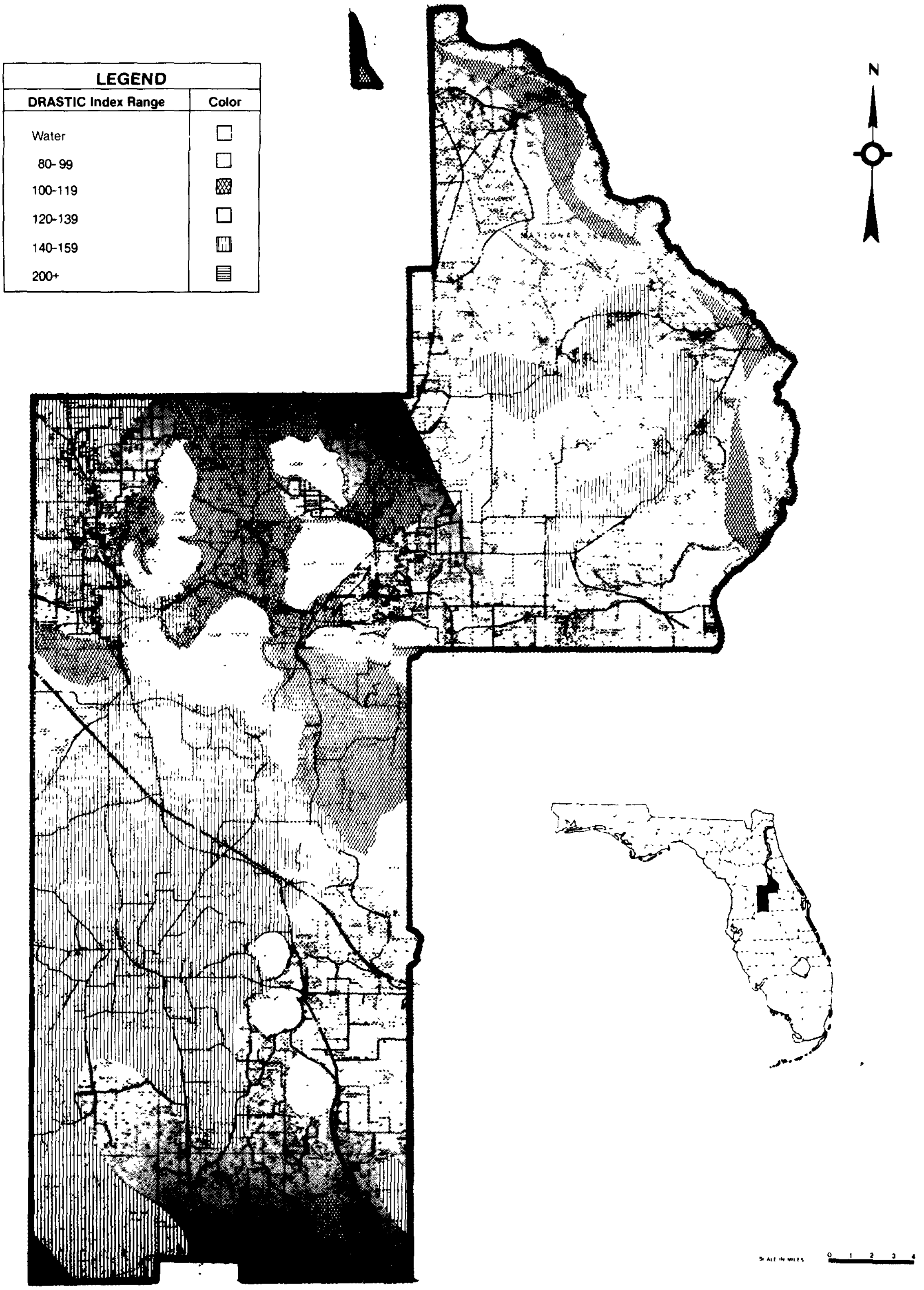


Figure 39. Generalized pollution potential map of the confined aquifer, Lake County, Florida.

Computation of the DRASTIC Indexes and identification of hydrogeologic settings relied on detailed information of the seven DRASTIC parameters. Specific descriptions and sources used to obtain this information are outlined in the following discussion centering around each DRASTIC parameter. A complete list of references is contained at the end of Section 5. The rating associated with the chosen range for each DRASTIC parameter appears in parenthesis for ease of reference.

Surficial Aquifer

Depth to Water -- Water levels were mapped based on general data contained in Knochenmus and Hughes (1976). Since no specific water-level data was available, depth to water was frequently inferred from topographic maps by noting differences between lake surface elevations and adjacent land areas. Where inferred water levels exceeded the depth to the top of the underlying limestone aquifer, the surficial aquifer was mapped as "aquifer not present" (ANP). Water levels averaged 0 to 5 (10) in swamp settings. Depth to water was assigned values of 5 to 15 feet (9) in areas adjacent to swamps and lakes. Water levels averaged 15 to 30 feet (7) in the west-central, northwestern and northeastern portions of the county. Water levels in sections of the east-central portion of the county also averaged 15 to 30 feet (7). Depth to water was chosen as 30 to 50 feet (5) in isolated areas in the east-central, southeast and northwest portions of the county. Water levels were estimated to be 50 to 75 feet (3) in the upland of the east-central and southeast portions of the county. The depth to water exceeded the depth to the top of the underlying limestone in the southwestern corner of the county. The area was assigned the designation of aquifer not present.

Net Recharge -- Values for net recharge were inferred based on annual surface runoff data and climatological data found in Knochenmus and Hughes (1976). A range of 10+ inches per year (9) was selected for the majority of the county. Values of 7 to 10 inches per year (8) was assigned to the northeastern portion of the county. The lower recharge value was selected based on greater surface runoff and the presence of strong upward ground-water gradients in this major ground-water discharge area.

Aquifer Media -- Information on aquifer media was contained in Knochenmus and Hughes (1976). The surficial aquifer consists of sand and gravel with varying amounts of clay which increase with depth. The aquifer media was chosen as sand and gravel and assigned a rating of (6) based on the high clay content at depth.

Soil Media -- Soils were mapped based on the Soil Survey of Lake County Area, Florida (Furman et al., 1975). The soil survey did not cover the Ocoee National Forest. Soil media north of Tier 17 south was inferred based on topography. Large submerged areas were called muck (2) and nonsubmerged areas were called sand (9). The principal soil media throughout the county is sand (9). Peat (8) and muck (2) occur interspersed with the sands in swampy areas throughout the county. Minor occurrences of shrinking and aggregated clay are present west of Lake Harris along the western border of the county, east and northeast of Lake

Griffin and adjacent to the southeastern boundary of the St. Johns River. This updated version of DRASTIC contains soil media designations for peat and muck which were not included in the original document. This addition was made to overcome the difficulties in mapping soil in the county and for clarification for the user.

Topography -- Percent slope was estimated by using 7 1/2 minute USGS topographic quadrangle maps. Contour intervals on the 7 1/2 minute maps were 5 feet. Areas of swamp settings throughout the county averaged 0 to 2 percent (10). Slopes average 2 to 6 percent (9) in the majority of the county where swamp settings are not present. Slopes of 6 to 12 percent (5) occur in the southeastern portion of the county.

Impact of the Vadose Zone Media -- Information on vadose zone media was obtained from Knochenmus and Hughes (1976). A vadose zone media of sand and gravel was chosen and assigned a typical value of (8).

Hydraulic Conductivity of the Aquifer -- Hydraulic conductivity values for the sand and gravel were inferred from a general description of the aquifer media in Knochenmus and Hughes (1976). Values of 300 to 700 gallons per day per square foot (4) were assigned for the majority of the county. Values of 700 to 1000 gallons per day per square foot (6) were assigned in the St. Johns River valley and the lake region in the central portion of the county based on estimates of less fine materials in the deposits.

Confined Aquifer

Depth to Water -- The Floridan aquifer was chosen as the aquifer to map throughout the county. The aquifer is confined to semi-confined in Lake County. In some areas the confining layer is discontinuous. Since DRASTIC does not effectively evaluate semi-confined aquifers, the aquifer had to be designated as either confined or unconfined. The Floridan was treated as confined because the confining layer is extensive throughout the county and discontinuous primarily in areas adjacent to sinkholes.

When evaluating a confined aquifer, the depth to water is changed to mean the depth to the top of the aquifer. Depth to the top of the limestone was mapped using information contained in Knochenmus (1971). Depths to top of the aquifer vary from 30 to 50 feet to 100+ feet. Shallow depths of 30 to 50 feet (5) occur in the southwest corner of the county, in a small area south of Lake Harris, in the northwest portion of the county and central section of the northeast portion of the county. Intermediate depths of 50 to 75 feet (3) occur throughout the south central portion of the county, in the majority of the northwest portion of the county, in the majority of the northeast portion of the county and in small sections of the central and south-central portions of the county. Depths of 100+ feet (1) occur in the north-central portion of the county, the majority of the southeastern corner of the county, and small areas in the northwest border of the county adjacent to the St. Johns River and northern section of the northeastern portion of the county.

Net Recharge -- Average values for net recharge were contained in Knochenmus and Hughes (1976). General information was obtained from Grubb (1977). Recharge values of 0 to 2 inches per year (1) were given for the St. Johns River valley due to strong upward gradients of ground-water flow. This is a major discharge area which has first order magnitude springs. Net recharge values of 2 to 4 inches per year (3) were found in the north central portion of the county in the areas surrounding Lakes Griffin, Yale, Eustis, Dora, Harris and Little Harris. A value of 4 to 7 inches per year (6) was indicated for the southwest portion of the county and for the central and northeast portion of the county. Net recharge averaged 7 to 10 inches per year (8) in the west and west-central portion of the county. A value of 10+ inches per year (1) was found in the southeastern portion of the county.

Aquifer Media -- Information on aquifer media was obtained from Knochenmus and Hughes (1976), Knochenmus (1971) and Grubb (1977). The Floridan Aquifer occurs extensively and continuously across the county. An aquifer media of karst limestone was chosen and assigned a rating of (10).

Soil Media -- Soils were mapped based on the Soil Survey of Lake County Area, Florida (Furman et al., 1975). The soil survey did not cover the Ocoee National Forest. Soil media north of Tier 17 south was inferred based on topography. Large submerged areas were called muck (2) and non-submerged areas were called sand (9). The principal soil media throughout the county is sand (9). Peat (8) and muck (2) occur interspersed with the sands in swampy areas throughout the county. Minor occurrences of shrinking and aggregated clay are present west of Lake Harris along the western border of the county, east and northeast of Lake Griffin and adjacent to the southeastern boundary of the St. Johns River. This updated version of DRASTIC contains soil media designations for peat and muck which were not included in the original document. This addition was made to overcome the difficulties in mapping soil in the county and for clarification for the user.

Topography -- Percent slope was estimated by using 7 1/2 minute USGS topographic quadrangle maps. Contour intervals on the 7 1/2 minute maps were 5 feet. Areas of swamp settings throughout the county averaged 0 to 2 percent (10). Slopes average 2 to 6 percent (9) in the majority of the county where swamp settings are not present. Slopes of 6 to 12 percent (5) occur in the southeastern portion of the county.

Impact of the Vadose Zone Media -- For the purpose of mapping, the Floridan is designated as a confined aquifer due to the presence of the Hawthorn Formation which is a silty confining bed as described by Knoehcnmus (1971) and Knochenmus and Hughes (1976). Although the Hawthorn is thin and locally breached in the west-central lakes area and parts of the southwestern and south-central to southeastern portions of the county, the Hawthorn is considered as occurring extensively and continuously across the county. Since the Floridan was considered as a confined aquifer, the impact of the vadose zone media was called silt/clay and assigned a rating of 2. In this updated version of DRASTIC, the impact of the vadose zone media would be chosen as confining layer and assigned a rating of (1).

Hydraulic Conductivity of the Aquifer -- Hydraulic conductivity values for the Floridan were inferred from transmissivity data presented in Knochenmus and Hughes (1976). A range of 2000+ gallons per day per square foot (10) was chosen for the entire county.

Minidoka County, Idaho

Minidoka County, Idaho, lies within the Columbia Lava Plateau ground-water region. The majority of the county is covered by thick deposits of basalt resulting from numerous sequences of individual lava flows. These igneous rocks are generally exposed throughout the northern part of the county and are overlain by loess and alluvial deposits in the central and southern sections of the county, respectively.

Ground-water in Minidoka County is derived primarily from a deep, unconfined aquifer comprised of highly permeable basalt. This aquifer has been developed for domestic, industrial and irrigation uses. Along the Snake River in the southern part of the county, the shallow, unconfined alluvium aquifer, which is in hydraulic connection with the areal basalts, has been developed for domestic uses.

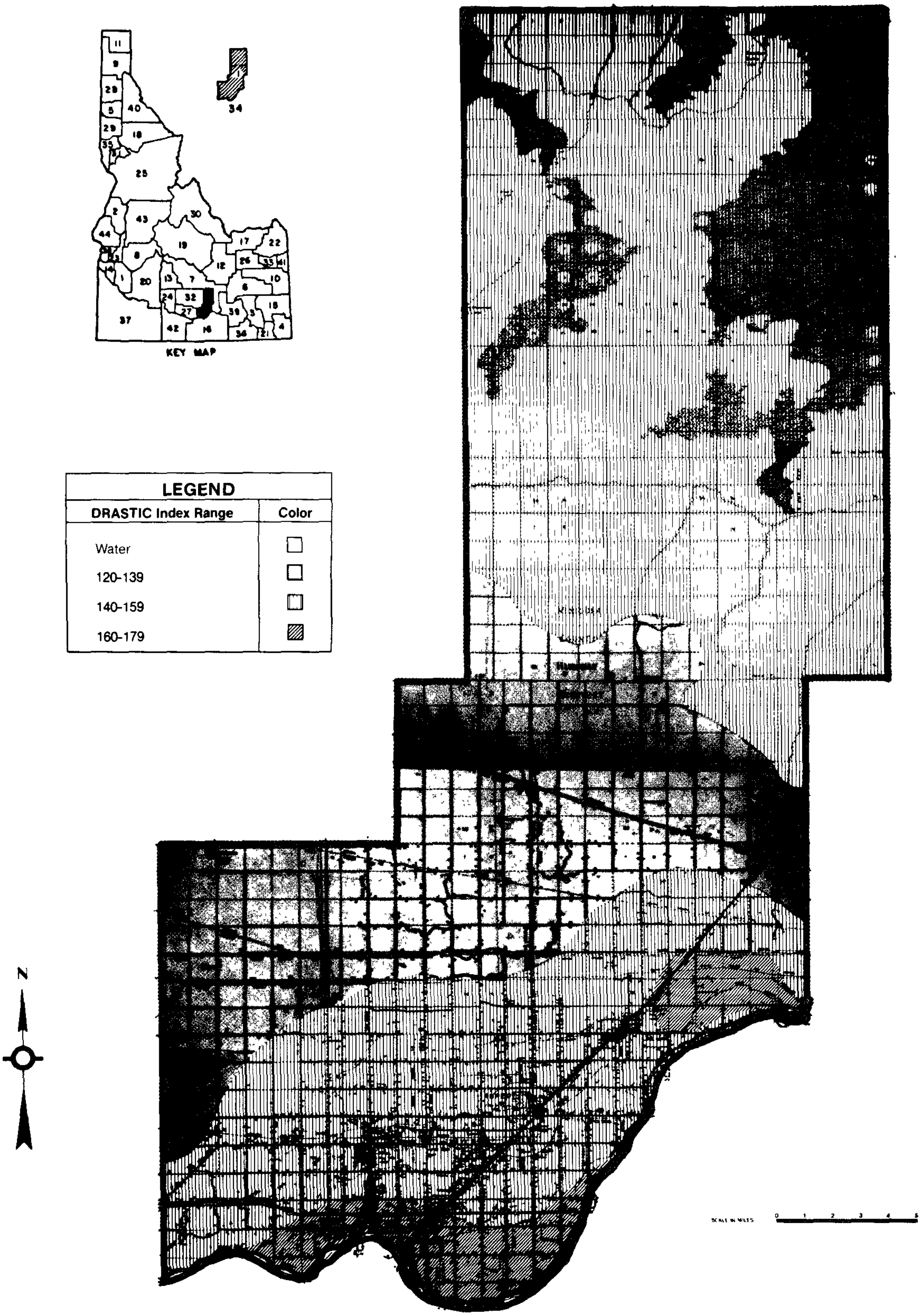
In mapping Minidoka County, two hydrogeologic settings were identified and included. Computed DRASTIC Index values range from 127 to 167. Table 28 details the settings and ranges of associated DRASTIC Indexes. Also noted in the table are the number of unique DRASTIC Index calculations which were made during the mapping effort. The DRASTIC Index numbers reflect evaluation of unconfined aquifers only.

TABLE 28. HYDROGEOLOGIC SETTINGS MAPPED IN MINIDOKA COUNTY, IDAHO

Hydrogeologic Setting	Range of DRASTIC Indexes	Number of DRASTIC Calculations
(3C) Hydraulically Connected Lava Flows	127-167	14
(3G) River Alluvium	152-166	4

Figure 40 shows a general pollution potential map for Minidoka County. The DRASTIC Indexes have been grouped in accordance with the National Color Code (Table 22). Selected screens have been used to illustrate the variability. The pollution potential map has been superimposed on a county highway map for geographic reference. No hydrogeologic setting lines have been delineated on the map.

Appendix I contains the full-size pollution potential map for Minidoka County complete with hydrogeologic setting designations and individual DRASTIC Index computations. The map has been superimposed on a county highway map for geographic reference. The DRASTIC Index values have not been grouped on the full-size map. The map has been divided into separate sheets which permit it to be incorporated into the document. An Index to the map sheets is provided for ease of geographic sheet location. The corresponding charts which detail the ranges of the seven DRASTIC parameters chosen for each area and the computation of the DRASTIC Index immediately follows the maps.



LEGEND	
DRASTIC Index Range	Color
Water	☐
120-139	☐
140-159	▥
160-179	▨

Figure 40. Generalized pollution potential map of Minidoka County, Idaho.

Computation of the DRASTIC Indexes and identification of hydrogeologic settings relied on detailed information of the seven DRASTIC parameters. Specific descriptions and sources used to obtain this information are outlined in the following discussion centering around each DRASTIC parameter. A complete list of references is contained at the end of Section 5. The rating associated with the chosen range for each DRASTIC parameter appears in parenthesis for ease of reference.

Depth to Water

Water level information was obtained from U.S. Geological Survey (1980), Mundorff et al. (1964), Lindholm et al. (1983), Crosthwaite and Scott (1956) and Young and Norvitch (1984). Depth to water primarily was based on 1980 water level data. Water levels in the Snake River basalts were 100+ feet (1) in all parts of the county except one small area in the southeastern corner of the county. In this area bordering the river alluvium, water levels were 75 to 100 feet (2). Depths to water in the river alluvium averaged 5 to 15 feet (9) in areas directly adjacent to the Snake River. Water levels in the remaining alluvium averaged 15 to 30 feet (7).

Net Recharge

General information on net recharge was found in Mundorff et al. (1964). Additional information was obtained from Gerald Lindholm (personal communication, U.S. Geological Survey, 1985). Values for net recharge in the basalts ranged from 0 to 2 inches per year (1), 2 to 4 inches per year (3), 4 to 7 inches per year (6), 7 to 10 inches per year (8) and 10+ inches per year (9). These variable ranges reflect irrigation and irrigation return flow contributions in the areas of higher recharge. Values in the river alluvium were assigned 10+ inches per year (9) due to intensive irrigation practices.

Aquifer Media

Information on aquifer media was derived from Whitehead (1984), Mundorf et al. (1964) and Crosthwaite and Scott (1956). The basalt aquifer was assigned a value of 10 based on the vesicular nature of the basalt, the presence of lava tubes and the extensive interconnection between interflow zones in the basalt flows. The river alluvium was called a sand and gravel aquifer media and assigned a value of (7) based on the presence of fine silt deposits contained within the alluvium.

Soil Media

Soils were mapped based on the Soil Survey of Minidoka County, Idaho (Hansen, 1985). The soil survey only covered the southern portion of the county. Soil media north of Tier 6 South was inferred from topographic maps and areal descriptions to be thin or absent (10) as a result of numerous surface basalt flows. Soil media in the majority of the county underlain by the basalt aquifer was silty loam (4). A small wedge of sandy loam (6) overlying the basalt aquifer is present in the southeastern corner of the county. Soil media overlying the alluvium ranged from sandy loam (6) to loam (5) to silty loam (4). The sandy loam occurs adjacent to the river and soils increase in fine materials northward away from the river.

Topography

Percent slope was estimated by using 7 1/2 minute USGS topographic quadrangle maps where available and 15 minute USGS topographic quadrangle maps in other areas. Only 15 minute maps were available for the northern portion of the county. Contour intervals on the 7 1/2 minute maps were 5 feet, 10 feet and 20 feet; intervals for the 15 minute maps were 20 feet. Slopes in the areas overlying the basalt ranged from 0 to 2 percent (10) in the central portion of the county to 2 to 6 percent (9) in the majority of the remaining area. Slopes were 6 to 12 percent (5) along the margin of the river alluvium and in an isolated corner in the western portion of the county. Slopes in the river alluvium in the southern portion of the county were 0 to 2 percent (10).

Impact of the Vadose Zone Media

Information for selecting values for the vadose zone media was obtained from Whitehead (1984), Mundorf et al. (1964), Crosthwaite and Scott (1956) and Graham (1979). The vadose zone media in the basalt areas are overlain with varying thicknesses of loess deposits. In areas where the loess deposits are less than 10 feet thick, a vadose zone media of basalt was selected and assigned a typical rating of (9). This rating was chosen due to the columnar jointing in the basalt and the ability of surface recharge to move quickly through the vadose zone. In areas where the loess deposits were greater than 10 feet thick, a vadose media of basalt was still chosen but assigned a rating of (8) in recognition of the possible attenuation properties of the loess. In general, loess deposits were less than 10 feet thick in the northern and western portions of the county. The river alluvium vadose zone media of sand and gravel with significant silt and clay was chosen and assigned a typical rating of (6) based on the amount of fine material and the variable degree of compaction within the deposits.

Hydraulic Conductivity of the Aquifer

Hydraulic conductivity values for the basalt were based on Mundorff et al. (1964). Information about the river alluvium was estimated based on a review of the aquifer media descriptions and supplemented by personal communication with Gerald Lindholm (U.S. Geological Survey, 1985). The hydraulic conductivity in the basalt was assigned a range of 2000+ gallons per day per square foot (10). The river alluvium was designated as 300 to 400 gallons per day per square foot (4) based on the high percentage of fines.

New Castle County, Delaware

New Castle County, Delaware, lies within the boundaries of two ground-water regions which are separated by the Fall Line; the northern area is within the Piedmont and Blue Ridge, while the remainder of the county lies within the Atlantic and Gulf Coastal Plain. Ground-water resources in the Piedmont and Blue Ridge region of the county are derived primarily from igneous and metamorphic rocks covered by variable thicknesses of saprolite. Unconfined ground water accumulates in the saprolite overlying the parent rock and often serves as a recharge source for these aquifers. Although the saprolite is an easily developed ground-water source, low yields and seasonal fluctuations typically limit the development of this resource. Ground water in the underlying igneous/metamorphic aquifer system provides small to moderate yields from fractures and faults. Wells in the Hockessin-Yorklyn and Pleasant Hill Valleys underlain by a white marble formation have much higher yields.

Within the Atlantic and Gulf Coastal Plain ground-water region, ground water is available in thick sequences of sand and gravel deposits which form the coastal plain. The Columbia deposits comprise the major unconfined aquifer in the county and overlie a sequence of deeper aquifers. The deeper aquifers are typically confined, but may occur under water table conditions in limited recharge areas. Most areas have abundant ground water resources.

In mapping New Castle County, four hydrogeologic settings were identified and included. Computed DRASTIC Index values range from 114 to 194. Table 29 details the settings and ranges of associated DRASTIC Indexes. Also noted in the table are the number of unique DRASTIC Index calculations which were made during the mapping effort. The DRASTIC Index numbers reflect evaluation of unconfined aquifers only.

TABLE 29. HYDROGEOLOGIC SETTINGS MAPPED IN NEW CASTLE COUNTY, DELAWARE

Hydrogeologic Setting	Range of DRASTIC Indexes	Number of DRASTIC Index Calculations
(8A) Mountain Slopes	117-135	2
(8D) Regolith	114-181	14
(10Ab) Unconsolidated and Semiconsolidated Shallow Surficial Aquifer	112-194	29
(10Ba) River Alluvium with Overbank Deposits	166	1

Figure 41 shows a general pollution potential map for New Castle County. The DRASTIC Indexes have been grouped in accordance with the National Color Code (Table 22). Selected screens have been used to illustrate the variability. The pollution potential map has been superimposed on a county highway map for geographic reference. No hydrogeologic setting lines have been delineated on the map.

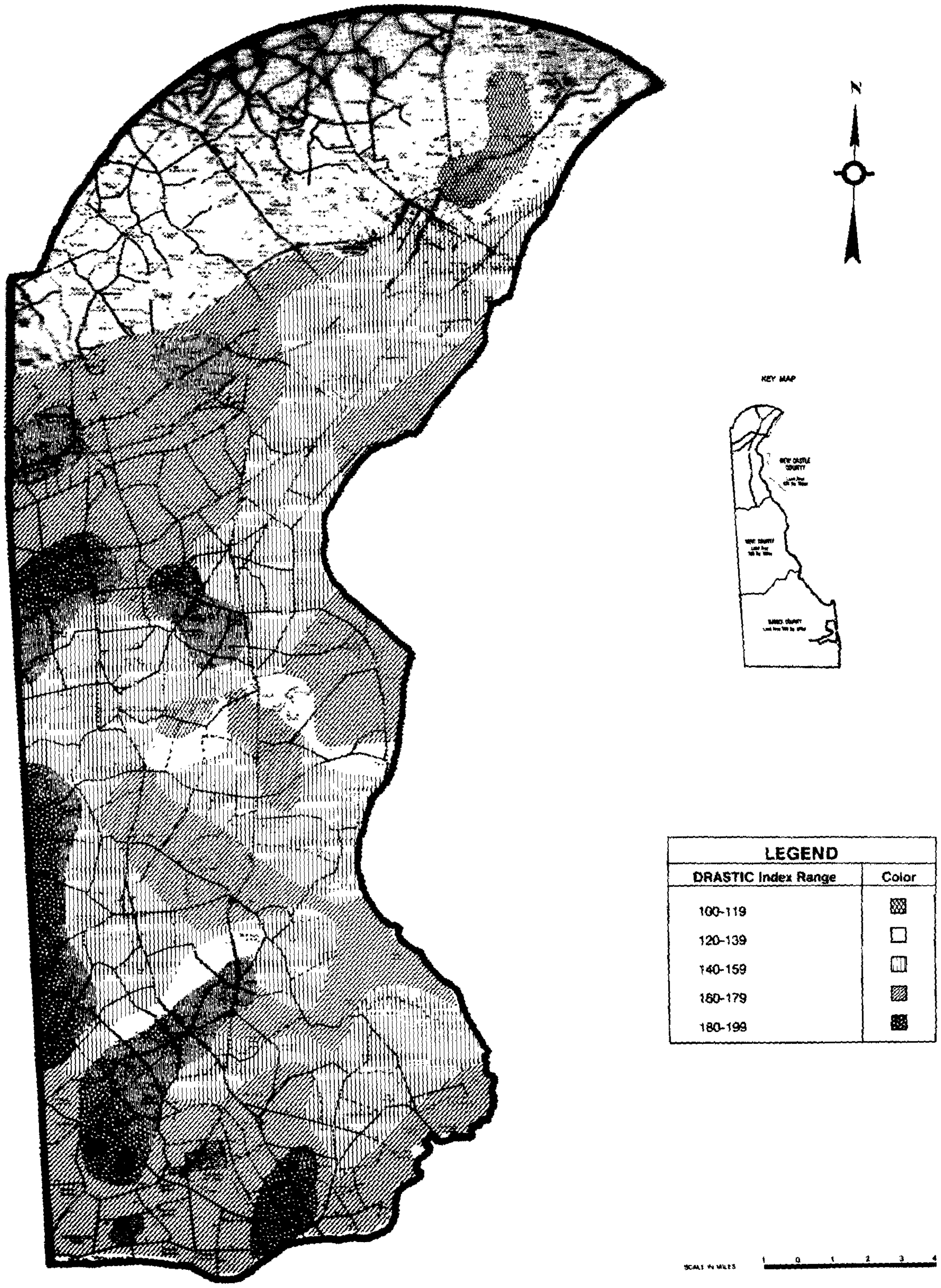


Figure 41. Generalized pollution potential map of New Castle County, Delaware.

Appendix J contains the full-size pollution potential map for New Castle County complete with hydrogeologic setting designations and individual DRASTIC Index computations. The map has been superimposed on a county highway map for geographic reference. The DRASTIC Index values have not been grouped on the full-size map. The map has been divided into separate sheets which permit it to be incorporated into the document. An Index to the map sheets is provided for ease of geographic sheet location. The corresponding charts which detail the ranges of the seven DRASTIC parameters chosen for each area and the computation of the DRASTIC Index immediately follows the maps.

Computation of the DRASTIC Indexes and identification of hydrogeologic settings relied on detailed information of the seven DRASTIC parameters. Specific descriptions and sources used to obtain this information are outlined in the following discussion centering around each DRASTIC parameter. A complete list of references is contained at the end of Section 5. The rating associated with the chosen range for each DRASTIC parameter appears in parenthesis for ease of reference.

Depth to Water

Water level information was generated using data stored in the computer files at the Water Resources Agency for New Castle County, Delaware. Water levels in most sections of the Piedmont in the northern portion of the county ranged from 5 to 15 feet (9) in flatter areas and 15 to 30 feet (7) in areas with greater relief. Depth to water was 0 to 5 feet (10) in the eastern portion of the county adjacent to the Delaware River. Water levels in the coastal plain ranged from 0 to 5 feet (10), 5 to 15 feet (9), 15 to 30 feet (7) and 30 to 50 feet (5). The depth to water was generally a reflection of topographic variation.

Net Recharge

Values for net recharge in the coastal plain were obtained from Johnston (1973), Groot et al. (1983) and Talley (1978). According to Johnston (1973), net recharge averages 13.6 inches per year; Groot et al. (1983) indicate that recharge is not less than 10.5 inches per year; Tolley indicates recharge ranges from 13 to 16 inches per year. Based on this information, a value of 10+ inches per year (9) was assigned for the entire coastal plain area. Published values for net recharge in the Piedmont area were unavailable. Based on information through Bob Finkle (personal communcation, Water Resources Agency for New Castle County, 1985) a value of 10+ inches per year (9) was also assigned for the Piedmont area.

Aquifer Media

Aquifer media was selected by using existing information in the data base of the Water Resources Agency for New Castle County, Delaware, supplementing the data base with the discussions in Petty et al. (1976) and reviewing maps by Woodruff and Thompson (1972; 1978) and Woodruff (1981). Information for the coastal plain had been entered into the data base by dividing the Columbia Formation into three major categories: A, B and C. Aquifer media was chosen based on the descriptions of these categories. Category A contains coarse sand with gravel beds, silty (dirty) gravels, coarse sand and coarse to medium sand. Category A was called sand and gravel and assigned a rating of (8). Category B contains fine to coarse sand and medium sand. The aquifer media for Category B was chosen as sand and gravel and assigned a rating of (6). Category C contains fine sand, silt or clay. The aquifer media for Category C was called sand and gravel and assigned a rating of (5). In this updated version of DRASTIC, Category C would have also been assigned a rating of (6) because the range for sand and gravel is 6 to 9. Aquifer media information in the Piedmont area had been entered into the data base by formation name. The Wilmington Complex consists of high-grade metamorphic gneisses and associated igneous rocks. The aquifer media for the Wilmington Complex was chosen as metamorphic/igneous and assigned a typical rating of (3). The Bryn Mawr Formation is a poorly sorted sand and gravel. The aquifer media was chosen as sand and gravel and assigned a rating of (6) based on the fine-grained material within the deposits. The Wissahikon Formation consists of gneisses, schists and amphibolites. The aquifer media was chosen as metamorphic/igneous and assigned a typical rating of (3). The Cockeysville Marble is a medium to coarse-grained white marble that develops solution cavities and is very permeable. Although marble is a metamorphic rock, the marble exhibits characteristics more similar to karst limestone. The aquifer media was chosen as karst limestone and assigned a rating of 10. Pegmatites occur locally in the Wissahickon Schist and Cockeysville marble. The aquifer media for Pegmatites was chosen as metamorphic/igneous and assigned a rating of (2). The aquifer media for river alluvium was called sand and gravel and assigned a rating of (5). In this updated version of DRASTIC, th rating would have been assigned a (6) because (6) is the lowest rating for aquifer media.

Soil Media

The information on soil for the entire county had been digitized into the data base using the Soil Survey of New Castle County, Delaware (Matthews and Lavoie, 1970). Since the information in the data base was entered by soil series name, each individual soil series was assigned a media designation based on the most significant soil layer. A map of soil media was generated using these soil media designations. The map was unacceptable because it was impossible to generalize the soil media into areas of 100 acres or larger (refer to the discussion in Section 5, Drawing the Map by Computer). The soil media were reassigned into groups based on the predominant soil media of each area. Soil media in the Piedmont were chosen as either silty loam (4) or loam (5). Soil media in the coastal plain were chosen as clay loam (3), silty loam (4), loam (5) and sandy loam (6).

Topography

Percent slope was generated from the existing data files of the Water Resources Agency for New Castle County, Delaware. Information for the data base was obtained from U.S. Geological Survey maps. Slopes in the Piedmont area range from 0 to 2 percent (10), 2 to 6 percent (9), 6 to 12 percent (5) to 12 to 18 percent (3). Slopes in the coastal plain were generally 0 to 2 percent (10) and 2 to 6 percent (9) with minor occurrences of 6 to 12 percent (5).

Impact of the Vadose Zone Media

Vadose zone media was selected based on designations existing in the data files of the Water Resources Agency for New Castle County, Delaware and by referring to Petty, et al. (1976), Woodruff and Thompson (1972; 1978) and Woodruff (1981). In the coastal plain, the Columbia Formation had been previously divided into three categories. The vadose zone media for Category A was chosen to be sand and gravel and assigned a typical rating of (8). Vadose zone media for Category B was called sand and gravel and assigned a rating of (6). Category C vadose zone media was designated as sand and gravel with significant silt and clay and assigned a rating of (4). In the Piedmont area, vadose zone media was assigned by formation. The Wilmington Complex was called metamorphic/igneous and assigned a rating of (2). The Wissahickon vadose zone media was chosen as metamorphic/igneous and assigned a rating of (4). The Bryn Mawr formation was designated as sand and gravel and assigned a rating of (5). In this revised version of DRASTIC, the Bryn Mawr sand and gravel vadose zone media would have received a rating of (6) because this is the lowest rating for sand and gravel or would have been called a sand and gravel with significant silt and clay and retained the rating of (5). The Cockeysville Marble was called metamorphic/igneous and assigned a rating of (6). The vadose zone media for the Pegmatites was designated as silt/clay and assigned a rating of (1). In this revised version of DRASTIC, the silt/clay would be assigned a rating of (2). The river alluvium vadose zone media was called sand and gravel with significant silt and clay and assigned a typical value of (6).

Hydraulic Conductivity of the Aquifer

Hydraulic conductivity values in the coastal plain were modified from data existing in the computer files of the Water Resources Agency of New Castle County, Delaware. The Columbia Formation had previously been divided into three categories. Category A had hydraulic conductivities which ranged from 748 to 1870 gallons per day per square foot. Since it was not possible to re-group the information into designated DRASTIC ranges, ratings were chosen to reflect a compromise. Hydraulic conductivity in Category A was assigned a rating of (8) which corresponds to 1000 to 2000 gallons per day per square foot. In Category B, hydraulic conductivities ranged from 374 to 561 gallons per day per square foot; a rating of (4), which corresponds to 300 to 700 gallons per day per square foot, was assigned. Hydraulic conductivities for Category C were 1 to 150 gallons per day per square foot; a rating of (1), which corresponds to 1 to 100 gallons per day per square foot, was assigned. In the Piedmont, hydraulic conductivity values had not been previously assigned. Hydraulic conductivity values were estimated based on media descriptions in Petty, et al. (1976) and from personal communication through Bob Finkle (Water Resources Agency For New Castle County, 1985). Values for hydraulic conductivity in the Wilmington Complex and Wissahickon formation were chosen as 100 to 300 gallons per day per square foot (2). In the Bryn Mawr Formation, a range of 700 to 1000 gallons per day per square foot (6) was chosen. Hydraulic conductivity in the Cockeysville Marble was assigned a value of 1000 to 2000 gallons per day per square foot (8). The Pegmatites were assigned a value of 1 to 100 gallons per day per square foot (1). Values for hydraulic conductivity in the river alluvium was chosen as 100 to 300 gallons per day per square foot (2).

Pierce County, Washington

Pierce County, Washington, lies within the boundaries of two ground-water regions; the western two-thirds is within the Alluvial Basins, and the eastern one-third lies within the Western Mountain Ranges. The western portion of the county is within the Puget Lowland, which is filled with very thick sequences of interbedded glacial sands, gravels and silts. The shallow aquifer consists of medium- to coarse-grained sands and gravels exhibiting shallow water-table conditions. These deposits are very permeable and provide significant quantities of water to domestic and municipal wells. The shallow aquifer provides recharge to deeper sand and gravel aquifers and is often in direct hydraulic connection with the deeper aquifers. Ground-water resources constitute over seventy-five percent of the drinking water used in this area. The volcanic mudflows and igneous/metamorphic rocks of the Cascade Range which occur in the eastern portion of the county provide low yields to wells. Most ground-water supplies are derived from alluvium adjacent to river valleys.

In mapping Pierce County, seven hydrogeologic settings were identified and included. Computed DRASTIC Index values range from 77 to 200. Table 30 details the settings and ranges of associated DRASTIC Indexes. Also noted in the table are the number of unique DRASTIC Index calculations which were made during the mapping effort. The DRASTIC Index numbers reflect evaluation of unconfined aquifers only.

TABLE 30. HYDROGEOLOGIC SETTINGS MAPPED IN PIERCE COUNTY, WASHINGTON

Hydrogeologic Setting	Range of DRASTIC Indexes	Number of DRASTIC Index Calculations
(1Ab) Mountain Slopes — West	77-79	2
(1D) Glaciated Mountain Valleys	175	1
(2G) Coastal Lowlands	130-200	15
(1H) Mud Flows	114-174	2
(2Ha) River Alluvium with Overbank Deposits	176-186	3
(2I) Mud Flows	112-174	4
(2J) Alternating Sandstone and Shale Sequences	104-108	2

Figure 42 shows a general pollution potential map for Pierce County. The DRASTIC Indexes have been grouped in accordance with the National Color Code (Table 22). Selected screens have been used to illustrate the variability. The pollution potential map has been superimposed on a county highway map for geographic reference. No hydrogeologic setting lines have been delineated on the map.

Appendix K contains the full-size pollution potential map for Pierce County complete with hydrogeologic setting designations and individual DRASTIC Index computations. The map has been superimposed on a county highway map for geographic reference. The DRASTIC Index values have not been grouped on the full-size map. The map has been divided into separate sheets which permit it to be incorporated into the document. An Index to the map sheets is provided for ease of geographic sheet location. The corresponding charts which detail the ranges of the seven DRASTIC parameters chosen for each area and the computation of the DRASTIC Index immediately follows the maps.

Computation of the DRASTIC Indexes and identification of hydrogeologic settings relied on detailed information of the seven DRASTIC parameters. Specific descriptions and sources used to obtain this information are outlined in the following discussion centering around each DRASTIC parameter. A complete list of references is contained at the end of Section 5. The rating associated with the chosen range for each DRASTIC parameter appears in parenthesis for ease of reference.

Depth to Water

Water-level information was obtained from Walters and Kimmel (1968), Hart Crowser and Associates (1984), Drost (1982), Griffin et al. (1962) and Brown and Caldwell (1985). Supplemental data was derived from well logs from the Tacoma-Pierce County Health Department. According to geologic reports, most of the aquifers in the western portion of the county are semi-confined. This area is referred to as the coastal lowland hydrogeologic setting. Only the recessional outwash aquifer (settings 2G6 through 2G8) and the Steilacoom gravels (settings 2G10 and 2G11) were designated as unconfined. Since DRASTIC does not effectively evaluate semi-confined aquifers, the aquifers must be designated as either confined or unconfined. Based on available information, all the aquifers in the coastal lowland area were evaluated as unconfined. Mud flows in the Puyallup River valley and in the north-central portion of the county were also semi-confined and evaluated as unconfined. Water levels in the coastal lowland area were evaluated based on aquifers. In areas of the Vashon Drift (settings 2G1, 2G2, 2G9 and 2G12 through 2G14) and the Mashel formation (setting 2G15), water levels were extremely variable ranging from 5 to 15 feet (9), 15 to 30 feet (7), 30 to 50 feet (5) and 50 to 75 feet (3). Water levels in the Steilacoom gravel (settings 2G10 and 2G11) averaged 5 to 15 feet (9) in areas adjacent to the Nisqually River and Puget Sound and 15 to 30 feet (7) in other areas. Depth to water in the Salmon Springs aquifer (settings 2G3 through 2G5) ranged from 50 to 75 feet

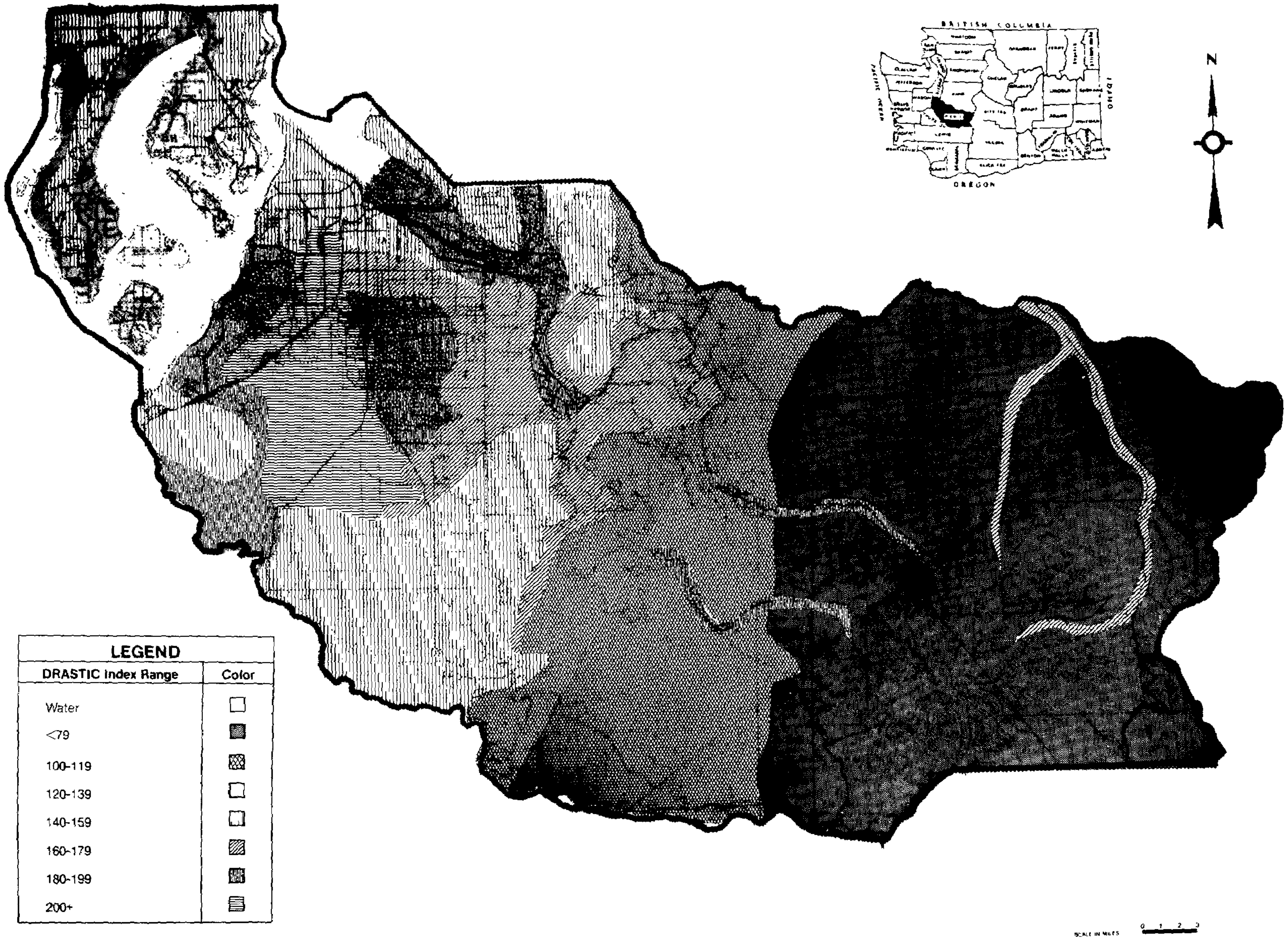


Figure 42. Generalized pollution potential map of Pierce County, Washington.

(3) and 75 to 100 feet (2). Water levels in the recessional outwash aquifer (settings 2G6 through 2G8) ranged from 15 to 30 feet (7) in areas adjacent to river valleys to 30 to 50 feet (5) in other areas. River alluvium (settings 1D1 and 2Ha1 through 2Ha3) had water depths which ranged from 5 to 15 feet (9) in glacial areas to 15 to 30 feet (7) in bedrock areas. Water levels in the mud flows (settings 1H1, 1H2 and 2I1 through 2I4) averaged 50 to 75 feet (2) except in areas where thin mudflows occurred in river valleys. In these areas, water levels averaged 15 to 30 feet (7). Information on depth to water in the metamorphic/igneous aquifer (settings 1Ab1 and 1Ab2) and bedded sandstone and shale aquifer (settings 2J1 and 2J2) was sparse or not available. Water depths were estimated to average 75 to 100 feet (2).

Net Recharge

Net recharge values were derived from Hart Crowser and Associates (1984). Since precipitation rates are high, recharge values of 10+ inches per year (9) were assigned to the majority of the coastal lowlands area (settings 2G1 through 2G14) in the western portion of the county. Recharge values were reduced to 7 to 10 inches per year (8) in the Mashel formation (setting 2G15) due to the presence of fine-grained deposits. The Mashel formation occupies the south-central and east-central portions of the county (setting 2G15). Net recharge was also chosen as 10+ inches per year (9) in the river alluvium (sesttings 1D1 and 2Ha1 through 2Ha3). In areas covered by mudflows (settings 1H1, 1H2 and 2I1 through 2I4), fine-grained deposits restrict recharge. Values of 4 to 7 inches per year (6) were assigned in most of the areas. Mudflows bordering the Nisqually River were assigned a value of 10+ inches per year (9) because the fine materials were removed by erosion. Areas of bedded sandstone and shale (settings 2J1 and 2J2) were assigned values of 7 to 10 inches per year (8) based on the occurrence of permeable sandstones within the unit and amount of fracturing. Values of 4 to 7 inches per year (6) were assigned to the metamorphic/igneous bedrock areas.

Aquifer Media

Information on aquifer media for the glacial deposits and river alluvium was obtained from Hart Crowser and Associates (1984), Brown and Caldwell (1985), Griffin et al. (1962), Walters and Kimmel (1968), Crandell (1963) and Drost (1982). The only available information for the metamorphic/igneous aquifer was found in Crandell (1969), Hammond (1980) and Gard (1968). This information was sparse; attempts to supplement the data by personal communication were unsuccessful. The Vashon drift (settings 2G1, 2G2, 2G9 and 2G12 through 2G14), the Mashel formation (setting 2G15), and the recessional outwash aquifer (settings 2G6 through 2G8) consist of moderately well-sorted and permeable sands and gravels. The aquifer media was chosen as sand and gravel and assigned a typical rating of (8). The Salmon Springs aquifer (settings 2G3 through 2G5) was called sand and gravel and assigned a typical value of (8) based on the yields of the aquifer. The river alluvium (settings 1D1 and 2Ha1 through 2Ha3) was called sand and gravel and assigned a typical rating of (8) based on the presence of moderate to well-sorted deposits and associated high permeabilities. The Steilacoom gravel aquifer (settings 2G10 and 2G11) was called a sand and gravel and assigned a rating of (9) because the deposits are very coarse, well-washed and thick. In the mudflow areas (settings 1H1, 1H2 and 2I1 through 2I4), the Vashon drift which contains lenses of sand and gravel was considered as the principal aquifer. An aquifer media of sand and gravel was chosen and assigned a typical rating of (8). The bedded sandstone and shale aquifer (settings 2J1 and 2J2) has not been widely developed and little information was available. The aquifer media was chosen as thin-bedded sandstone, limestone and shale sequences and assigned a typical rating of (6). The metamorphic/igneous aquifer media (settings 1Ab1 and 1Ab2) was assigned a typical value of (3) because no information was available.

Soil Media

Soils were mapped based on the Soil Survey of Pierce County, Washington (Zulauf, 1979). Soils east of Range 4E or Range 5E were not included in the soil survey. The glacial coastal lowland area (settings 2G1 through 2G15) are typically overlain by sandy loam (6). Minor occurrences of silty loam (4) are present adjacent to the Nisqually and Puyallup Rivers and in the western portion of the county; sand (9) also is found in small amounts. River alluvium soil media (settings 1D1 and 2Ha1 through 2Ha3) was silty loam (4) and sandy loam (6). Areas covered by mudflows (settings 1H1, 1H2 and 2I1 through 2I4) were overlain by loam (5). Soil information was not available for the bedded sandstone and shale aquifer area (settings 2J1 and 2J2) or the metamorphic/igneous aquifer area (settings 1Ab1 and 1Ab2). Soil media in these areas were assigned loam (5).

Topography

Percent slope was estimated by using 7 1/2 minute USGS topographic quadrangle maps where available and 15 minute USGS topographic quadrangle maps in other areas. Only 15 minute maps were available for the north-eastern portion of the county. Contour intervals on the 7 1/2 minute maps were 20 feet, 25 feet and 40 feet; intervals for the 15 minute maps were 80 feet. Slopes range from 0 to 2 percent (10) and 2 to 6 percent (9) in the central portion of the county and increase westward and eastward. Slopes in the western portion of the county average 6 to 12 percent (5). Slopes in the east-central portion of the county also average 6 to 12 percent (5), but quickly rise to 12 to 18 percent (3) and 18+ percent (1) in the eastern portion of the county.

Impact of the Vadose Zone Media

Information on the vadose zone media for the glacial deposits and river alluvium was obtained from Griffin et al. (1962), Walters and Kimmel (1968), Drost (1982), Brown and Caldwell (1985) and Crandell (1963). Information for the bedrock aquifers was found in Crandell (1969), Hammond (1980) and Gard (1968). Vashon drift areas (settings 2G1, 2G2, 2G9 and

2G12 through 2G14), and the Mashel formation (setting 2G15) were designated as sand and gravel with significant silt and clay and assigned a rating of (7) based on the amount of sand within the deposits. Areas covered by Steilacoom gravel (settings 2G10 and 2G11) and recessional outwash (settings 2G6 through 2G8) were called sand and gravel and assigned a rating of (8) because the deposits are well-sorted and very permeable. Salmon Springs areas (settings 2G3 through 2G5) were called sand and gravel and assigned a typical value of (8) where the aquifer media was outcropping. In areas where the Salmon Springs aquifer was covered by finer-grained glacial deposits the vadose zone media was chosen as sand and gravel with significant silt and clay and assigned a typical rating of (6). River alluvium was chosen as sand and gravel with significant silt and clay and assigned a rating of (7) based on the presence of coarser-grained material within the alluvium. Vadose zone media in mudflow areas (settings 1H1, 1H2 and 2I1 through 2I4) was chosen as sand and gravel with significant silt and clay. The majority of the mudflows were assigned a typical rating of (6); in areas of the Osceola mudflow a rating of (5) was assigned based on fines and thicker deposits; in mudflows in the south-central portion of the county adjacent to the Nisqually River, a rating of (7) was assigned because the materials were thinner and coarser. Bedded sandstone and shale areas (settings 2J1 and 2J2) were assigned a vadose zone media of bedded limestone, sandstone and shale and assigned a typical rating of (6). The metamorphic/igneous areas (settings 1Ab1 and 1Ab2) were assigned a typical rating of (4).

Hydraulic Conductivity of the Aquifer

Hydraulic conductivity values for the glacial and river alluvium aquifers were obtained from Brown and Caldwell (1985) and Hart Crowser and Associates (1984). Values for the bedrock aquifers were unavailable and estimated from available aquifer media descriptions. Hydraulic conductivities in the Vashon drift (settings 2G1, 2G2, 2G9 and 2G12 through 2G14), the Mashel formation (setting 2G15) and the recessional outwash aquifer (settings 2G6 through 2G8) were approximated to average 700 to 1000 gallons per day per square foot (6) because the deposits are moderately well-sorted sand and gravel and have moderately high well yields. In the area immediately adjacent to the Nisqually and Puyallup Rivers the hydraulic conductivity values were lowered to 300 to 700 gallons per day per square foot (4) due to the presence of greater amounts of silts in the deposits. Areas of Steilacoom gravel (settings 2G10 and 2G11) were highly permeable and assigned a value of 2000+ gallons per day per square foot (10). The Salmon Springs aquifer (settings 2G3 through 2G5) contained more fine materials and was assigned a value of 300 to 700 gallons per day per square foot (4). Values for conductivities in the river alluvium (settings 1D1 and 2Ha1 through 2Ha3) were chosen as 1000 to 2000 gallons per day per square foot (8) based on aquifer descriptions of moderately well-sorted sands and gravels with significant amounts of sand and gravel. Values of hydraulic conductivity for the mudflow areas (settings 1H1, 1H2 and 2I1 through 2I4) were assigned based on the interbedding of fine materials with the sand and gravel aquifer. In the southern part of the county, values of 1000 to 2000 gallons per day per square foot (8) were chosen; values for the other mudflows were lower and estimated at 100 to 300 gallons per day per square foot (1) and 300 to 700 gallons per day per square foot (4). Hydraulic conductivities in the bedded sandstone and shale (settings 2J1 and 2J2) and the metamorphic/igneous aquifers (settings 1Ab1 and 1Ab2) were estimated at 1 to 100 gallons per day per square foot (1).

Portage County, Wisconsin

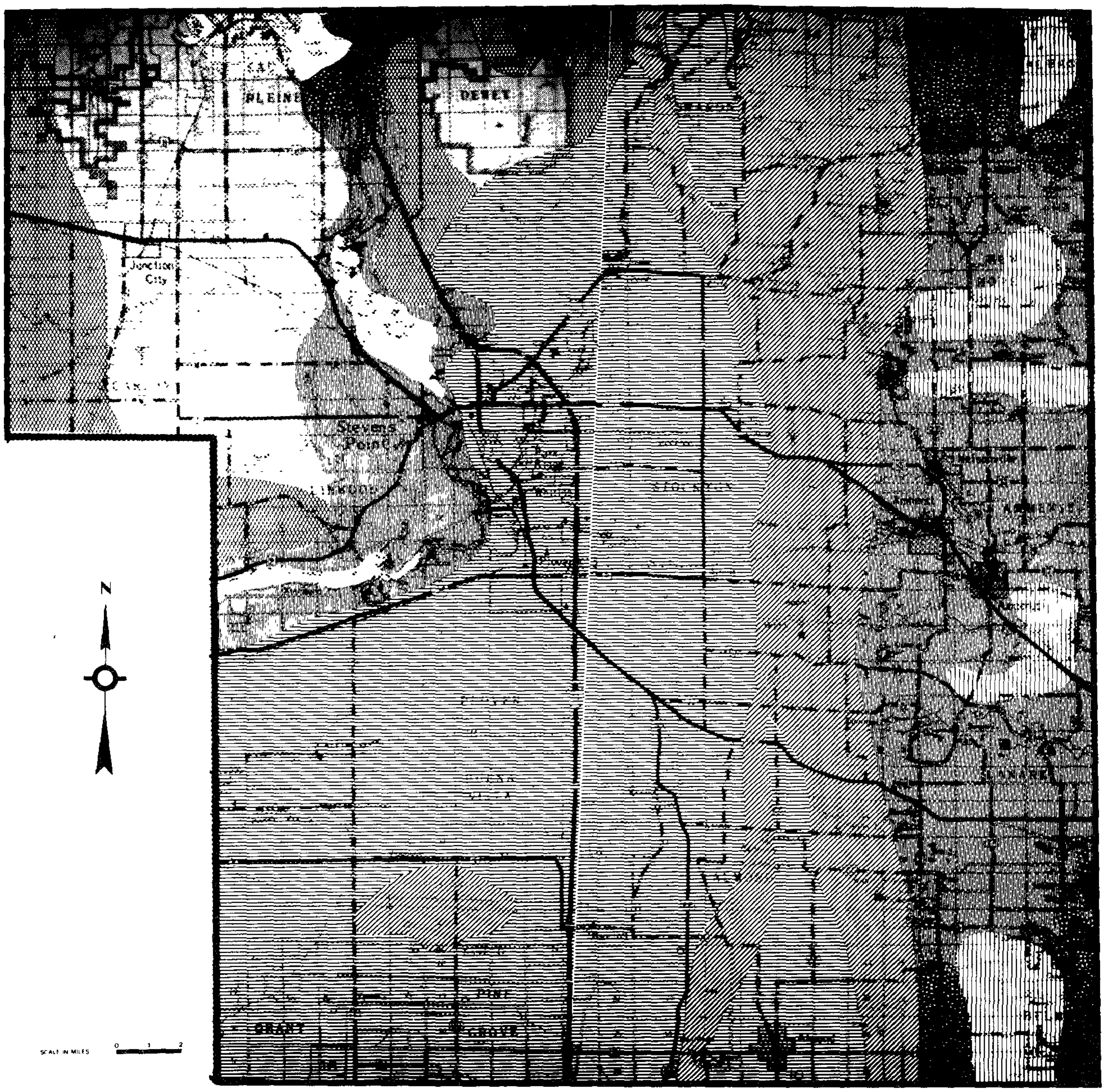
Portage County, Wisconsin, is situated within two ground-water regions; the northwestern part of the county is located in the Northeast and Superior Uplands and the remainder of the county is within the Glaciated Central Region. The water resources of the northwestern part of the county are derived primarily from metamorphic and igneous rocks which are in hydraulic connection with overlying thin glacial till. This aquifer yields supplies sufficient for domestic use only. The majority of the county is covered by thick sequences of glacial outwash sand and gravel which constitutes the major ground-water resource. These areas are characterized by highly permeable soils and shallow water depths.

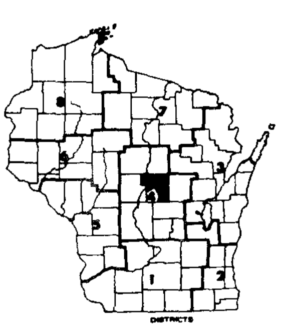
In mapping Portage County, nine hydrogeologic settings were identified and included. Computed DRASTIC Index values range from 99 to 200. Table 31 details the settings and ranges of associated DRASTIC Indexes. Also noted in the table are the number of unique DRASTIC Index calculations which were made during the mapping effort. The DRASTIC Index numbers reflect evaluation of unconfined aquifers only.

TABLE 31. HYDROGEOLOGIC SETTINGS MAPPED IN PORTAGE COUNTY, WISCONSIN

Hydrogeologic Setting	Range of DRASTIC Indexes	Number of DRASTIC Calculations
(7Ba) Outwash	182-200	4
(7C) Moraine	145-161	2
(7Eb) River Alluvium without Overbank Deposits	193	1
(7I) Swamp/Marsh	160	1
(9Da) Glacial Till over Crystalline Bedrock	109	1
(9E) Outwash	134-142	2
(9Gb) River Alluvium without Overbank Deposits	155-193	3
(9H) Swamp/Marsh	126-139	2
(9I) Bedrock Uplands	99-111	4

Figure 43 shows a general pollution potential map for Portage County. The DRASTIC Indexes have been grouped in accordance with the National Color Code (Table 22). Selected screens have been used to illustrate the variability. The pollution potential map has been superimposed on a county highway map for geographic reference. No hydrogeologic setting lines have been delineated on the map.





LEGEND

DRASTIC Index Range	Color
80- 99	□
100-119	▩
120-139	□
140-159	□
160-179	▨
180-199	▩
200+	▤

Figure 43. Generalized pollution potential map of Portage County, Wisconsin.

Appendix L contains the full-size pollution potential map for Portage County complete with hydrogeologic setting designations and individual DRASTIC Index computations. The map has been superimposed on a county highway map for geographic reference. The DRASTIC Index values have not been grouped on the full-size map. The map has been divided into separate sheets which permit it to be incorporated into the document. An Index to the map sheets is provided for ease of geographic sheet location. The corresponding charts which detail the ranges of the seven DRASTIC parameters chosen for each area and the computation of the DRASTIC Index immediately follows the maps.

Computation of the DRASTIC Indexes and identification of hydrogeologic settings relied on detailed information of the seven DRASTIC parameters. Specific descriptions and sources used to obtain this information are outlined in the following discussion centering around each DRASTIC parameter. A complete list of references is contained at the end of Section 5. The rating associated with the chosen range for each DRASTIC parameter appears in parenthesis for ease of reference.

Depth to Water

Water-level information was primarily obtained from Map number 7 in Lippelt (1981). Additional information was found in part 2 of Devaul and Green (1971) and part 2 of Olcott (1968). All surficial aquifers were determined to be unconfined based on information found in Holt (1965) and Bell and Sherrill (1974). Water levels were shallow throughout most of the county ranging from 0 to 5 feet (10), 5 to 15 (9) and 15 to 30 feet (7). Water levels in the bedrock uplands in the northwestern portion of the county were slightly deeper ranging from 15 to 30 feet (7) and 30 to 50 feet (5).

Net Recharge

Net recharge values were derived from Holt (1965) and Bell and Sherrill (1974). High recharge values of 10+ inches per year (9) were assigned to the outwash in the central and eastern portion of the county because the soil, vadoze zone and aquifer materials are very permeable. Recharge rates on the moraines were assigned a value of 7 to 10 inches per year (8) because the deposits contain greater amounts of silts and clays than in the outwash area. Recharge was also assigned a value of 7 to 10 inches per year (8) in the river alluvium because of the presence of fine materials. Net recharge in the swampy areas received a value of 4 to 7 inches per year (6) based on the presence of fine materials and organic mucks. Swamps are also local discharge areas which indicates that ground-water gradients are toward the surface and not toward the aquifer. However, ground-water pumpage could easily reverse the low gradients in these areas. The glacial till area in the northwestern portion of the county was assigned a value of 2 to 4 inches per year (3) based on the description of fine-grained deposits in the area. The recharge for the thin outwash areas in the northwestern portion of the county was designated as 4 to 7 inches per year (6). This value reflects better sorting than the adjacent glacial till but more fine-grained materials than in the central and eastern outwash deposits. The bedrock uplands areas were assigned recharge values of 2 to 4 inches per year (3) based on the permeabilities of the underlying crystalline and sedimentary rocks and the presence of only moderate jointing and fracturing within the bedrock.

Aquifer Media

Information on aquifer media was derived from Holt (1965) and Bell and Sherrill (1974). Additional information on aquifer yields is contained in map 18 of Lippelt and Hennings (1981). The major outwash aquifer in the central portion of the county consists of very thick sequences of well-sorted sands and gravels. These deposits were called sand and gravel and received the highest rating of (9). Outwash and morainal aquifers in the eastern portion of the county contained slightly more fines than the outwash in the central portion of the county. The media was designated sand and gravel and assigned a typical value of (8) based on the references and personal communication with Truman Bennett (Bennett and Williams, 1985). Outwash aquifers in the western portion of the county were poorly sorted sand and gravel lenses with a significant amount of fine material. These deposits were called sand and gravel and assigned a value of (5). The glacial tills in the western portion of the county containing lenses of sand and gravel in a fine-grained matrix were also called sand and gravel and assigned a lower value of (4). In this updated version of DRASTIC, the aquifer media in the western outwash and the glacial till would be chosen as glacial till and assigned the same rating. The designation of glacial till as an aquifer media was made to help in clarification of the system and to provide a rating for these types of deposits. Aquifers underlying the swampy areas were designated as sand and gravel (8) in the glaciated central ground-water region and sand and gravel (5) in the northeast and Superior Upland ground-water region. The western sand and gravels would have been designated as glacial till and assigned a rating of (5). River alluvium serving as an aquifer was called sand and gravel and assigned a typical rating of (8). The metamorphic and igneous aquifers were moderately weathered and fractured and were assigned a value of (5). In the updated version of DRASTIC, these aquifers would have received a rating of (4). The sandstone aquifer received a rating of (7) due to the presence of moderate fracturing.

Soil Media

Soils were mapped based on the soil survey of Portage County (Otter and Fiala, 1978). The soil media was assigned using the general soil association map. Soils formed in the outwash and moraine sands and gravels were sandy loam (6) in the majority of the county and loam in parts of the western portion of the county. Soils in the silty glacial drift in the western portion of the county were called silty loam (4). Soils formed in alluvial or organic deposits were called muck (2). The updated version of DRASTIC contains muck as a soil media because of the importance to pollution potential and because no organic soil designations were contained in the original draft. Soils formed in river alluvium were called sandy loam (6). The permeable soils and vadose zone deposits determined the choice of the hydrogeologic setting designation as river alluvium without overbank deposits. Soils formed in loamy materials and the underlying residuum from bedrock in the western portion of the county were called loam (5) and sandy loam (6).

Topography

Percent slope was estimated by using 7 1/2 minute USGS topographic quadrangle maps and adapting slope values assigned to soil series in the soil survey (Otter and Faila, 1978). Contour intervals on the topographic maps were either 5 or 10 feet. Topography averaged 0 to 2 percent (10) in the swamp and river alluvium areas; outwash areas ranged from 0 to 2 percent (10) to 2 to 6 percent (9); moraines and bedrock uplands ranged from 2 to 6 percent (9) to 6 to 12 percent (5).

Impact of the Vadose Zone Media

Information on the vadose zone media was obtained from Holt (1965) and Bell and Sherrill (1974). The vadose zone media for the outwash area in the central portion of the county was called sand and gravel and assigned a typical value of (8). The outwash in the eastern portion of the county contained more silts and clays. These deposits were called sand and gravel with significant silt and clay and assigned a rating of (8). The high rating was assigned based on high permeabilities within the deposits. Vadose zone deposits in the Outer and Second Moraine areas contained more fines than the outwash area but still had a high sand content. The vadose zone media was chosen as sand and gravel with significant silt and clay and assigned a rating of (7). Vadose zone media in the Elderon and Arnott moraines which had a higher silt and clay content were called sand and gravel with significant silt and clay but assigned a lower rating of (5). The vadose zone media in the river alluvium was called sand and gravel in areas of well-washed sands and assigned a typical value of (8). Where more fines were present, the deposits were called sand and gravel with significant silt and clay and assigned ratings of (7) and (6) depending on the amount of fines. Ratings of (6) were assigned where the alluvium was thinner and not as well-sorted. The vadose zone media for glacial till in the western portion of the county was called sand and gravel with significant silt and clay and assigned a typical value of (6). Vadose zone media for the thin outwash aquifers were called sand and gravel with significant silt and clay based on the presence of silts and clays. A rating of (7) was assigned based on the higher sand content than in the adjacent glacial tills. Vadose zone media overlying unconsolidated aquifers in swampy areas was called sand and gravel with significant silt and clay and assigned a rating of (6). The metamorphic/igneous vadose zone media overlying metamorphic/igneous aquifers in swampy areas was assigned a typical rating of (4). Metamorphic/igneous vadose zone media in the bedrock uplands was assigned a rating of (5) based on moderate jointing and fracturing. The sandstone vadose zone media in the bedrock uplands was assigned a rating of (7) based on the degree of fracturing.

Hydraulic Conductivity of the Aquifer

Hydraulic conductivity values were based on discussions contained in Holt (1965), Bell and Sherrill (1974), Devaul and Green (1971) and Olcott (1968). The outwash aquifer in the central and eastern portion of the county was assigned a range of 2000+ gallons per day per square foot (10) based on available pumping test data. Conductivity values in the Outer and Second Moraines and in the swampy area of the glaciated central ground-water region were assigned a range of 700 to 1000 gallons per day per square foot (6) based on an increasing content of fine materials. The conductivity in the Arnott and Elderon Moraines received a range of 300 to 700 gallons per day per square foot (4) based on an even higher content of fine materials. River alluvium adjacent to the central outwash aquifer was assigned a range of 2000+ gallons per day per square foot because of a lack of fines. Other river alluvium received ranges of 700 to 1000 gallons per day per square foot (6) and 300 to 700 gallons per day per square foot (4) based on increasing amounts of fine materials. Hydraulic conductivities in the glacial till were assigned a range of 1 to 100 gallons per day per square foot (1) based on the presence of only localized lenses of sand and gravel and the presence of fine materials. The thin outwash contains better-sorted sand and gravel lenses and was assigned a range of 100 to 300 gallons per day per square foot (2). The thin outwash adjacent to the river contained even better-sorted sand and gravel and was assigned a range of 300 to 700 gallons per day per square foot (4). Bedrock aquifers underlying swampy areas and in the bedrock uplands were assigned a range of 1 to 100 gallons per day per square foot based on low permeabilities and average well yields in the area.

Yolo County, California

Yolo County, California, lies within the Alluvial Basins ground-water region. From west to east, the hydrogeologic settings exemplify a typical cross section through an alluvial basin sequence. In the western portion of the county, marine sandstones and shales yield only small quantities of remnant saline water. Older continental deposits, alluvial fans and river alluvium comprised of sands, silts and clays provide the majority of the ground-water resources for the county. Conductivities are variable but typically provide significant well yields. These aquifers are usually unconfined and where they overlap, are hydraulically connected. Agricultural irrigation water provides significant recharge to these aquifers.

In mapping Yolo County, five hydrogeologic settings were identified and included. Computed DRASTIC Index values range from 67.to 192. Table 32 details the settings and ranges of associated DRASTIC Indexes. Also noted in the table are the number of unique DRASTIC Index calculations which were made during the mapping effort. The DRASTIC Index numbers reflect evaluation of unconfined aquifers only.

TABLE 32. HYDROGEOLOGIC SETTINGS MAPPED IN YOLO COUNTY, CALIFORNIA

Hydrogeologic Setting	Range of DRASTIC Indexes	Number of DRASTIC Index Calculations
(2A) Mountain Slopes	67-81	3
(2B) Alluvial Mountain Valleys	148	1
(2C) Alluvial Fans	119-160	6
(2Ha) River Alluvium with Overbank Deposits	139-192	3
(2K) Continental Deposits	92-112	3

Figure 44 shows a general pollution potential map for Yolo County. The DRASTIC Indexes have been grouped in accordance with the National Color Code (Table 22). Selected screens have been used to illustrate the variability. The pollution potential map has been superimposed on a county highway map for geographic reference. No hydrogeologic setting lines have been delineated on the map.

Appendix M contains the full-size pollution potential map for Yolo County complete with hydrogeologic setting designations and individual DRASTIC Index computations. The map has been superimposed on a county highway map for geographic reference. The DRASTIC Index values have not been grouped on the full-size map. The map has been divided into separate sheets which permit it to be incorporated into the document. An Index to the map sheets is provided for ease of geographic sheet location. The corresponding charts which detail the ranges of the seven DRASTIC parameters chosen for each area and the computation of the DRASTIC Index immediately follows the maps.

Computation of the DRASTIC Indexes and identification of hydrogeologic settings relied on detailed information of the seven DRASTIC parameters. Specific descriptions and sources used to obtain this information are outlined in the following discussion centering around each DRASTIC parameter. A complete list of references is contained at the end of Section 5. The rating associated with the chosen range for each DRASTIC parameter appears in parenthesis for ease of reference.

Depth to Water

Water-level information was primarily obtained from published data in California Department of Water Resources (1978; 1985). Additional information was found in Olmsted and Davis (1961). In general, water levels deepen from east to west. Water levels in the mountain slopes in the western portion of the county were 100+ feet (1) and averaged 15 to 30 feet (7) in the alluvial mountain valleys. The continental deposits which are adjacent to the mountains had water levels which ranged from 100+ feet (1) in the northern portion of the county to 50 to 75 feet (3) in the

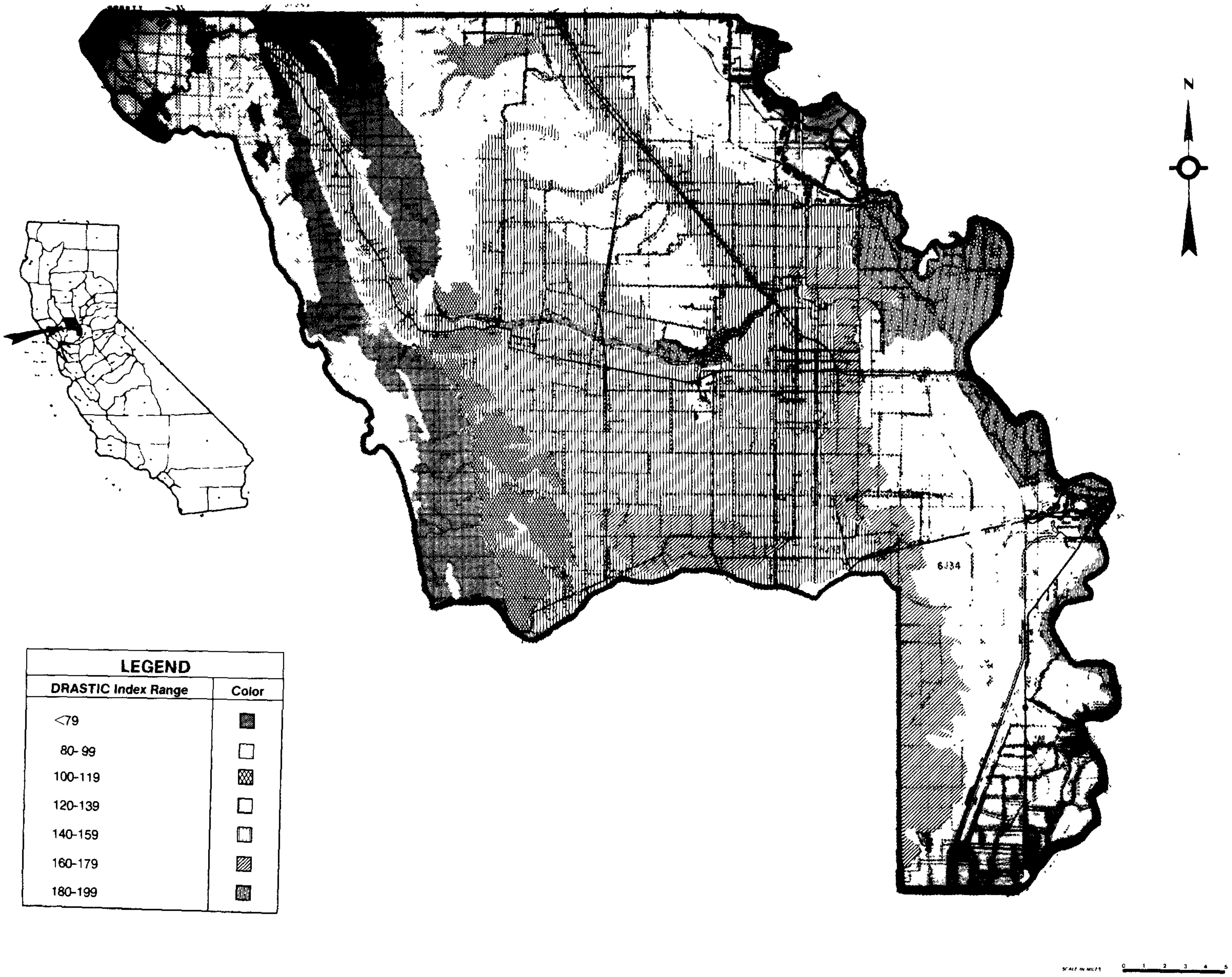


Figure 44. Generalized pollution potential map of Yolo County, California.

central and southern portions of the county. Depth to water in the alluvial fans ranged from 50 to 75 feet (3) in the western areas bordering the continental deposits to 30 to 50 feet (5) in the center of the county to 15 to 30 feet (7) bordering the flood basins (setting 2Ha1) in the eastern portion of the county. The flood basins and river alluvium had water levels which averaged 15 to 30 feet (7).

Net Recharge

Values for net recharge were based on information found in Olmsted and Davis (1961) and California Department of Water Resources (1978). Recharge values were calculated for township areas from the data in California Department of Water Resources (1978). Net recharge values reflect recharge from precipitation and irrigation. Mountain slopes were assigned a value of 0 to 2 inches per year (1) based on moderate precipitation, steep slopes and the low permeability of the deposits. The alluvial mountain valleys were given a value of 2 to 4 inches per year (3). Net recharge values for the continental deposits were chosen as 2 to 4 inches per year because the deposits are semi-consolidated and have a moderately high silt content. Recharge to the alluvial fans was strongly influenced by irrigation. Net recharge to the alluvial fans was calculated to be 2 to 4 inches per year (3) in the northern portion of the county. Values increased southward and were calculated to be 4 to 7 inches per year (6) and 7 to 10 inches per year (8). A value of 10+ inches per year (1) occurred in the central portion of the county.

Aquifer Media

Information on aquifer media was obtained from California Department of Water Resources (1978) and Olmsted and Davis (1961). Additional information was found on the geologic maps of the Sacramento Quadrangle (Wagner et al., 1981) and the Santa Rosa Quadrangle (Wagner and Bortugno, 1982). The mountain slopes were comprised of sedimentary sequences deposited in a marine environment. The aquifer media was chosen as thin bedded sandstone, limestone and shale sequences and assigned a typical value of (6). Sand and gravel was chosen as the aquifer media in the alluvial mountain valleys and assigned a typical value of (8) due to the coarseness of the deposits. The continental deposits are sequences of semi-consolidated sand, silt and clay. The aquifer media was chosen as sand and gravel and assigned a typical value of (8) because the deposits are semi-consolidated sands, gravels and silts. The alluvial fans were called sand and gravel and assigned a typical rating of (8). Lenses of sand and gravel serve as the aquifer in the flood basins (setting 2Ha1) and the river alluvium (settings 2Ha2 and 2Ha3). Sand and gravel was chosen as the aquifer media and assigned a typical value of (8).

Soil Media

Soils were mapped based on the Soil Survey of Yolo County, California (Andrews, 1972). Soils on mountain slopes in the western portion of the county are thin or absent (10). Other soils on mountain slopes are predominantly clay loam (3) with minor occurrences of shrinking and aggregated clay (7) in the northwestern portion of the county. Soils in the alluvial mountain valleys are silty loam (4). Soils overlying the continental deposits are silty loam (4) in the western portion of the county and shrinking and aggregated clay (7) in the central portion of the county. Alluvial fan deposits are overlain by clay loam (3). Soils in flood basins (setting 2Ha1) are shrinking and aggregated clay (7). River alluvium soil media (settings 2Ha2 and 2Ha3) are silty loam (4) in the eastern portion of the county and sand (9) in the central portion of the county.

Topography

Percent slope was estimated by using 7 1/2 minute USGS topographic quadrangle maps. Contour intervals on the 7 1/2 minute maps were 5 feet, 20 feet and 40 feet. Slopes were 18+ percent (1) in the western and northwestern portion of the county and gradually lessened eastward and southward. Slopes of 6 to 12 percent (5) and 2 to 6 percent occur in the central portion of the county and 0 to 2 percent slopes are found in the eastern and southeastern portions of the county.

Impact of the Vadose Zone Media

Information on the vadose zone media was obtained from California Department of Water Resources (1978) and Olmsted and Davis (1961). The vadose zone media in the mountain slope area was called bedded limestone, sandstone and shale and assigned a typical rating of (6). Vadose zone media in the alluvial mountain valleys was chosen as sand and gravel and assigned a typical rating of (8) due to the relative coarseness of the deposits. The continental deposits were designated as sand and gravel with significant silt and clay and assigned a typical rating of (6) based on an average amount of fine material and semi-consolidation of the deposits. Alluvial fan areas were also called sand and gravel with significant silt and clay, but were assigned a rating of (7) based on the increased sand and gravel content of the deposits. Vadose zone media in the flood basins (setting 2Ha1) was chosen as silt/clay and assigned a rating of (2) based on the presence of significant amounts of fines in the deposits and the semi-confined conditions. In this updated version of DRASTIC, the silt/clay would have been assigned a rating of (3). Vadose zone media in the river alluvium was called sand and gravel and assigned a typical value of (8).

Hydraulic Conductivity of the Aquifer

Hydraulic conductivity values for the various aquifer media were based on information in California Department of Water Resources (1978) and Olmsted and Davis (1961). Where no values were given, estimates of conductivity were made from aquifer media descriptions. The aquifer in the mountain slopes was essentially non-water bearing and assigned a value of 1 to 100 gallons per day per square foot (1). The hydraulic conductivity of the sand and gravel in the alluvial mountain valleys was estimated to be 700 to 1000 gallons per day per square foot (6). Values of conductivity in the continental deposits were estimated to be 300 to 700 gallons per day per square foot (4) based on moderate well yields. The lenses of sand and gravel in the alluvial fans are relatively coarse and moderately sorted. These deposits were assigned a value of 700 to 1000 gallons per day per square foot (6) based on published values and moderately high well yields. Values for conductivity of the sand and gravel within the flood basin area (setting 2Ha1) were estimated to range from 300 to 700 gallons per day per square foot (4). In the river alluvium the well-sorted highly permeable sands and gravels in the eastern portion of the county were assigned a value of 2000+ gallons per day per square foot (10). Hydraulic conductivity values for the river alluvium in the central portion of the county were chosen as 1000 to 2000 gallons per day per square foot (8).

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SECTION 6

IMPACT - RISK FACTORS

The DRASTIC Index estimates the vulnerability of any setting to pollution on the basis of determinable geologic and hydrologic parameters. It does not, however, indicate a variety of other parameters that often point out the significance of the DRASTIC Index under the influence of cultural and physical modifications. For example, an area with a low DRASTIC Index, indicating moderate or low vulnerability to contamination, may be located very near to a large population center. The proximity to a population that can be exposed greatly increases the risk, or impact, of an incidence of pollution at the prospective site. Thus it can quickly be noted that not only the size of the population exposed, and the human/non-human nature of that population, but also the time required for the pollutant to travel from the point of incidence to the population at risk, is a serious consideration within a given setting. Similarly, the relative "value" of an underlying aquifer may require special consideration when assessing the factors which influence pollution potential. This may become particularly important in areas where the aquifer is the only source of ground water or where ground-water supplies are abundant and have not been fully developed.

Travel time is considered only tangentially by the DRASTIC Index. It is implied by "hydraulic conductivity," but becomes interpretable, and meaningful, only when the distance to be traveled from a source of contamination to a point of concern is known, and when the gradient, or inclination of the water table is considered. Thus, the travel time of a pollutant from point of introduction until it reaches a population is not given by the DRASTIC Index, but must be evaluated separately, by persons with adequate data and expertise for each specific site.

In a similar manner, the risk to a given population depends on the toxicity of the pollutant being introduced and the degree of exposure of the population to the pollutant. Obviously, if the pollutant being introduced is non-toxic to the population exposed, there is little or no risk to that population as a consequence of the exposure. When the pollutant is quite toxic, it is obvious that minimal exposure of the population may be very serious, even where travel time as controlled by gradient, distance, and hydraulic conductivity is great.

Essentially, the DRASTIC Index for a given setting is derived on the basis of the vulnerability of the site to an invasion of water, hence the name "hydrogeological setting." Actually, the concern is not about the vulnerability of a setting to water, but rather with the vulnerability of that setting to contaminants. Water forms the common baseline, but the site vulnerability varies with the specific properties of the contaminant being applied. Obviously all settings cannot be mapped for all potential contaminants, so in many instances critical judgements have to be made about the risks involved. Where accidental spills are involved, these judgements must be made rapidly, conservatively, and on the basis of the best data available. Where design judgements are to be made, they should be made on the basis of adequate field and laboratory testing. It should always be kept in mind that some substances are so toxic that there are no "safe" settings available.

In addition to travel time, toxicity, and population exposed, the risk is influenced by "loading" factors. Whether the application rate is a slug application, as in an accidental spill; an intermittent application, as with pesticides and fertilizers; or a continuous application, such as a leaking tank or lagoon, has an obvious bearing upon the total load of material reaching an exposed population. Loading is also influenced by the concentration of the polluting substance. If the incident pollutant is highly concentrated, it is apparent that the exposed population is at much greater risk than would be the case if the pollutant were less concentrated. All of the attenuating factors, dilution, dispersion, sorption, filtration, reaction etc. are more effective at lesser loading rates.

In order to assist in the understanding of the basic risk factors, travel time, population exposed, loading and toxicity, and how these risk factors impact the DRASTIC Index, the following acronym is suggested:

I Inclination of the water table (gradient)
Direction of slope in ft/ft (feet per foot)

M Measured horizontal distance
Distance to point of exposure in feet or miles

P Population exposed
Human or non-human

A Application rate
Slug, intermittent, or continuous

C Concentration
Concentration of pollutant, often in mg/l

T Toxicity
Degree of toxicity to the population exposed

When the DRASTIC Index of a particular setting is evaluated with regard to these parameters of impact, as a consequence of a particular pollutant, a reasonable judgement can be made with respect to the risk to the population exposed.

Section 7

GROUND-WATER REGIONS AND HYDROGEOLOGIC SETTINGS OF THE UNITED STATES

The focus of this document is to present a system which allows the user to evaluate the ground-water pollution potential of any area in the United States and to produce a map of the results. The mapping application of the methodology requires the designation of hydrogeologic settings. This section contains descriptions of 111 hydrogeologic settings. Although a conscientious attempt has been made to identify all major hydrogeologic settings in the United States, it is possible that additional settings may exist.

As described in Section 2, Development of the System and Overview, the entire United States has been divided into 13 geographic ground-water regions. These ground-water regions were developed and described by Heath (1984) (Figure 1). This methodology uses these major ground-water regions as a geographic framework to begin to assess ground-water pollution potential. This section contains an annotated description, a geographic location map and a block diagram illustrating the major hydrogeologic features for each ground-water region (Heath, 1984). Table 33 provides a summary of principal physical and hydrologic characteristics of the ground-water regions. Table 34 lists common ranges for the hydraulic characteristics of the ground-water regions.

The ground-water regions have been subdivided into mapping units called hydrogeologic settings. Each hydrogeologic setting contains a written narrative, a block diagram showing the geology of the setting and two DRASTIC charts portraying sample DRASTIC Index calculations. Figure 45 provides a legend for the identification of the geologic materials portrayed in the block diagrams of each hydrogeologic setting. The charts display the DRASTIC Index and the Pesticide DRASTIC Index for each typical hydrogeologic setting. These charts have been produced as examples of conditions which might typically exist in the hydrogeologic setting within the specific ground-water region. The charts are intended to only be examples and not to represent absolute values for the hydrogeologic setting. The significant difference between the two charts is the difference in weights assigned for each DRASTIC factor.

The hydrogeologic settings and the DRASTIC Indexes from the example charts have been grouped to assist the user in evaluating the relative pollution potential for many hydrogeologic settings. Tables 35 through 37 contain lists of the hydrogeologic settings and associated DRASTIC Indexes sorted by ground-water region, ratings and setting title respectively. Tables 38 through 40 contain the same information for Pesticide DRASTIC Indexes taken from the example charts.

TABLE 33. SUMMARY OF THE PRINCIPAL PHYSICAL AND HYDROLOGIC CHARACTERISTICS OF THE GROUND-WATER REGIONS OF THE UNITED STATES (AFTER HEATH, 1984)

Region No.	Name	Components of the system														Characteristics of the dominant aquifers																				
																Water-bearing openings					Composition			Storage and transmission properties							Recharge and discharge conditions					
		Unconfined aquifer			Confining beds			Confined aquifers				Presence and arrangement				Primary			Secondary		Degree of solubility			Porosity			Transmissivity				Recharge			Discharge		
		Hydrologically insignificant	Minor aquifer or not very productive	Dominant aquifer	Hydrologically insignificant	Thin, discontinuous, or v leaky	Interlayered with aquifers	Hydrologically insignificant	Not highly productive	Multiple productive aquifers	The dominant productive aquifer	Single unconfined aquifer	Two interconnected aquifers	Unconfined aquifer, confining bed, confined aquifer	complex interbedded sequence	Pores in unconsolidated dep	Pores in semiconsolidated rocks	Tubes and cooling cracks in lava	Fractures and faults	Solution-enlarged openings	Insoluble	Mixed soluble and insoluble	Soluble	Large (>0 2)	Moderate (0 01 -0 2)	Small (<0 01)	Large (>2,500 m^2day^{-1})	Moderate (250-2,500 m^2day^{-1})	Small (25-250 m^2day^{-1})	Very small (<25 m^2day^{-1})	Uplands between streams	Losing streams	Leakage through confining beds	Springs and surface seepage	Evaporation and basin sinks	Into other aquifers
1	Western Mountain Ranges		X		X				X				X			X			X		X				X				X		X	X		X		
2	Alluvial Basins			X			X			X					X	X					X			X			X					X			X	X
3	Columbia Lava Plateau		X				X			X					X	X		X	X		X					X	X					X		X		
4	Colorado Plateau and Wyoming Basin	X					X			X					X		X		X		X					X			X		X		X	X		
5	High Plains			X	X			X				X				X					X			X			X					X		X		
6	Nonglaciated Central Region		X				X			X					X		X		X	X		X				X		X			X		X	X		X
7	Glaciated Central Region		X				X			X					X	X	X		X	X		X			X			X					X			X
8	Piedmont and Blue Ridge		X		X				X				X			X			X		X					X				X	X			X		
9	Northeast and Superior Uplands		X			X			X				X			X			X		X					X			X		X			X		
10	Atlantic and Gulf Coastal Plain		X				X			X					X	X				X		X			X			X			X		X	X		X
11	Southeast Coastal Plain		X				X				X			X		X				X			X	X			X				X		X	X		
12	Hawaii			X		X		X				X						X			X			X			X				X	X		X		
13	Alaska			X		X			X						X	X			X			X			X			X				X		X		

TABLE 34. COMMON RANGES FOR THE HYDRAULIC CHARACTERISTICS OF GROUND WATER REGIONS OF THE UNITED STATES (AFTER HEATH, 1984)

Region No	Region	Geologic Situation	Common Ranges in Hydraulic Characteristics of the Dominant Aquifers															
			Transmissivity				Hydraulic Conductivity				Recharge Rate				Well Yield			
			$m^2\,day^{-1}$		$ft^2\,day^{-1}$		$m\,day^{-1}$		$ft\,day^{-1}$		$mm\,yr^{-1}$		$in\,yr^{-1}$		$m^3\,min^{-1}$		$gal\,min^{-1}$	
			low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high
1	Western Mountain Ranges	Mountains with thin soils over fractured rocks, alternating with narrow alluvial and, in part, glaciated valleys		100	5	5,000,000	0.0003	15	0.001	50	3	50	0.1	2	0.04	0.4	10	100
2	Alluvial Basins	Thick[1] alluvial (locally glacial) deposits in basins and valleys bordered by mountains	20	20,000	2,000	200,000	30	600	100	2,000	0.03	30	0.001	1	0.4	20	100	5,000
3	Columbia Lava Plateau	Thick sequence of lava flows interbedded with unconsolidated deposits and overlain by thin soils	2,000	500,000	20,000	5,000,000	200	3,000	500	10,000	5	300	0.2	10	0.4	80	100	20,000
4	Colorado Plateau and Wyoming Basin	Thin[1] soils over fractured sedimentary rocks	0.5	100	5	1,000	0.003	2	0.01	5	0.3	50	0.01	2	0.04	2	10	1,000
5	High Plains	Thick alluvial deposits over fractured sedimentary rocks	1,000	10,000	10,000	100,000	30	300	100	1,000	5	80	0.2	3	0.4	10	100	3,000
6	Nonglaciated Central region	Thin regolith over fractured sedimentary rocks	300	10,000	3,000	100,000	3	300	10	1,000	5	500	0.2	20	0.4	20	100	5,000
7	Glaciated Central region	Thick glacial deposits over fractured sedimentary rocks	100	2 000	1,000	20,000	2	300	5	1,000	5	300	0.2	10	0.2	2	50	500
8	Piedmont and Blue Ridge	Thick regolith over fractured crystalline and metamorphosed sedimentary rocks	9	200	100	2,000	0.001	1	0.003	3	30	300	1	10	0.2	2	50	500
9	Northeast and Superior Uplands	Thick glacial deposits over fractured crystalline rocks	50	500	500	5,000	2	30	5	100	30	300	1	10	0.1	1	20	200
10	Atlantic and Gulf Coastal Plain	Complexly interbedded sands, silts and clays	500	10 000	5,000	100,000	3	100	10	400	50	500	2	20	0.4	20	100	5,000
11	Southeast Coastal Plain	Thick layers of sand and clay over semiconsolidated carbonate rocks	1,000	100 000	10,000	1,000,000	30	3 000	100	10,000	30	500	1	20	4	80	1,000	20,000
12	Hawaiian Islands	Lava flows segmented by dikes interbedded with ash deposits, and partly overlain by alluvium	10,000	100,000	100 000	1,000 000	200	3,000	500	10,000	30	1,000	1	40	0.4	20	100	5,000
13	Alaska	Glacial and alluvial deposits in part perennially frozen and overlying crystalline, metamorphic, and sedimentary rocks	100	10,000	1,000	100,000	30	600	100	2,000	3	300	0.1	10	0.04	4	10	1,000

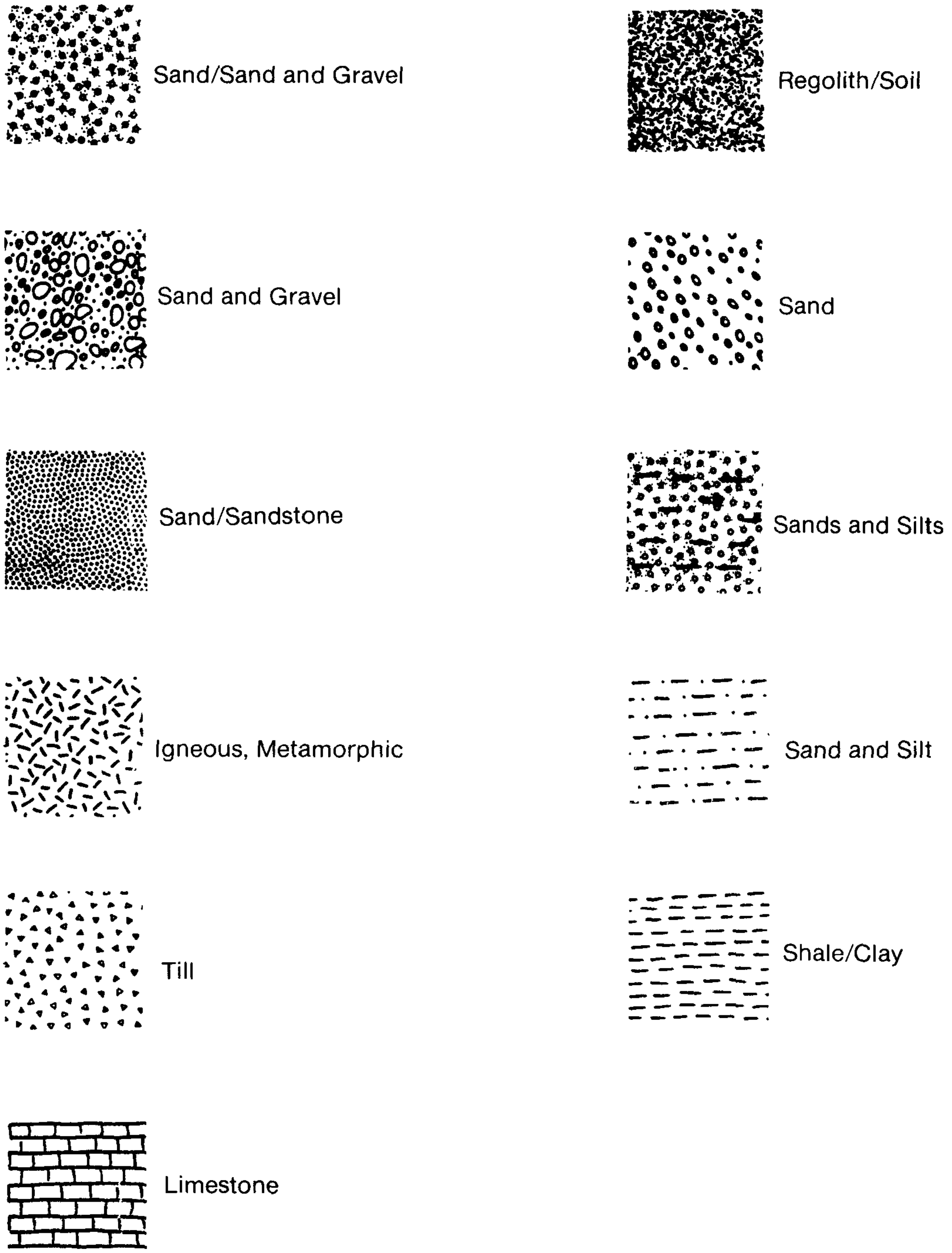


Figure 45. Map legend.

TABLE 35. HYDROGEOLOGIC SETTINGS AND ASSOCIATED DRASTIC INDEXES SORTED BY GROUND-WATER REGIONS

SETTINGS	DESCRIPTIONS	RATING
1Aa East	Mountain Slopes	65
1Ab West	Mountain Slopes	70
1Ba East	Alluvial Mountain Valleys	128
1Bb West	Alluvial Mountain Valleys	146
1Ca East	Mountain Flanks	83
1CB West	Mountain Flanks	106
1D	Glacial Mountain Valleys	180
1Ea East	Wide Alluvial Valleys (External Drainage)	158
1Eb West	Wide Alluvial Valleys (External Drainage)	180
1F	Coastal Beaches	196
1G	Swamp/Marsh	139
1H	Mud Flows	130
2A	Mountain Slopes	74
2B	Alluvial Mountain Valleys	132
2C	Alluvial Fans	122
2D	Alluvial Basins (Internal Drainage)	122
2E	Playa Lakes	110
2F	Swamp/Marsh	127
2G	Coastal Lowlands	202
2Ha	River Alluvium with Overbank Deposits	163
2Hb	River Alluvium without Overbank Deposits	191
2I	Mud Flows	149
2J	Alternating Sandstone and Shale Sequences	112
2K	Continental Deposits	98
3A	Mountain Slopes	86
3B	Alluvial Mountain Valleys	168
3C	Hydraulically Connected Lava Flows	146
3D	Lava Flows Not Connected Hydraulically	105
3E	Alluvial Fans	105
3F	Swamp/Marsh	179
3G	River Alluvium	147
4A	Resistant Ridges	88
4B	Consolidated Sedimentary Rock	87
4C	River Alluvium	152
4D	Alluvium and Dune Sand	102
4E	Swamp/Marsh	176
5A	Ogallala	109
5B	Alluvium	107
5C	Sand Dunes	150
5D	Playa Lakes	110
5E	Braided River Deposits	185
5F	Swamp/Marsh	198
5Ga	River Alluvium with Overbank Deposits	129
5Gb	River Alluvium without Overbank Deposits	143
5H	Alternating Sandstone, Limestone and Shale Sequences	80
6A	Mountain Flanks	103
6B	Alluvial Mountain Valleys	152
6C	Mountain Flanks	105
6Da	Alternating Sandstone, Limestone and Shale — Thin Soil	139
6Dd	Alternating Sand, Limestone and Shale — Deep Regolith	125
6E	Solution Limestone	196
6Fa	River Alluvium with Overbank Deposits	126
6Fb	River Alluvium without Overbank Deposits	187
6G	Braided River Deposits	190
6H	Triassic Basins	106
6I	Swamp/Marsh	144
6J	Metamorphic/Igneous Domes and Fault Blocks	71
6K	Unconsolidated and Semiconsolidated Aquifers	101
7Aa	Glacial Till Over Bedded Sedimentary Rock	103
7Ab	Glacial Till Over Outwash	137
7Ac	Glacial Till Over Solution Limestone	139
7Ad	Glacial Till Over Sandstone	109
7Ae	Glacial Till Over Shale	88
7Ba	Outwash	176
7Bb	Outwash Over Bedded Sedimentary Rock	156
7Bc	Outwash Over Solution Limestone	186
7C	Moraine	135
7D	Buried Valley	156
7Ea	River Alluvium with Overbank Deposits	134
7Eb	River Alluvium without Overbank Deposits	191
7F	Glacial Lake Deposits	135
7G	Thin Till Over Bedded Sedimentary Rock	121
7H	Beaches, Beach Ridges and Sand Dunes	202
7I	Swamp/Marsh	160
8A	Mountain Slopes	75
8B	Alluvial Mountain Valleys	162
8C	Mountain Flanks	106
8D	Regolith	100
8E	River Alluvium	176
8F	Mountain Crests	70
8G	Swamp/Marsh	120
9A	Mountain Slopes	75
9B	Alluvial Mountain Valley	180
9C	Mountain Flanks	106
9Da	Glacial Till Over Crystalline Bedrock	113
9Db	Glacial Till Over Outwash	139
9E	Outwash	190
9F	Moraine	166
9Ga	River Alluvium with Overbank Deposits	146
9Gb	River Alluvium without Overbank Deposits	191
9H	Swamp/Marsh	120
9I	Bedrock Uplands	118
9J	Glacial Lake/Glacial Marine Deposits	120
9K	Beaches, Beach Ridges and Sand Dunes	161
10Aa	Regional Aquifers	82
10Ab	Unconsolidated and Semiconsolidated Shallow Surficial Aquifer	184
10Ba	River Alluvium with Overbank Deposits	142
10Bb	River Alluvium without Overbank Deposits	187
10C	Swamp	202
11A	Solution Limestone and Shallow Surficial Aquifers	218
11B	Coastal Deposits	191
11C	Swamp	224
11D	Beaches and Bars	190
12A	Mountain Slopes	164
12B	Alluvial Mountain Valleys	184
12C	Volcanic Uplands	165
12D	Coastal Beaches	201
13A	Alluvium	140
13B	Glacial and Glaciolacustrine Deposits of the Interior Valleys	141
13C	Coastal Lowland Deposits	140
13D	Bedrock of the Uplands and Mountains	92

TABLE 36. HYDROGEOLOGIC SETTINGS AND ASSOCIATED DRASTIC INDEXES SORTED BY RATING

SETTINGS	DESCRIPTIONS	RATING
1Aa East	Mountain Slopes	65
8F	Mountain Slopes	70
1Ab West	Mountain Slopes	70
6J	Metamorphic/Igneous Domes and Fault Blocks	71
2A	Mountain Slopes	74
8A	Mountain Slopes	75
9A	Mountain Slopes	75
5H	Alternating Sandstone, Limestone and Shale Sequences	80
10Aa	Regional Aquifers	82
1Ca East	Mountain Flanks	83
3A	Mountain Slopes	86
4B	Consolidated Sedimentary Rock	87
4A	Resistant Ridges	88
7Ae	Glacial Till Over Shale	88
13D	Bedrock of the Uplands and Mountains	92
2K	*Continental Deposits*	98
8D	Regolith	100
6K	Unconsolidated and Semiconsolidated Aquifers	101
4D	Alluvium and Dune Sand	102
6A	Mountain Flanks	103
7Aa	Glacial Till Over Bedded Sedimentary Rock	103
6C	Mountain Flanks	105
3D	Lava Flows Not Connected Hydraulically	105
3E	*Alluvial Fans*	105
9C	Mountain Flanks	106
6H	Triassic Basins	106
1Cb West	*Mountain Flanks*	106
8C	Mountain Flanks	106
5B	Alluvium	107
7Ad	Glacial Till Over Sandstone	109
5A	Ogallala	109
2E	Playa Lakes	110
5D	Playa Lakes	110
2J	Alternating Sandstone and Shale Sequences	112
9Da	*Glacial Till Over Crystalline Bedrock*	113
9I	Bedrock Uplands	118
9J	Glacial Lake/Glacial Marine Deposits	120
8G	Swamp/Marsh	120
9H	Swamp/Marsh	120
7G	Thin Till Over Bedded Sedimentary Rock	121
2D	Alluvial Basins (Internal Drainage)	122
2C	Alluvial Fans	122
6Dd	*Alternating Sand, Limestone and Shale — Deep Regolith*	125
6Fa	River Alluvium with Overbank Deposits	126
2F	Swamp/Marsh	127
1Ba East	Alluvial Mountain Valleys	128
5Ga	River Alluvium with Overbank Deposits	129
1H	Mud Flows	130
2B	Alluvial Mountain Valleys	132
7Ea	*River Alluvium with Overbank Deposits*	134
7F	Glacial Lake Deposits	135
7C	Moraine	135
7Ab	Glacial Till Over Outwash	137
7Ac	Glacial Till Over Solution Limestone	139
1G	Swamp/Marsh	139
6Da	Alternating Sandstone, Limestone and Shale— Thin Soil	139
9Db	Glacial Till Over Outwash	139
13A	Alluvium	140
13C	Coastal Lowland Deposits	140
13B	Glacial and Glaciolacustrine Deposits of the Interior Valleys	141
10Ba	River Alluvium with Overbank Deposits	142
5Gb	River Alluvium without Overbank Deposits	143
6I	Swamp/Marsh	144
9Ga	River Alluvium with Overbank Deposits	146
1Bb West	Alluvial Mountain Valleys	146
3C	Hydraulically Connected Lava Flows	146
3G	River Alluvium	147
2I	Mud Flows	149
5C	Sand Dunes	150
4C	River Alluvium	152
6B	*Alluvial Mountain Valleys*	152
7Bb	Outwash Over Bedded Sedimentary	156
7D	Buried Valley	156
1Ea East	Wide Alluvial Valleys (External Drainage)	158
7I	Swamp/Marsh	160
9K	Beaches, Beach Ridges and Sand Dunes	161
8B	Alluvial Mountain Valleys	162
2Ha	River Alluvium with Overbank Deposits	163
12A	Mountain Slopes	164
12C	Volcanic Uplands	165
9F	Moraine	166
3B	*Alluvial Mountain Valleys*	168
7Ba	Outwash	176
8E	River Alluvium	176
4E	Swamp/Marsh	176
3F	Swamp/Marsh	179
9B	Alluvial Mountain Valley	180
1Eb West	Wide Alluvial Valleys (External Drainage)	180
1D	Glacial Mountain Valleys	180
12B	*Alluvial Mountain Valleys*	184
10Ab	Unconsolidated and Semiconsolidated Shallow Surficial Aquifer	184
5E	Braided River Deposits	185
7Bc	Outwash Over Solution Limestone	186
10Bb	River Alluvium without Overbank Deposits	187
6Fb	River Alluvium without Overbank Deposits	187
11D	Beaches and Bars	190
6G	Braided River Deposits	190
9E	Outwash	190
9Gb	River Alluvium without Overbank Deposits	191
11B	Coastal Deposits	191
2Hb	River Alluvium without Overbank Deposits	191
7Eb	River Alluvium without Overbank Deposits	191
1F	Coastal Deposits	196
6E	Solution Limestone	196
5F	Swamp/Marsh	198
12D	Coastal Beaches	201
7H	Beaches, Beach Ridges and Sand Dunes	202
2G	Coastal Lowlands	202
10C	Swamp	202
11A	Solution Limestone and Shallow Surficial Aquifers	218
11C	Swamp	224

TABLE 37. HYDROGEOLOGIC SETTINGS AND ASSOCIATED DRASTIC INDEXES SORTED BY SETTING TITLE

SETTINGS	DESCRIPTIONS	RATING
2D	Alluvial Basins (Internal Drainage)	122
2C	Alluvial Fans	122
3E	Alluvial Fans	105
9B	Alluvial Mountain Valleys	180
8B	Alluvial Mountain Valleys	162
12B	Alluvial Mountain Valleys	184
1Bb West	Alluvial Mountain Valleys	146
2B	Alluvial Mountain Valleys	132
6B	Alluvial Mountain Valleys	152
3B	Alluvial Mountain Valleys	168
1Ba East	Alluvial Mountain Valleys	128
13A	Alluvium	140
5B	Alluvium	107
4D	Alluvium and Dune Sand	102
6Dd	Alternating Sand, Limestone and Shale — Deep Regolith	125
2J	Alternating Sandstone and Shale Sequences	112
6Da	Alternating Sandstone, Limestone and Shale — Thin Soil	139
5H	Alternating Sandstone, Limestone and Shale Sequences	80
11D	Beaches and Bars	190
7H	Beaches, Beach Ridges and Sand Dunes	202
9K	Beaches, Beach Ridges and Sand Dunes	161
9I	Bedrock Uplands	118
13D	Bedrock of the Uplands and Mountains	92
6G	Braided River Deposits	190
5E	Braided River Deposits	185
7D	Buried Valley	156
12D	Coastal Beaches	201
1F	Coastal Beaches	196
11B	Coastal Deposits	191
13C	Coastal Lowland Deposits	140
2G	Coastal Lowlands	202
4B	Consolidated Sedimentary Rock	87
2K	Continental Deposits	98
7F	Glacial Lake Deposits	135
9J	Glacial Lake/Glacial Marine Deposits	120
1D	Glacial Mountain Valleys	180
7Aa	Glacial Till Over Bedded Sedimentary Rock	103
9Da	Glacial Till Over Crystalline Bedrock	113
9Db	Glacial Till Over Outwash	139
7Ab	Glacial Till Over Outwash	137
7Ad	Glacial Till Over Sandstone	109
7Ae	Glacial Till Over Shale	88
7Ac	Glacial Till Over Solution Limestone	139
13B	Glacial and Glaciolacustrine Deposits of the Interior Valleys	141
3C	Hydraulically Connected Lava Flows	146
3D	Lava Flows Not Connected Hydraulically	105
6J	Metamorphic/Igneous Domes and Fault Blocks	71
7C	Moraine	135
9F	Moraine	166
8F	Mountain Crests	70
6C	Mountain Flanks	105
8C	Mountain Flanks	106
1Cb West	Mountain Flanks	106
1Ca East	Mountain Flanks	83
9C	Mountain Flanks	106
6A	Mountain Flanks	103
3A	Mountain Slopes	86
9A	Mountain Slopes	75
1Aa East	Mountain Slopes	65
2A	Mountain Slopes	74
1Ab West	Mountain Slopes	70
12A	Mountain Slopes	164
8A	Mountain Slopes	75
2I	Mud Flows	149
1H	Mud Flows	130
5A	Ogallala	109
9E	Outwash	190
7Ba	Outwash	176
7Bb	Outwash Over Bedded Sedimentary Rock	156
7Bc	Outwash Over Solution Limestone	186
2E	Playa Lakes	110
5D	Playa Lakes	110
10Aa	Regional Aquifers	82
8D	Regolith	100
4A	Resistant Ridges	88
8E	River Alluvium	176
3G	River Alluvium	147
4C	River Alluvium	152
6Fa	River Alluvium with Overbank Deposits	126
9Ga	River Alluvium with Overbank Deposits	146
7Ea	River Alluvium with Overbank Deposits	134
10Ba	River Alluvium with Overbank Deposits	142
5Ga	River Alluvium with Overbank Deposits	129
2Ha	River Alluvium with Overbank Deposits	163
6Fb	River Alluvium without Overbank Deposits	187
9Gb	River Alluvium without Overbank Deposits	191
7Eb	River Alluvium without Overbank Deposits	191
10Bb	River Alluvium without Overbank Deposits	187
2Hb	River Alluvium without Overbank Deposits	191
5Gb	River Alluvium without Overbank Deposits	143
5C	Sand Dunes	150
6E	Solution Limestone	196
11A	Solution Limestone and Shallow Surficial Aquifers	218
10C	Swamp	202
11C	Swamp	224
6I	Swamp/Marsh	144
5F	Swamp/Marsh	198
1G	Swamp/Marsh	139
3F	Swamp/Marsh	179
8G	Swamp/Marsh	120
2F	Swamp/Marsh	127
4E	Swamp/Marsh	176
9H	Swamp/Marsh	120
7I	Swamp/Marsh	160
7G	Thin Till Over Bedded Sedimentary Rock	121
6H	Triassic Basins	106
10Ab	Unconsolidated and Semiconsolidated Shallow Surficial Aquifer	184
6K	Unconsolidated and Semiconsolidated Aquifers	101
12C	Volcanic Uplands	165
1Eb West	Wide Alluvial Valleys (External Drainage)	180
1Ea East	Wide Alluvial Valleys (External Drainage)	158

TABLE 38. HYDROGEOLOGIC SETTINGS AND ASSOCIATED PESTICIDE DRASTIC INDEXES SORTED BY GROUND-WATER REGIONS

SETTINGS	DESCRIPTIONS	RATING
1Aa East	Mountain Slopes	91
1Ab West	Mountain Slopes	97
1Ba East	Alluvial Mountain Valleys	166
1Bb West	Alluvial Mountain Valleys	184
1Ca East	Mountain Flanks	99
1Cb West	Mountain Flanks	122
1D	Glacial Mountain Valleys	214
1Ea East	Wide Alluvial Valleys (External Drainage)	192
1Eb West	Wide Alluvial Valleys (External Drainage)	214
1F	Coastal Beaches	221
1G	Swamp/Marsh	158
1H	Mud Flows	132
2A	Mountain Slopes	105
2B	Alluvial Mountain Valleys	165
2C	Alluvial Fans	155
2D	Alluvial Basins (Internal Drainage)	157
2E	Playa Lakes	139
2F	Swamp/Marsh	146
2G	Coastal Lowlands	215
2Ha	River Alluvium with Overbank Deposits	181
2Hb	River Alluvium without Overbank Deposits	224
2I	Mud Flows	172
2J	Alternating Sandstone and Shale Sequences	120
2K	Continental Deposits	99
3A	Mountain Slopes	92
3B	Alluvial Mountain Valleys	202
3C	Hydraulically Connected Lava Flows	157
3D	Lava Flows Not Connected Hydraulically	143
3E	Alluvial Fans	123
3F	Swamp/Marsh	208
3G	River Alluvium	155
4A	Resistant Ridges	117
4B	Consolidated Sedimentary Rock	108
4C	River Alluvium	176
4D	Alluvium and Dune Sand	131
4E	Swamp/Marsh	213
5A	Ogallala	136
5B	Alluvium	135
5C	Sand Dunes	177
5D	Playa Lakes	139
5E	Braided River Deposits	216
5F	Swamp/Marsh	229
5Ga	River Alluvium with Overbank Deposits	129
5Gb	River Alluvium without Overbank Deposits	149
5H	Alternating Sandstone, Limestone and Shale Sequences	88
6A	Mountain Flanks	132
6B	Alluvial Mountain Valleys	176
6C	Mountain Flanks	126
6Da	Alternating Sandstone, Limestone and Shale — Thin Soil	180
6Dd	Alternating Sand, Limestone and Shale — Deep Regolith	145
6E	Solution Limestone	216
6Fa	River Alluvium with Overbank Deposits	164
6Fb	River Alluvium without Overbank Deposits	209
6G	Braided River Deposits	221
6H	Triassic Basins	135
6I	Swamp/Marsh	165
6J	Metamorphic/Igneous Domes and Fault Blocks	96
6K	Unconsolidated and Semiconsolidated Aquifer	109
7Aa	Glacial Till Over Bedded Sedimentary Rock	125
7Ab	Glacial Till Over Outwash	153
7Ac	Glacial Till Over Solution Limestone	153
7Ad	Glacial Till Over Sandstone	129
7Ae	Glacial Till Over Shale	111
7Ba	Outwash	196
7Bb	Outwash Over Bedded Sedimentary Rocks	182
7Bc	Outwash Over Solution Limestone	206
7C	Moraine	156
7D	Buried Valley	178
7Ea	River Alluvium with Overbank Deposits	157
7Eb	River Alluvium without Overbank Deposits	224
7F	Glacial Lake Deposits	165
7G	Thin Till Over Bedded Sedimentary Rock	143
7H	Beaches, Beach Ridges and Sand Dunes	225
7I	Swamp/Marsh	174
8A	Mountain Slopes	102
8B	Alluvial Mountain Valleys	185
8C	Mountain Flanks	123
8D	Regolith	117
8E	River Alluvium	198
8F	Mountain Crests	113
8G	Swamp/Marsh	141
9A	Mountain Slopes	102
9B	Alluvial Mountain Valley	202
9C	Mountain Flanks	122
9Da	Glacial Till Over Crystalline Bedrock	142
9Db	Glacial Till Over Outwash	161
9E	Outwash	210
9F	Moraine	180
9Ga	River Alluvium with Overbank Deposits	164
9Gb	River Alluvium without Overbank Deposits	213
9H	Swamp/Marsh	141
9I	Bedrock Uplands	158
9J	Glacial Lake/Glacial Marine Deposits	146
9K	Beaches, Beach Ridges and Sand Dunes	199
10Aa	Regional Aquifers	113
10Ab	Unconsolidated and Semiconsolidated Shallow Surficial Aquifer	206
10Ba	River Alluvium with Overbank Deposits	165
10Bb	River Alluvium without Overbank Deposits	220
10C	Swamp	233
11A	Solution Limestone and Shallow Surficial Aquifers	243
11B	Coastal Deposits	224
11C	Swamp	251
11D	Beaches and Bars	225
12A	Mountain Slopes	177
12B	Alluvial Mountain Valleys	192
12C	Volcanic Uplands	174
12D	Coastal Beaches	230
13A	Alluvium	164
13B	Glacial and Glaciolacustrine Deposits of the Interior Valleys	166
13C	Coastal Lowland Deposits	164
13D	Bedrock of the Uplands and Mountains	118

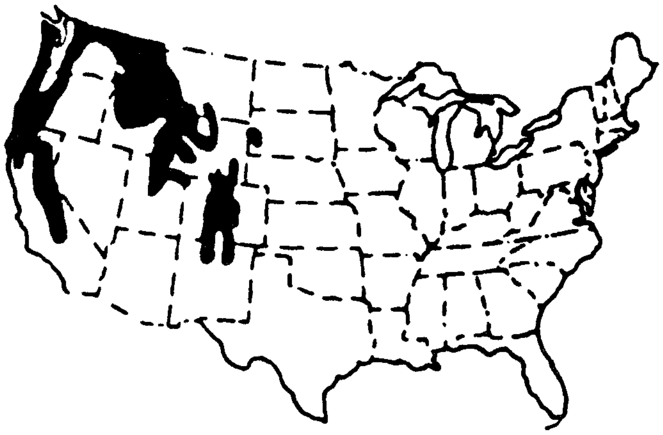
TABLE 39. HYDROGEOLOGIC SETTINGS AND ASSOCIATED PESTICIDE DRASTIC INDEXES SORTED BY RATING

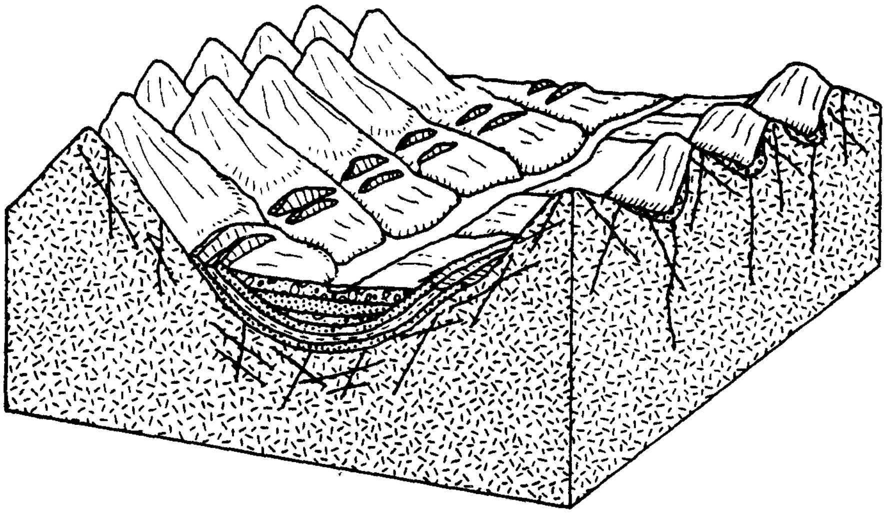
SETTINGS	DESCRIPTIONS	RATING
5H	Alternating Sandstone, Limestone and Shale Sequences	88
1Aa East	Mountain Slopes	91
3A	Mountain Slopes	92
6J	Metamorphic/Igneous Domes and Fault Blocks	96
1Ab West	Mountain Slopes	97
1Ca East	Mountain Flanks	99
2K	Continental Deposits	99
8A	Mountain Slopes	102
9A	Mountain Slopes	102
2A	Mountain Slopes	105
4B	Consolidated Sedimentary Rock	108
6K	Unconsolidated and Semiconsolidated Aquifer	109
7Ae	Glacial Till Over Shale	111
10Aa	Regional Aquifers	113
8F	Mountain Crests	113
8D	Regolith	117
4A	Resistant Ridges	117
13D	Bedrock of the Uplands and Mountains	118
2J	Alternating Sandstone and Shale Sequences	120
9C	Mountain Flanks	122
1Cb West	Mountain Flanks	122
8C	Mountain Flanks	123
3E	Alluvial Fans	123
7Aa	Glacial Till Over Bedded Sedimentary Rock	125
6C	Mountain Flanks	126
5Ga	River Alluvium with Overbank Deposits	129
7Ad	Glacial Till Over Sandstone	129
4D	Alluvium and Dune Sand	131
1H	Mud Flows	132
6A	Mountain Flanks	132
6H	Triassic Basins	135
5B	Alluvium	135
5A	Ogallala	136
2E	Playa Lakes	139
5D	Playa Lakes	139
9H	Swamp/Marsh	141
8G	Swamp/Marsh	141
9Da	Glacial Till Over Crystalline Bedrock	142
7G	Thin Till Over Bedded Sedimentary Rock	143
3D	Lava Flows Not Connected Hydraulically	143
6Dd	Alternating Sand, Limestone and Shale — Deep Regolith	145
2F	Swamp/Marsh	146
9J	Glacial Lake/Glacial Marine Deposits	146
5Gb	River Alluvium without overbank deposits	149
7Ab	Glacial Till Over Outwash	153
7Ac	Glacial Till Over Solution Limestone	153
2C	Alluvial Fans	155
3G	River Alluvium	155
7C	Moraine	156
3C	Hydraulically Connected Lava Flows	157
7Ea	River Alluvium with Overbank Deposits	157
2D	Alluvial Basins (Internal Drainage)	157
1G	Swamp/Marsh	158
9I	Bedrock Uplands	158
9Db	Glacial Till Over Outwash Deposits	161
6Fa	River Alluvium with Overbank	164
13A	Alluvium	164
9Ga	River Alluvium with Overbank Deposits	164
13C	Coastal Lowland Deposits	164
10Ba	River Alluvium with Overbank Deposit	165
7F	Glacial Lake Deposits	165
6I	Swamp/Marsh	165
2B	Alluvial Mountain Valleys	165
1Ba East	Alluvial Mountain Valleys	166
13B	Glacial and Glaciolacustrine Deposits of the Interior Valleys	166
2I	Mud Flows	172
7I	Swamp/Marsh	174
12C	Volcanic Uplands	174
6B	Alluvial Mountain Valleys	176
4C	River Alluvium	176
12A	Mountain Slopes	177
5C	Sand Dunes	177
7D	Buried Valley	178
9F	Moraine	180
6Da	Alternating Sandstone, Limestone and Shale — Thin Soil	180
2Ha	River Alluvium with Overbank Deposits	181
7Bb	Outwash over Bedded Sedimentary	182
1Bb West	Alluvial Mountain Valleys	184
8B	Alluvial Mountain Valleys	185
12B	Alluvial Mountain Valleys	192
1Ea East	Wide Alluvial Valleys (External Drainage)	192
7Ba	Outwash	196
8E	River Alluvium	198
9K	Beaches, Beach Ridges and Sand Dunes	199
3B	Alluvial Mountain Valleys	202
9B	Alluvial Mountain Valleys	202
7Bc	Outwash Over Solution Limestone	206
10Ab	Unconsolidated and Semiconsolidated Shallow Surficial Aquifer	206
3F	Swamp/Marsh	208
6Fb	River Alluvium Without Overbank Deposits	209
9E	Outwash	210
9Gb	River Alluvium Without Overbank Deposits	213
4E	Swamp/Marsh	213
1D	Glacial Mountain Valleys	214
1Eb West	Wide Alluvial Valleys (External Drainage)	214
2G	Coastal Lowlands	215
5E	Braided River Deposits	216
6E	Solution Limestone	216
10Bb	River Alluvium Without Overbank Deposits	220
6G	Braided River Deposits	221
1F	Coastal Beaches	221
2Hb	River Alluvium Without Overbank Deposits	224
7Eb	River Alluvium Without Overbank Deposits	224
11B	Coastal Deposits	224
11D	Beaches and Bars	225
7H	Beaches, Beach Ridges and Sand Dunes	225
5F	Swamp/Marsh	229
12D	Coastal Beaches	230
10C	Swamp	233
11A	Solution Limestone and Shallow Surficial Aquifers	243
11C	Swamp	251

TABLE 40. HYDROGEOLOGIC SETTINGS AND ASSOCIATED PESTICIDE DRASTIC INDEXES SORTED BY SETTING TITLE

SETTINGS	DESCRIPTIONS	RATING
2D	Alluvial Basins (Internal Drainage)	157
2C	Alluvial Fans	155
3E	Alluvial Fans	123
9B	Alluvial Mountain Valley	202
8B	Alluvial Mountain Valleys	185
12B	Alluvial Mountain Valleys	192
1Bb West	Alluvial Mountain Valleys	184
2B	Alluvial Mountain Valleys	165
6B	Alluvial Mountain Valleys	176
3B	Alluvial Mountain Valleys	202
1Ba East	Alluvial Mountain Valleys	166
13A	Alluvium	164
5B	Alluvium	135
4D	Alluvium and Dune Sand	131
6Dd	Alternating Sand, Limestone and Shale — Deep Regolith	145
2J	Alternating Sandstone and Shale Sequences	120
6Da	Alternating Sandstone, Limestone and Shale — Thin Soil	180
5H	Alternating Sandstone, Limestone and Shale Sequences	88
11D	Beaches and Bars	225
7H	Beaches, Beach Ridges and Sand Dunes	225
9K	Beaches, Beach Ridges and Sand Dunes	199
9I	Bedrock Uplands	158
13D	Bedrock of the Uplands and Mountains	118
6G	Braided River Deposits	221
5E	Braided River Deposits	216
7D	Buried Valley	178
12D	Coastal Beaches	230
1F	Coastal Beaches	221
11B	Coastal Deposits	224
13C	Coastal Lowland Deposits	164
2G	Coastal Lowlands	215
4B	Consolidated Sedimentary Rock	108
2K	Continental Deposits	99
7F	Glacial Lake Deposits	165
9J	Glacial Lake/Glacial Marine Deposits	146
1D	Glacial Mountain Valleys	214
7Aa	Glacial Till Over Bedded Sedimentary Rock	125
9Da	Glacial Till Over Crystalline Bedrock	142
9Db	Glacial Till Over Outwash	161
7Ab	Glacial Till Over Outwash	153
7Ad	Glacial Till Over Sandstone	129
7Ae	Glacial Till Over Shale	111
7Ac	Glacial Till Over Solution Limestone	153
13B	Glacial and Glaciolacustrine Deposits of the Interior Valleys	166
3C	Hydraulically Connected Lava Flows	157
3D	Lava Flows Not Connected Hydraulically	143
6J	Metamorphic/Igneous Domes and Fault Blocks	96
7C	Moraine	156
9F	Moraine	180
8F	Mountain Crests	113
6C	Mountain Flanks	126
8C	Mountain Flanks	123
1Cb West	Mountain Flanks	122
1Ca East	Mountain Flanks	99
9C	Mountain Flanks	122
6A	Mountain Flanks	132
3A	Mountain Slopes	92
9A	Mountain Slopes	102
1Aa East	Mountain Slopes	91
2A	Mountain Slopes	105
1Ab West	Mountain Slopes	97
12A	Mountain Slopes	177
8A	Mountain Slopes	102
2I	Mud Flows	172
1H	Mud Flows	132
5A	Ogallala	136
9E	Outwash	210
7Ba	Outwash	196
7Bb	Outwash Over Bedded Sedimentary Rock	182
7Bc	Outwash Over Solution Limestone	206
2E	Playa Lakes	139
5D	Playa Lakes	139
10Aa	Regional Aquifers	113
8D	Regolith	174
4A	Resistant Ridges	117
8E	River Alluvium	198
3G	River Alluvium	147
4C	River Alluvium	176
6Fa	River Alluvium with Overbank Deposits	164
9Ga	River Alluvium with Overbank Deposits	164
7Ea	River Alluvium with Overbank Deposits	157
10Ba	River Alluvium with Overbank Deposits	165
5Ga	River Alluvium with Overbank Deposits	129
2Ha	River Alluvium with Overbank Deposits	181
6Fb	River Alluvium without Overbank Deposits	209
9Gb	River Alluvium without Overbank Deposits	213
7Eb	River Alluvium without Overbank Deposits	224
10Bb	River Alluvium without Overbank Deposits	220
2Hb	River Alluvium without Overbank Deposits	224
5Gb	River Alluvium without Overbank Deposits	149
5C	Sand Dunes	177
6E	Solution Limestone	216
11A	Solution Limestone and Shallow Surficial Aquifers	243
10C	Swamp	233
11C	Swamp	251
6I	Swamp/Marsh	165
5F	Swamp/Marsh	229
1G	Swamp/Marsh	158
3F	Swamp/Marsh	208
8G	Swamp/Marsh	141
2F	Swamp/Marsh	146
4E	Swamp/Marsh	213
9H	Swamp/Marsh	141
7I	Swamp/Marsh	117
7G	Thin Till Over Bedded Sedimentary Rock	143
6H	Triassic Basins	135
10Ab	Unconsolidated and Semiconsolidated Shallow Surficial Aquifer	206
6K	Unconsolidated and Semiconsolidated Aquifer	109
12C	Volcanic Uplands	174
1Eb West	Wide Alluvial Valleys (External Drainage)	214
1Ea East	Wide Alluvial Valleys (External Drainage)	192

1. WESTERN MOUNTAIN RANGES GROUND-WATER REGION





1Aa East	Mountain Slopes
1Ab West	Mountain Slopes
1Ba East	Alluvial Mountain Valleys
1Bb West	Alluvial Mountain Valleys
1Ca East	Mountain Flanks
1Cb West	Mountain Flanks
1D	Glacial Mountain Valleys
1Ea East	Wide Alluvial Valleys (External Drainage)
1Eb West	Wide Alluvial Valleys (External Drainage)
1F	Coastal Beaches
1G	Swamp/Marsh
1H	Mud Flows

1. WESTERN MOUNTAIN RANGES

(Mountains with thin soils over fractured rocks, alternating with narrow alluvial and, in part, glaciated valleys)

The Western Mountain Ranges encompass three areas totaling 708,000 km2. The largest area extends in an arc from the Sierra Nevada in California, north through the Coast Ranges and Cascade Mountains in Oregon and Washington, and east and south through the Rocky Mountains in Idaho and Montana into the Bighorn Mountains in Wyoming and the Wasatch and Uinta Mountains in Utah. The second area includes the southern Rocky Mountains, which extend from the Laramie Range in southeastern Wyoming through central Colorado into the Sangre de Cristo Range in northern New Mexico. The smallest area includes the part of the Black Hills in South Dakota in which Precambrian rocks are exposed. Summits in the Rocky Mountains and Sierra Nevada exceed 3,500 m. The general appearance of the Western Mountains Ranges, with the exception of the Black Hills, is tall, massive mountains alternating with relatively narrow, steep-sided valleys. The summits and sides of the mountains in much of the region have been carved into distinctive shapes by mountain glaciers. The ranges that comprise the southern Rocky Mountains are separated by major lowlands that include North Park, Middle Park, South Park, and the Wet Mountain Valley. These lowlands occupy downfolded or down-faulted structural troughs as much as 70 km wide and 160 km long. The mountains in the Black Hills are lower in altitude than most of the mountains in other parts of the region.

As would be expected in such a large region, both the origin of the mountains and the rocks that form them are complex. Most of the mountain ranges are underlain by granitic and metamorphic rocks flanked by consolidated sedimentary rocks of Paleozoic to Cenozoic age. The other ranges, including the San Juan Mountains in southwestern Colorado and the Cascade Mountains in Washington and Oregon, are underlain by lavas and other igneous rocks.

The summits and slopes of most of the mountains consist of bedrock exposures or of bedrock covered by a layer of boulders and other rock fragments produced by frost action and other weathering processes acting on the bedrock. This layer is generally only a few meters thick on the upper slopes but forms a relatively thick apron along the base of the mountains. The narrow valleys are underlain by relatively thin, coarse, bouldery alluvium washed from the higher slopes. The large synclinal valleys and those that occupy downfaulted structural troughs are underlain by moderately thick deposits of coarse-grained alluvium transported by streams from the adjacent mountains.

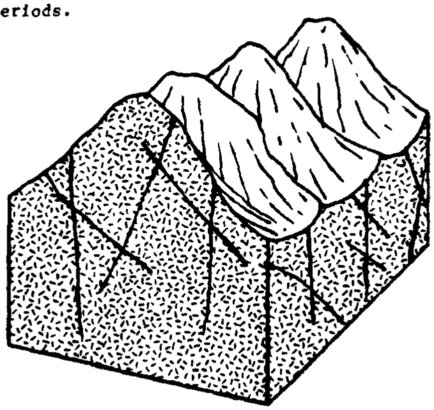
The Western Mountain Ranges and the mountain ranges in adjacent regions are the principal sources of water supplies developed at lower altitudes in the western half of the conterminous United States. As McGuinness (1963) noted, the mountains of the west are moist "islands" in a sea of desert or semidesert that covers the western half of the Nation. The mountains force moisture-laden air masses moving eastward from the Pacific to rise to higher and cooler altitudes. As the air cools, moisture condenses into clouds and precipitates. The heaviest precipitation falls on the western slopes; thus, these slopes are the major source of runoff and are also the most densely vegetated. Much of the precipitation falls as snow during the winter, and its slow melting, starting at the lower altitudes in early spring, maintains streamflow at large rates until late June or early July. Small glaciers occur in the higher mountain ranges, especially in the northern Rocky Mountains, the Cascades, and the Sierra Nevada; locally, as in northern Washington they also provide significant sources of summer runoff.

Melting snow and rainfall at the higher altitudes in the region provide abundant water for ground-water recharge. However, the thin soils and bedrock fractures in areas underlain by crystalline rocks fill quickly, and the remaining water runs off overland to streams. Because of their small storage capacity, the underground openings provide limited base runoff to the streams, which at the higher altitudes flow only during rains or snowmelt periods. Thus, at the higher altitudes in this region underlain by crystalline rocks, relatively little opportunity exists for development of ground-water supplies. The best opportunities exist in valleys that contain at least moderate thicknesses of saturated alluvium or in areas underlain by permeable sedimentary or volcanic rocks. Ground-water supplies in the valleys are obtained both from wells drawing from the alluvium and from wells drawing from the underlying rocks. The yields of wells in crystalline bedrock and wells drawing water from small, thin deposits of alluvium are generally adequate only for domestic and stock needs. Large yields can be obtained from the alluvial deposits that overlie the major lowlands and from wells completed in permeable sedimentary or volcanic rocks.

WESTERN MOUNTAIN RANGES

(1Aa) Mountain Slopes - East

This hydrogeologic setting is characterized by steep slopes on the sides of mountains, a thin soil cover and highly fractured bedrock. Ground water is obtained primarily from the fractures in the bedrock which may be of sedimentary, metamorphic or igneous origin. The fractures provide localized sources of ground water and well yields are typically limited even though the hydraulic conductivity is often high because of the fractures. Due to the steep slopes, thin soil and small storage capacity of the fractures, runoff is significant. Thicker weathered zones (soils) may develop locally particularly on talus slopes with local perched zones common. These eastern facing slopes are located in the rain shadow of the mountains and only limited rainfall is derived from the moisture laden prevailing westerly winds, thus ground water recharge rarely exceeds 1 inch/year. Ground water levels are extremely variable but are typically deep. Most of these areas are water deficient on an annual basis. The migration of pollutants introduced at the surface will be dependent on the current climatic conditions; pollutants will tend to infiltrate easier and further during wet periods as opposed to dry periods.



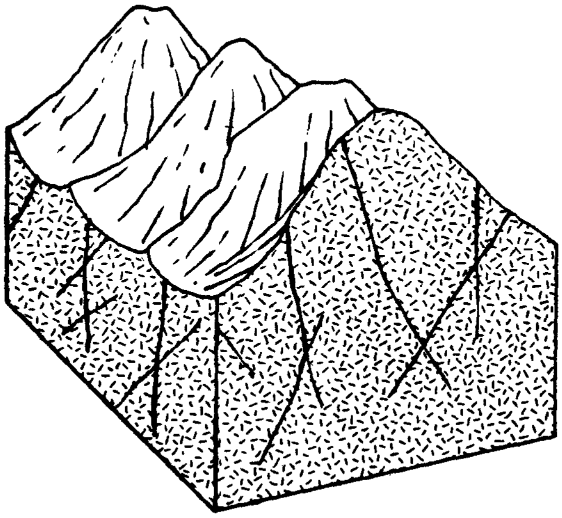
SETTING 1 Aa Mountain Slopes East		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Thin or Absent	2	10	20
Topography	18+%	1	1	1
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	65

SETTING 1 Aa Mountain Slopes East		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Thin or Absent	5	10	50
Topography	18+%	3	1	3
Impact Vadose Zone	Metamorphic/Igneous	4	4	16
Hydraulic Conductivity	100-300	2	2	4
			Pesticide Drastic Index	91

WESTERN MOUNTAIN RANGES

(1Ab) Mountain Slopes - West

This setting is similar to (1Aa) Mountain Slopes-East except that ground water levels are typically more shallow and precipitation greatly exceeds the amount which falls on the eastern slopes. Even though rainfall is more abundant, recharge is still low due to the steepness of the slopes and density of the underlying bedrock and may only exceed 2 inches/year in places where precipitation is very high and soil cover is unusually favorable. Due to increased precipitation, pollutants may tend to migrate to the water table more rapidly, but be more diluted, than on the comparable eastern slopes.



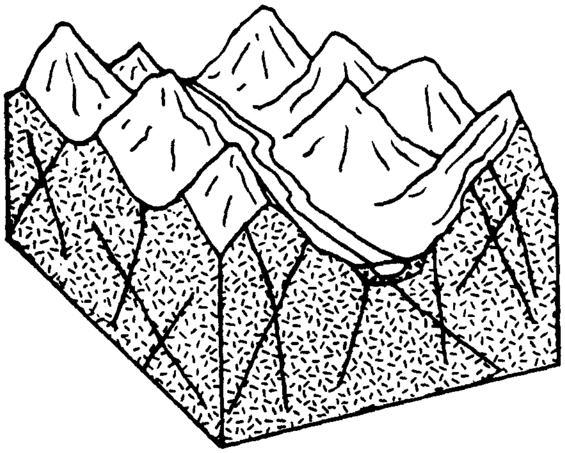
SETTING 1 Ab Mountain Slopes West		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Thin or Absent	2	10	20
Topography	18+%	1	1	1
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	70

SETTING 1 Ab Mountain Slopes West		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Thin or Absent	5	10	50
Topography	18+%	3	1	3
Impact Vadose Zone	Metamorphic/Igneous	4	4	16
Hydraulic Conductivity	100-300	2	2	4
			Pesticide Drastic Index	97

WESTERN MOUNTAIN RANGES

(1Ba) Alluvial Mountain Valleys - East

This hydrogeologic setting of eastward facing interior valleys is characterized by thin, bouldery alluvium which overlies fractured bedrock of sedimentary, metamorphic or igneous origin. The alluvium, which is derived from the surrounding steep slopes serves as a localized source of water. Where soil cover exists, it typically is gravel-sized and offers little protection from pollution. Water levels are typically moderately deep because of the lack of precipitation on the eastern slopes and the low net recharge. Ground water is obtained from the coarser-grained deposits within the valley, but these deposits also have a finer-grained fraction which can influence water movement. Ground water may also be obtained from the fractures in the underlying bedrock which are typically in direct hydraulic connection with the overlying alluvium. Since these valleys are usually structurally controlled, there is the possibility that any pollutants introduced at the surface may migrate into the fractures beneath the alluvium and disperse rapidly from the site of incidence.



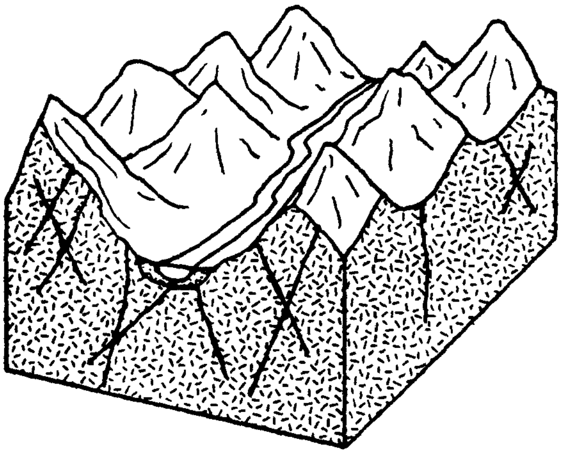
SETTING 1 Ba Alluvial Mountain Valleys East		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Gravel	2	10	20
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	128

SETTING 1 Ba Alluvial Mountain Valleys East		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Gravel	5	10	50
Topography	2-6%	3	9	27
Impact Vadose Zone	Sand and Gravel	4	6	32
Hydraulic Conductivity	100-300	2	2	4
			Pesticide Drastic Index	166

WESTERN MOUNTAIN RANGES

(1Bb) Alluvial Mountain Valleys - West

This setting, which includes coastal valleys and westward-sloping interior valleys, is similar to (1Ba) Narrow Alluvial Valleys-East. Water levels are typically shallower due to higher amounts of precipitation and subsequently greater ground-water recharge. Soils tend to be deeper with better developed soil profiles. Bedrock weathering is usually deeper, with increased mass wasting due to freeze/thaw cycles that may occur in the higher valleys of some areas. The migration of pollutants introduced at the surface will, in most cases, be predictably downgradient in the relatively short, straight, narrow, well-defined valleys.



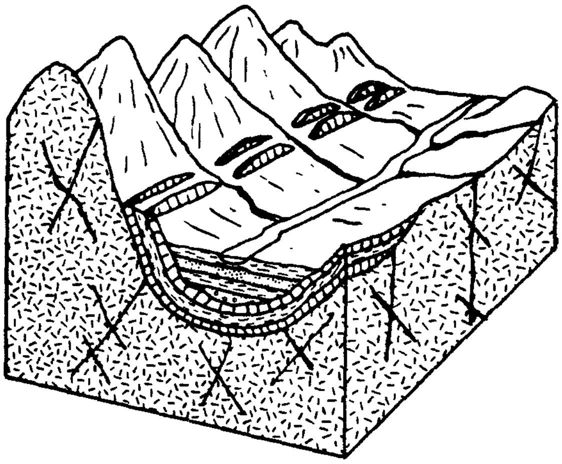
SETTING 1 Bb Alluvial Mountain Valleys West		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Gravel	2	10	20
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	146

SETTING 1 Bb Alluvial Mountain Valleys West		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Gravel	5	10	50
Topography	2-6%	3	9	27
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	100-300	2	2	4
			Pesticide Drastic Index	184

WESTERN MOUNTAIN RANGES

(1Ca) Mountain Flanks - East

This hydrogeologic setting is characterized by moderate to steep topographic relief and dipping fractured consolidated sedimentary rocks, which dip toward and underlie the adjacent wide alluvial valleys. Soil cover is usually thicker than on the upper mountain slopes and typically has weathered to a sandy loam. Alluvium and/or talus deposits are not included in this setting. These sedimentary rocks, when fractured, typically have hydraulic conductivities similar to the fractured bedrock on the mountain slopes. Depth to the water table varies, but is typically deep due to lack of precipitation and moderate topographic relief, and net recharge is very low. Pollutants that may be introduced at the surface will tend to migrate most rapidly along dipping bedding planes, and through fractures.



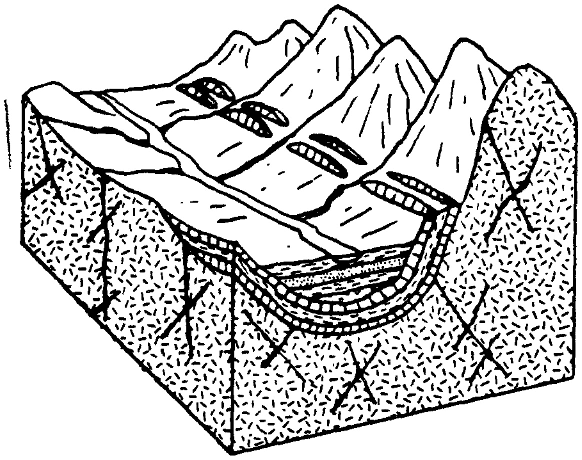
SETTING 1 Ca Mountain Flanks East		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Sandy Loam	2	6	12
Topography	12-18%	1	3	3
Impact Vadose Zone	Bedded LS, SS, SH	5	6	30
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	83

SETTING 1 Ca Mountain Flanks East		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Sandy Loam	5	6	30
Topography	12-18%	3	3	9
Impact Vadose Zone	Bedded LS, SS, SH	4	6	24
Hydraulic Conductivity	100-300	2	2	4
			Pesticide Drastic Index	99

WESTERN MOUNTAIN RANGES

(1Cb) Mountain Flanks - West

This setting is similar to (1Ca) Mountain Flanks-East. Ground water levels, however, are typically not quite as deep and ground-water recharge is greater due to the greater amount of precipitation on the western slopes. Soil depths are often greater, with more developed soil profiles. These soils are characterised by higher clay and loam content than those that occur on the eastern slopes. Analagous to the eastern flanks, any pollutants that are introduced will tend to migrate along bedding planes and fractures.



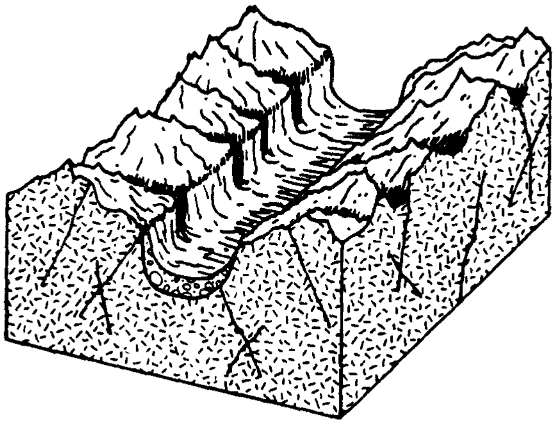
SETTING 1 Cb Mountain Flanks West		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	2-4	4	3	12
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Sandy Loam	2	6	12
Topography	12-18%	1	3	3
Impact Vadose Zone	Bedded LS, SS, SH	5	6	30
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	106

SETTING 1 Cb Mountain Flanks West		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	2-4	4	3	12
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Sandy Loam	5	6	30
Topography	12-18%	3	3	9
Impact Vadose Zone	Bedded LS, SS, SH	4	6	24
Hydraulic Conductivity	100-300	2	2	4
			Pesticide Drastic Index	122

WESTERN MOUNTAIN RANGES

(1D) Glaciated Mountain Valleys

This hydrogeologic setting is characterized by moderate topographic relief, and very coarse-grained deposits associated with the near mountain glacial features, such as cirques and paternoster lakes. These deposits may serve as localized sources of water. Water tables are typically shallow with coarse-grained deposits present at the surface. Mountain glaciers may be present in some areas. Although precipitation may not be great, recharge is relatively high when compared to other settings in the region because of the large volumes of water produced from the glaciers during the summer melting cycle. These recent glacial deposits are underlain by fractured bedrock of igneous or metamorphic origin all of which are in direct hydraulic connection with the overlying deposits. The fractured bedrock may also serve as a local source of ground water.



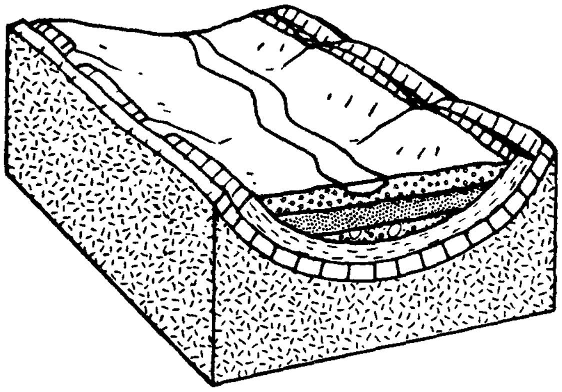
SETTING 1 D Glacial Mountain Valleys		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Gravel	2	10	20
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	180

SETTING 1 D Glacial Mountain Valleys		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Gravel	5	10	50
Topography	2-6%	3	9	27
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	214

WESTERN MOUNTAIN RANGES

(1Ea) Wide Alluvial Valleys (External Drainage) - East

This hydrogeologic setting is characterized by low relief and moderately thick deposits of coarse-grained alluvium deposited by water. It is similar to (1Ba) Narrow Alluvial Mountain Valleys except that the valleys are better developed and the streams which occupy their channels have a shallower gradient. Typically the alluvial deposits are finer-grained and thicker than the narrow alluvial valleys. The alluvium in this setting serves as the major source of ground water and is often capable of supplying large quantities of water. Surficial deposits are usually coarse-grained and water levels are relatively shallow even through precipitation and net recharge are low. The alluvium is underlain by layers of permeable sedimentary rock which receive their primary source of recharge from the adjacent mountain flanks. The sedimentary sequence is underlain by fractured bedrock of igneous or metamorphic origin. Ground water may also be obtained from the permeable sedimentary rocks.



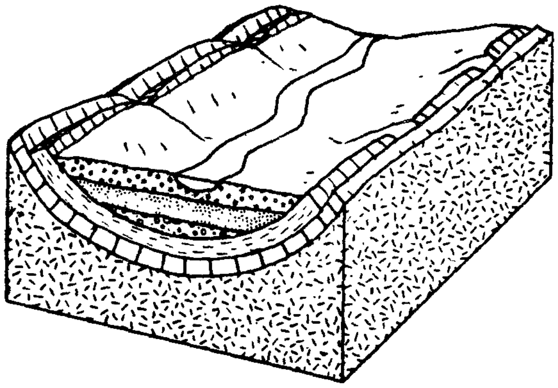
SETTING 1 Ea Wide Alluvial Valleys (External Drainage) East		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water Table	15-30	5	7	35
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Gravel	2	10	20
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	158

SETTING 1 Ea Wide Alluvial Valleys (External Drainage, East		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water Table	15-30	5	7	35
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Gravel	5	10	50
Topography	2-6%	1	9	27
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	192

WESTERN MOUNTAIN RANGES

(1Eb) Wide Alluvial Valleys (External Drainage) - West

This setting is similar to (1Ea) Wide Alluvial Valleys (External Drainage) - East except that water levels are typically shallow because of higher precipitation and greater ground-water recharge. Soils tend to be better-developed and thicker in the areas bordering the mountain flanks, however, in the valley lowlands, gravelly soils predominate. Pollutants introduced at the surface in these wide alluvial valleys tend to migrate rapidly in the coarser-grained deposits and travel into and along fracture planes.



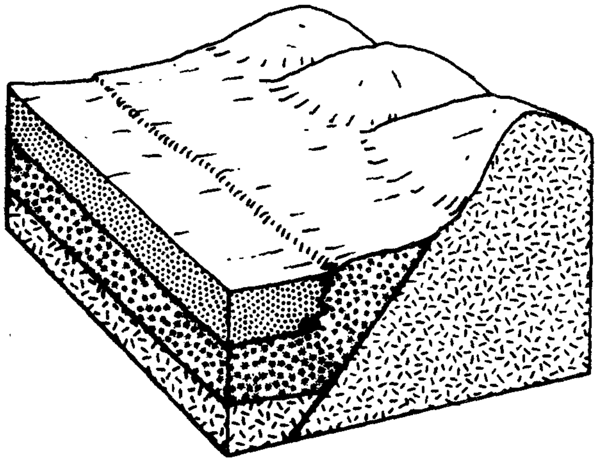
SETTING 1 Eb Wide Alluvial Valleys (External Drainage) West		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water Table	5-15	5	9	45
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Gravel	2	10	20
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	160

SETTING 1 Eb Wide Alluvial Valleys (External Drainage West		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water Table	5-15	5	9	45
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Gravel	5	10	50
Topography	2-6%	3	9	27
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	214

WESTERN MOUNTAIN RANGES

(1F) Coastal Beaches

This hydrogeologic setting is characterized by low topographic relief, near sea level elevation and sandy surface soils. These areas have very high potential infiltration rates. These areas are commonly ground-water discharge areas, which, when utilized for fresh water supply, are quickly endangered by salt-water intrusion. Due to their very permeable nature and thin vadose zone, they are very vulnerable to pollution. Under natural gradients, pollution of this zone is usually discharged to the sea. However, with inland pumping, flow is rapidly reversed to the pumping center.



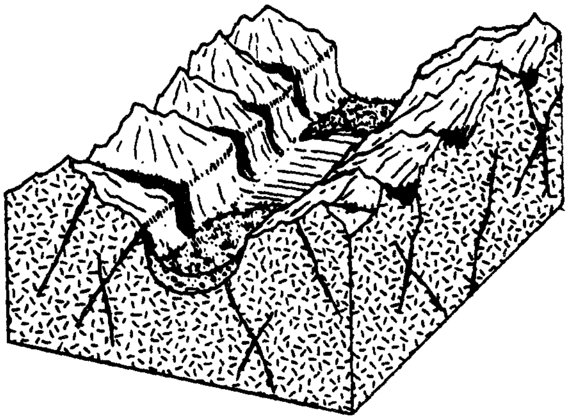
SETTING 1 F Coastal Beaches		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	196

SETTING 1 F Coastal Beaches		Pesticide		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	5	9	45
Topography	0-2%	3	10	30
Impact Vadose Zone	Sand and Gravel	4	8	24
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	221

WESTERN MOUNTAIN RANGES

(1G) Swamp/Marsh

This hydrogeologic setting is characterized by low topographic relief, very high water levels and high-organic content silts and clays along the coast. In the interior alluvial valleys, this setting may also contain evaporitic deposits and saline-tolerant vegetation. In fresh-water environments, these areas are typified by poorly drained soils with high water tables. Recharge is potentially high and is dependant primarily on precipitation. The swamp deposits very rarely serve as significant aquifers; water is usually obtained from the underlying bedrock. However, the swamp deposits may serve as a source of recharge to the aquifer.



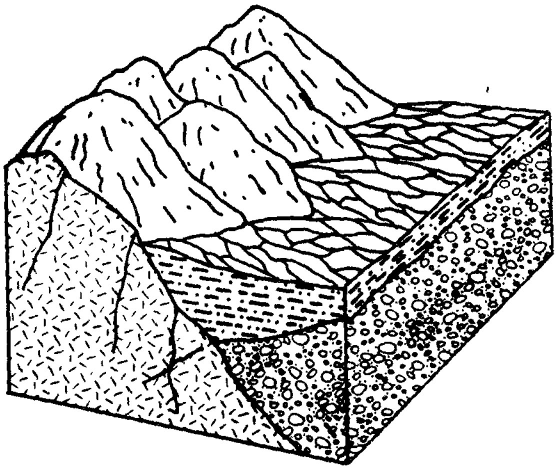
SETTING 1 G Swamp/Marsh		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	4-7	4	6	24
Aquifer Media	Bedded SS, LS SH Sequences	3	6	18
Soil Media	Muck	2	2	4
Topography	0-2	1	10	10
Impact Vadose Zone	S & G w/sig. Silt and Clay	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	139

SETTING 1 G Swamp/Marsh		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	4-7	4	6	24
Aquifer Media	Bedded SS, LS SH Sequences	3	6	18
Soil Media	Muck	5	2	10
Topography	0-2	3	10	30
Impact Vadose Zone	S & G w/sig. Silt and Clay	4	6	24
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	158

WESTERN MOUNTAIN RANGES REGION

(1H) Mud Flows

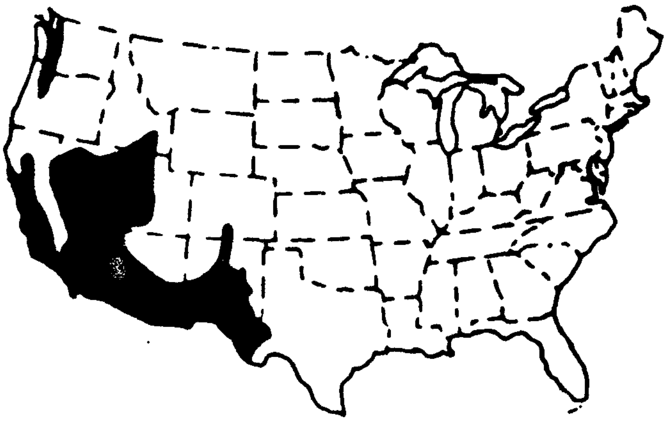
This hydrogeologic setting is characterized by low to moderate topography and variable thicknesses of unsorted mixtures of boulders and pebbles in a fine-grained matrix. The deposits originated from the adjacent mountain slopes and tend to be thicker toward the mountains and thinner in the valleys with no well-developed drainage pattern. The mud flows are typically underlain by glacial and alluvial deposits which serve as the major aquifer. Recharge is moderate to low because the mud flows restrict infiltration and may even serve to confine the underlying aquifer.

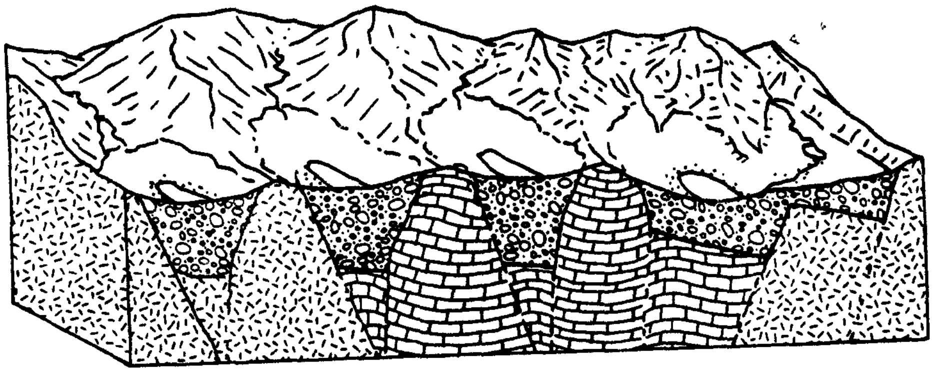


SETTING 1 H Mud Flows		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	2	4	8
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	130

SETTING 1 H Mud Flows		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	5	4	20
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	4	6	24
Hydraulic Conductivity	300-700	2	4	8
			Pesticide Drastic Index	132

2. ALLUVIAL BASINS GROUND-WATER REGION





2A	Mountain Slopes
2B	Alluvial Mountain Valleys
2C	Alluvial Fans
2D	Alluvial Basins (Internal Drainage)
2E	Playa Lakes
2F	Swamp/Marsh
2G	Coastal Lowlands
2Ha	River Alluvium With Overbank Deposits
2Hb	River Alluvium Without Overbank Deposits
2I	Mud Flows
2J	Alternating Sandstone and Shale Sequences
2K	Continental Deposits

2. ALLUVIAL BASINS

(Thick alluvial deposits in basins and valleys bordered by mountains and locally of glacial origin)

The Alluvial Basins region occupies a discontinuous area of 1,025,000 km2 extending from the Puget Sound-Williamette Valley area of Washington and Oregon to west Texas. The region consists of an irregular alternation of basins or valleys and mountain ranges. From the standpoint of topography, it is useful to contrast this region with the Western Mountain Ranges. In the Western Mountain ranges the high areas, the mountains, are the dominant feature. In the Alluvial Basins region the low areas, the basins and valleys, are the dominant feature. The principal exception to this generalization is the Coast Ranges of southern California which, though included in this region, topographically more closely resemble the Western Mountain Ranges.

Most of the Nevada and all of the Utah parts of this region are an area of internal drainage referred to as the Great Basin. No surface or subsurface flow leaves this part of the region, and all water reaching it from adjacent areas and from precipitation is returned to the atmosphere by evaporation or by the transpiration of plants.

The basins and valleys are diverse in size, shape, and altitude. They range in altitude from about 85 m below sea level in Death Valley in California to 2,000 m above sea level in the San Luis Valley in Colorado. The basins range in size from a few hundred meters in width and a kilometer or two in length to, for the Central Valley of California, as much as 80 km in width and 650 km in length. The crests of the mountains are commonly 1,000 to 1,500 m above the adjacent valley floors.

The surrounding mountains, and the bedrock beneath the basins, consist of granite and metamorphic rocks of Precambrian to Tertiary age and consolidated sedimentary rocks of Paleozoic to Cenozoic age. The rocks are broken along fractures and faults that may serve as water-bearing openings. However, the openings in the granitic and metamorphic rocks in the mountainous area have a relatively small capacity to store and to transmit ground water.

The dominant element in the hydrology of the region is the thick (several hundred to several thousand meters) layer of generally unconsolidated alluvial material that partially fills the basins. Except for the part of the region in Washington and Oregon, the material was derived from erosion of the adjacent mountains and was transported down steep-gradient streams into the basins, where it was deposited as alluvial fans. Generally, the coarsest material in an alluvial fan occurs at its apex, adjacent to the mountains; the material gets progressively finer toward the center of the basins. In time, the fans formed by adjacent streams coalesced to form a continuous and thick deposit of alluvium that slopes gently from the mountains toward the center of the basins. These alluvial-fan deposits are overlain by or grade into fine-grained flood plain, lake, or playa deposits in the central part of most basins. The fine-grained deposits are especially suited to large-scale cultivation.

The Puget Sound and Willamette Valley areas differ geologically from the remainder of the region. The Puget Sound area is underlain by thick and very permeable deposits of gravel and sand laid down by streams of glacial meltwater derived from ice tongues that invaded the area from the north during the Pleistocene. The gravel and sand are interbedded with clay in parts of the area. The Willamette Valley is mostly underlain by interbedded sand, silt and clay deposited on floodplains by the Willamette River and other streams.

The Alluvial Basins region is the driest area in the United States, with large parts of it being classified as semiarid and arid. Annual precipitation in the valleys in Nevada and Arizona ranges from about 100 to 400 mm. However, in the mountainous areas throughout the region, in the northern part of the Central Valley of California, and in the Washington-Oregon area, annual precipitation ranges from about 400 mm to more than 800 mm. The region also receives runoff from streams that originate in the mountains of the Western Mountain Ranges region.

Because of the very thin cover of unconsolidated material on the mountains in the Alluvial Basins region, precipitation runs off rapidly down the valleys and out onto the fans where it infiltrates into the alluvium. The water moves through the sand and gravel layers toward the centers of the basins. The centers of many basins consist of flat-floored, vegetation-free areas onto which ground water may discharge and on which overland runoff may collect during intense storms. The water that collects in these areas, which are called playas, evaporates relatively quickly, leaving both a thin deposit of clay and other sediment transported by overland runoff and a crust consisting of the soluble salts that were dissolved in the water.

Studies in the region have shown that the hydrology of the alluvial basins is more complex than that described in the preceding paragraph, which applies only to what has been described as "undrained closed basins." Water may move through permeable bedrock from one basin to another, arriving, ultimately, at a large playa referred to as a "sink" into the ground, as the name might imply, but by evaporating, as in other playas. In those parts of the Alluvial Basin region drained by perennial streams, including the Puget Sound-Willamette Valley area, the Central Valley of California, and some of the valleys in Arizona and New Mexico, ground water discharges to the streams from the alluvial deposits. However, before entering the streams, water may move down some valleys through the alluvial deposits for tens of kilometers. A reversal of this situation occurs along the lower Colorado River and at the upstream end of the valleys of some of the other perennial streams; in these areas, water moves from the streams into the alluvium to supply the needs of the adjacent vegetated zones.

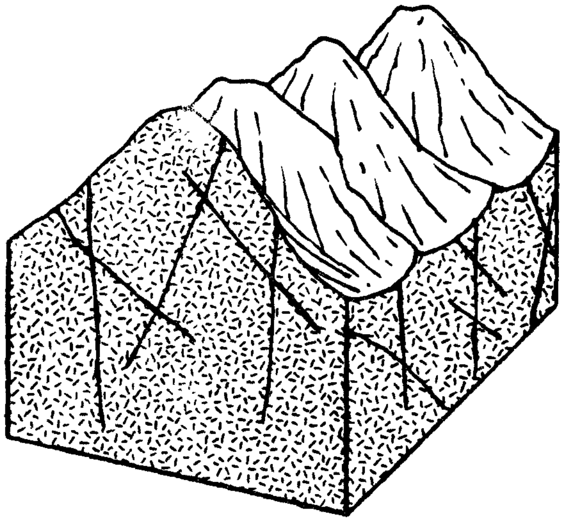
Ground water is the major source of water in the Alluvial Basins region. Many of the valleys in this region have been developed for agriculture. Because of the dry climate, agriculture requires intensive irrigation. In the part of this region drained by the Colorado River, ground water used for irrigation in 1975 amounted to about 6 billion cubic meters (4,864,000 acre-feet). Most of the ground water is obtained from wells drawing from the sand and gravel deposits in the valley alluvium. These deposits are interbedded with finer grained layers of silt and clay that are also saturated with water. When hydraulic heads in the sand and gravel layers are lowered by withdrawals, the water in the silt and clay begins to move slowly into the sand and gravel. The movement, which in some areas takes decades to become significant, is accompanied by compaction of the silt and clay and subsidence of the land surface. Subsidence is most severe in parts of the Central Valley, where it exceeds 9 m in one area, and in southern Arizona, where subsidence of more than 4 m has been observed.

In both the Alluvial Basins and the Colorado Plateau regions, large volumes of water are transpired by phreatophytes (water-loving plants) of small economic value that live along streams and in other wet areas. In an effort to increase the amount of water available for irrigation and other uses, numerous studies have been made to determine the volumes of water used by phreatophytes and to devise means to control them. A few small control efforts have been made, but none have proven economically effective.

ALLUVIAL BASINS

(2A) Mountain Slopes

This hydrogeologic setting is characterized by steep slopes on the side of mountains, a thin soil cover and highly fractured bedrock. Ground water is obtained primarily from the fractures in the bedrock which may be of sedimentary, metamorphic or igneous origin. The fractures provide only localized sources of ground water and well yields are typically limited even though the hydraulic conductivity may be high because of the fractures. Due to the steep slopes, thin soil cover and small storage capacity of the fractures, runoff is significant and ground-water recharge is minimal. Ground-water levels are extremely variable, but are typically deep.



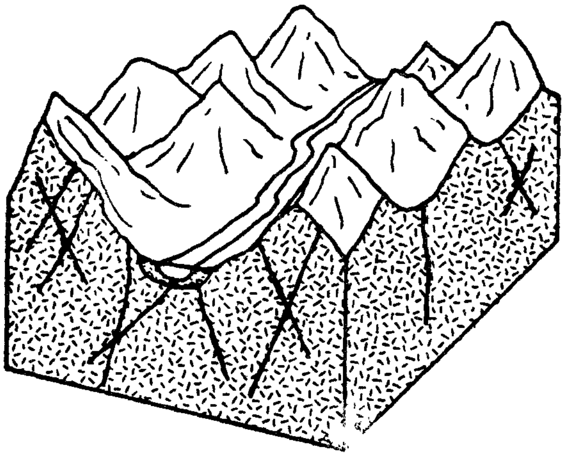
SETTING 2 A Mountain Slopes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Thin or Absent	2	10	20
Topography	12-18%	1	3	3
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	74

SETTING 2 A Mountain Slopes		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Thin or Absent	5	10	50
Topography	12-18%	3	3	9
Impact Vadose Zone	Metamorphic/Igneous	4	4	16
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	105

ALLUVIAL BASINS

(2B) Alluvial Mountain Valleys

This hydrogeologic setting is characterized by thin bouldery alluvium which overlies fractured bedrock of sedimentary, metamorphic or igneous origin. Slopes in the valley typically range from 2 to 6 percent. The alluvium, which is derived from the surrounding steep slopes serves as a localized source of water. Water levels are moderate in depth, but because of the low rainfall, ground-water recharge is low. Ground water may also be obtained from the fractures in the underlying bedrock which are typically in direct hydraulic connection with the overlying alluvium.



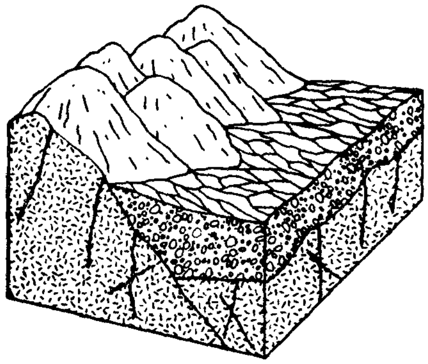
SETTING 2 B Alluvial Mountain Valleys		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	132

SETTING 2 B Alluvial Mountain Valleys		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	5	9	45
Topography	2-6%	3	9	27
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	300-700	2	4	8
			Pesticide Drastic Index	165

ALLUVIAL BASINS

(2C) Alluvial Fans

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



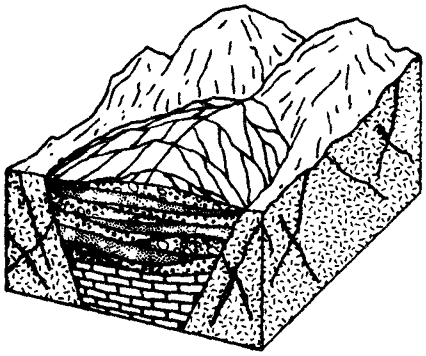
SETTING 2 C Alluvial Fans		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	122

SETTING 2 C Alluvial Fans		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	5	9	45
Topography	2-6%	3	9	27
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	300-700	2	4	8
			Pesticide Drastic Index	155

ALLUVIAL BASINS

(2D) Alluvial Basins (Internal Drainage)

This hydrogeologic setting is characterized by low topographic relief and thick deposits of unconsolidated alluvial material formed by coalescing alluvial fans. The sand and gravel deposits within the alluvium are the major source of water in the region. The sand and gravel is interbedded with finer-grained layers of saturated clay and silt which serve as a source of recharge to the sand and gravel when head differences are significant. The alluvium is underlain by fractured igneous or metamorphic rocks and consolidated sedimentary rocks. Although some of the sedimentary rocks are permeable and water may be obtained from fractures in the crystalline bedrock, the abundance of water in the alluvium and the greater depth of the bedrock serves to minimize use of these sources. Since these basins have internal drainage, natural gradients are low near the basin centers. Thus, the primary direction of pollutant migration, under normal conditions, would be downward, and outward radially from the point of incidence.



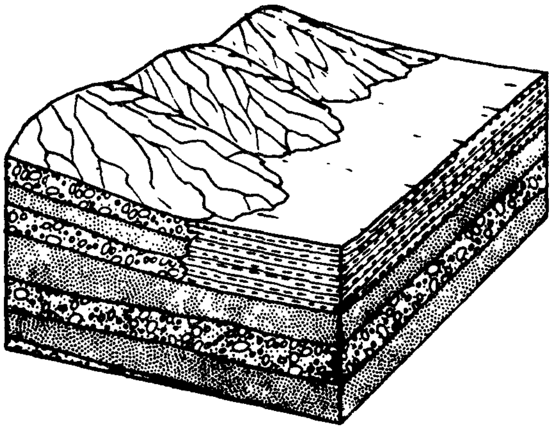
SETTING 2 D Alluvial Basins (Internal Drainage)		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	S & G w/ sig. Silt and Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	122

SETTING 2 D Alluvial Basins (Internal Drainage)		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	5	9	45
Topography	2-6%	3	9	27
Impact Vadose Zone	S & G w/ sig. Silt and Clay	4	6	24
Hydraulic Conductivity	300-700	2	4	8
			Pesticide Drastic Index	157

ALLUVIAL BASINS

(2E) Playa Lakes

This hydrogeologic setting is characterized by very low topographic relief and thin layers of clays and other fine-grained sediments which overlie alluvial deposits. The playa areas serve as a catchment for water during periods of significant runoff; when the precipitation event is over, the water evaporates, leaving a crust of soluble salts on the surface. Ground water is obtained from the layers of sand which underlie the finer-grained deposits. Water levels are extremely variable but are typically deep. The playa beds are significant recharge areas due to the ground-water "mounding" that occurs seasonally beneath the playas. The rate of recharge, as compared to evaporation, is largely a function of the permeability of the materials forming the bed of the playa, and the precipitation distribution over time.



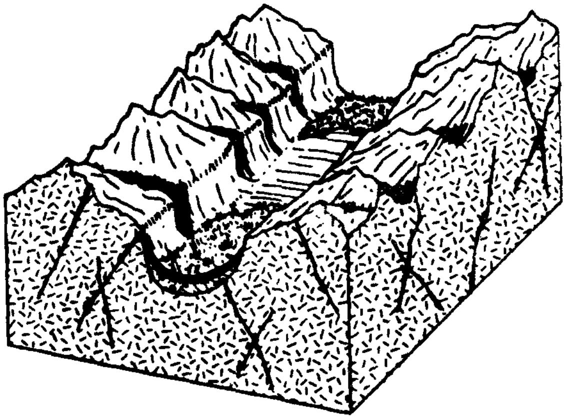
SETTING 2 E Playa Lakes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water Table	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Shrink/Agg. Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	S & G w/ sig. Silt and Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	110

SETTING 2 E Playa Lakes		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water Table	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Shrink/Agg. Clay	5	7	35
Topography	0-2%	3	10	30
Impact Vadose Zone	S & G w/ sig. Silt and Clay	4	6	24
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	139

ALLUVIAL BASINS

(2F) Swamp/Marsh

This hydrogeologic setting is characterized by low topographic relief, very high water levels and high organic content silts and clays along the coast. In the interior alluvial valleys, this setting may also contain evaporitic deposits and saline-tolerant vegetation. In fresh-water environments, these areas are typified by poorly drained soils with high water tables. Recharge is potentially high and is dependant primarily on precipitation. The swamp deposits very rarely serve as significant aquifers; water is usually obtained from the underlying bedrock. However, the swamp deposits may serve as a source of recharge to the aquifer.

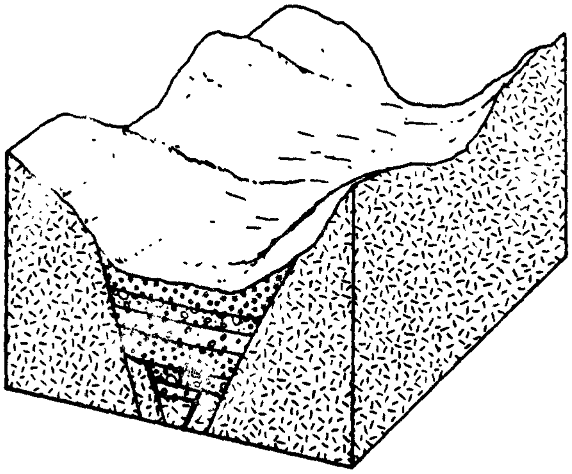


SETTING 2 F Swamp/Marsh		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	2-4	4	3	12
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Muck	2	2	4
Topography	0-2	1	10	10
Impact Vadose Zone	S & G w/sig. Silt and Clay	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	127

SETTING 2 F Swamp/Marsh		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	2-4	4	3	12
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Muck	5	2	10
Topography	0-2	3	10	30
Impact Vadose Zone	S & G w/sig. Silt and Clay	4	6	24
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	140

(2G) Coastal Lowlands

This hydrogeologic setting is characterized by thick and very permeable deposits of gravel and sand laid down by streams of glacial meltwater from the Pleistocene glaciers. The gravel and sand are interbedded with clay in parts of the area. Floodplain deposits and interbedded volcanics are also included in some areas. The area is characterized by the Willamette Valley - Puget Sound trough. Recharge is high and water levels are shallow to moderate. The sand and gravels and interbedded volcanics both may serve as prolific aquifers.

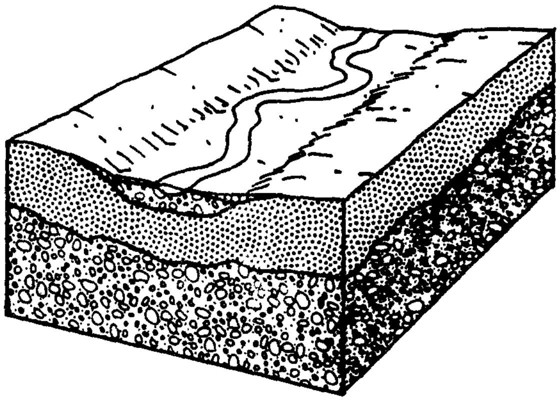


SETTING 2 G Coastal Lowlands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	2-6	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	40
			Drastic Index	202

SETTING 2 G Coastal Lowlands		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	5	9	45
Topography	2-6	3	9	27
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	215

(2Ha) River Alluvium With Overbank Deposits

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



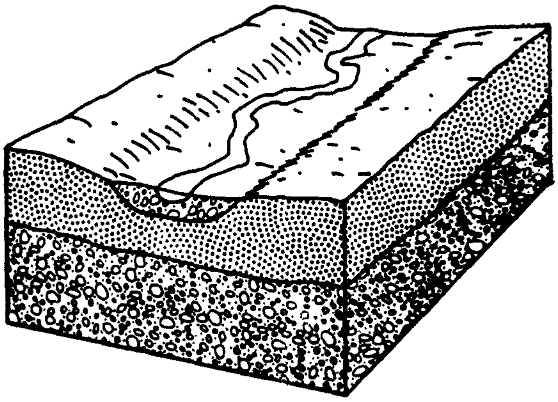
SETTING 2 Ha River Alluvium With Overbank Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	2	4	8
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	1[illegible]

SETTING 2 Ha River Alluvium With Overbank Deposit		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	5	4	20
Topography	0-2%	3	10	30
Impact Vadose Zone	S&G w/sig Silt & Clay	4	6	24
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	181

ALLUVIAL BASINS

(2Hb) River Alluvium Without Overbank Deposits

This setting is identical to (2Ha) River Alluvium with Overbank Deposits except that no significant fine-grained floodplain deposits occupy the stream valley. This results in significantly higher recharge where precipitation is adequate and sandy soils occur at the surface. Water levels are moderate to shallow in depth. Hydraulic contact with the surface stream is usually excellent, with alternating recharge/discharge relationships varying with stream stage. These deposits also serve as a good source of recharge to the underlying glacial deposits.



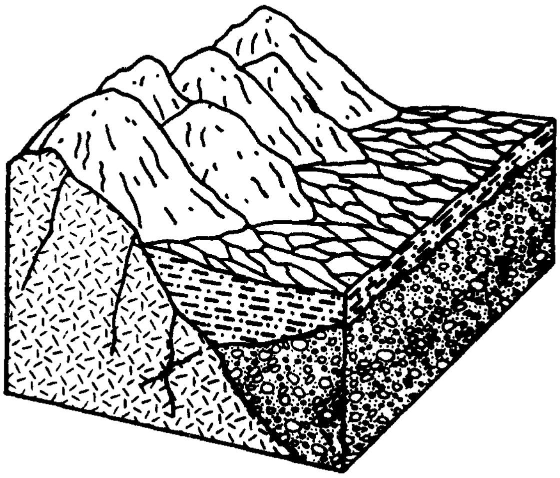
SETTING 2 Hb River Alluvium Without Overbank Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000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

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

ALLUVIAL BASINS

(2I) Mud Flows

This hydrogeologic setting is characterized by low topography and variable thicknesses of unsorted mixtures of boulders and pebbles in a fine-grained matrix. The deposits originated from the adjacent mountains and tend to be thicker toward the mountains and thinner in the valleys with no well developed drainage pattern. The mud flows are underlain by glacial and alluvial deposits which serve as the major aquifer. Recharge is moderate to low because the mud flows restrict infiltration and may even serve to confine the underlying aquifer.



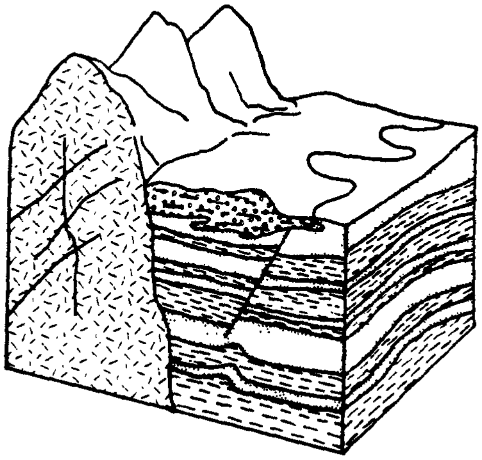
SETTING 2 I Mud Flows		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Loam	2	5	10
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	149

SETTING 2 I Mud Flows		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Loam	5	5	25
Topography	0-2%	3	10	30
Impact Vadose Zone	S&G w/sig Silt & Clay	4	6	24
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	172

ALLUVIAL BASINS

(2J) Alternating Sandstone and Shale Sequences

This hydrogeologic setting is characterized by moderate topographic relief and loamy soils underlain by fractured and folded alternating layers of sedimentary rocks with a typically high percentage of volcanic fragments. The bedrock may be overlain by interbedded unconsolidated deposits comprised of volcanic mud flows, alluvium, ash, sands and silts. The recharge is typically high in areas of the region where precipitation is high. Water levels are extremely variable but are typically deep. The bedrock aquifer yields only small amounts of water from the interconnected fractures.



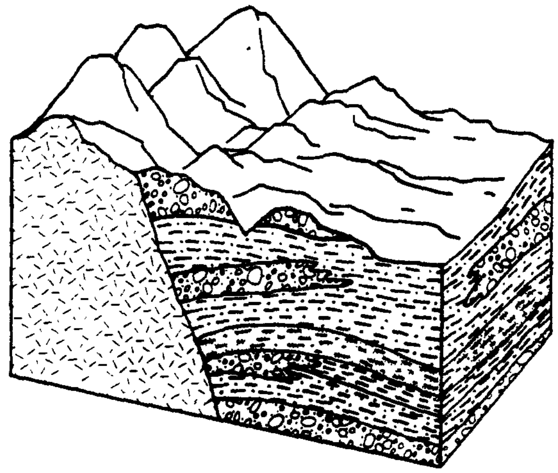
SETTING 2 J Alternating Sandstone, Shale Sequences		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	7-10	4	8	32
Aquifer Media	Bedded SS, LS Sh Sequences	3	6	18
Soil Media	Loam	2	5	10
Topography	2-6%	1	9	9
Impact Vadose Zone	Bedded LS, SS, Sh	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	112

SETTING 2 J Alternating Sandstone, Shale Sequences		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	7-10	4	8	32
Aquifer Media	Bedded SS, LS Sh Sequences	3	6	18
Soil Media	Loam	5	5	25
Topography	2-6%	1	9	9
Impact Vadose Zone	Bedded LS, SS, Sh	4	6	24
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	120

ALLUVIAL BASINS

(2K) Continental Deposits

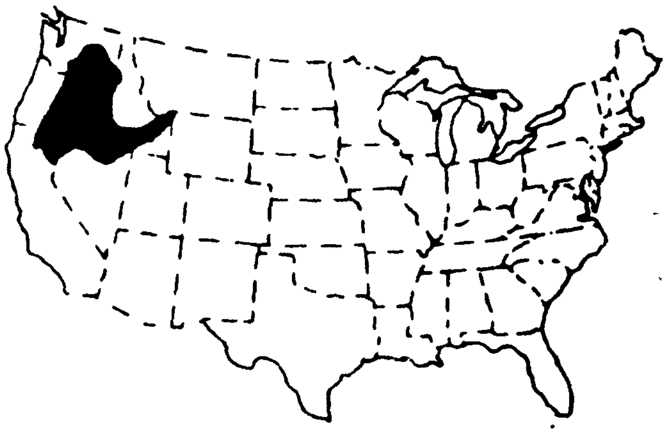
This hydrogeologic setting is characterized by moderate to low topographic relief and thick deposits of interbedded sand, silt and clay with discontinuous lenses of coarser sand and gravel which formed on broad floodplains. The deposits may be partially consolidated due to subsequent deformation. The sand and gravel deposits within the alluvium serve as locally important sources of water. The deposits are underlain by sedimentary, metamorphic and igneous rocks which typically do not yield significant quantities of water. Recharge is limited throughout most of the area by low precipitation.

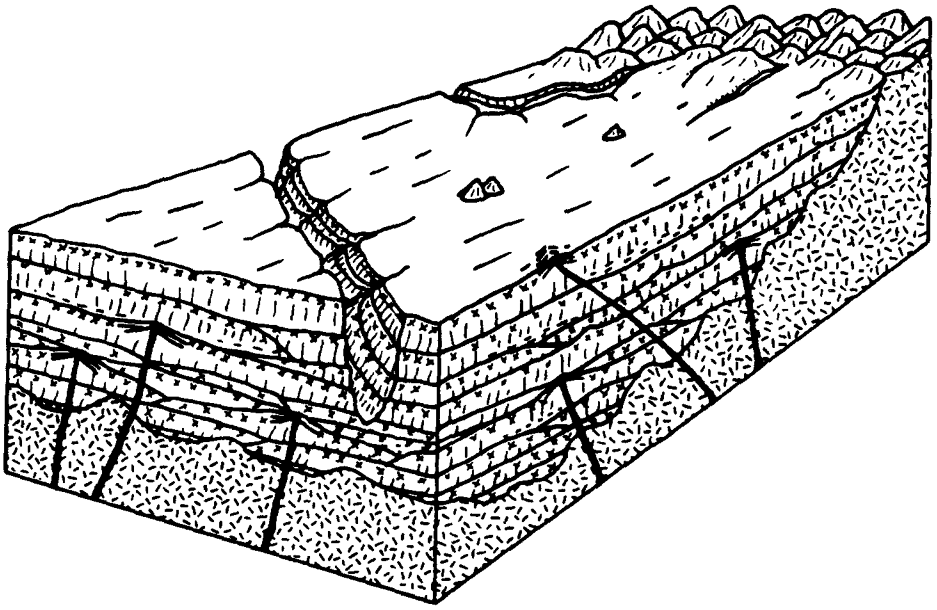


SETTING 2 K Continental Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silt Loam	2	4	8
Topography	6-12%	1	5	5
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	98

SETTING 2 K Continental Deposits		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silt Loam	5	4	20
Topography	6-12%	1	5	5
Impact Vadose Zone	S&G w/sig Silt & Clay	4	7	28
Hydraulic Conductivity	300-700	2	4	8
			Pesticide Drastic Index	99

3. COLUMBIA LAVA PLATEAU GROUND-WATER REGION





3A	Mountain Slopes
3B	Alluvial Mountain Valleys
3C	Hydraulically Connected Lava Flows
3D	Lava Flows Not Connected Hydraulically
3E	Alluvial Fans
3F	Swamp/Marsh
3G	River Alluvium

3. COLUMBIA LAVA PLATEAU

(Thick sequence of lava flows irregularly interbedded with thin unconsolidated deposits and overlain by thin soils)

The Columbia Lava Plateau occupies an area of 366,000 km2 in northeastern California, eastern Washington and Oregon, southern Idaho, and northern Nevada. As its name implies, it is basically a plateau standing at an altitude generally between 500 and 1,800 m above sea level that is underlain by a great thickness of lava flows irregularly interbedded with silt, sand, and other unconsolidated deposits. The plateau is bordered on the west by the Cascade Range, on the north by the Okanogan Highlands, and on the east by the Rocky Mountains. On the south it grades into the Alluvial Basins region, as the area occupied by lava flows decreases and the typical "basin and range" topography of the Alluvial Basins region gradually prevails. Most of the plateau in Idaho is exceptionally flat over large areas, the principal relief being low cinder (volcanic) cones and lava domes. This area and much of the area in California, southeastern Oregon, and Nevada is underlain by much of the youngest lava, some of which is less than 1,000 years old. In Washington the flows are older, some dating back to the Miocene Epoch. Altitudes in a few of the mountainous areas in the plateau region exceed 3,000 m.

The great sequence of lava flows, which ranges in thickness from less than 50 m adjacent to the bordering mountain ranges to more than 1,000 m in south-central Washington and southern Idaho, is the principal water-bearing unit in the region. The water-bearing lava is underlain by granite, metamorphic rocks, older lava flows, and sedimentary rocks, most of which are very permeable. Individual lava flows in the water-bearing zone range in thickness from several meters to more than 50 m and average about 15 m. Most of the lava is basalt which reached the surface both through extensive fissures and through local eruption centers. Because basaltic lava is very fluid when molten, it flows considerable distances down surface depressions and over gently sloping surfaces and forms, when it solidifies, a relatively flat surface. Some flows are sheetlike and can be followed visually for several kilometers along the walls of steep canyons. Other flows, where the lava issuing from eruption centers followed surface depressions, are lobate, or tonguelike.

The volcanic rocks yield water mainly from permeable zones that occur at or near the contacts between some flow layers. The origin of these flow-contact or interflow zones is complex but involves, among other causes, the relatively rapid cooling of the top of flows, which results in formation of a crust. As the molten lava beneath continues to flow, the crust may be broken into a rubble of angular fragments which in places contain numerous holes where gas bubbles formed and which give the rock the appearance of a frozen froth.

The slower cooling of the central and lower parts of the thicker flows results in a dense, flint-like rock which in the lower part contains relatively widely spaced, irregular fractures and which grade upward into a zone containing relatively closely spaced vertical fractures that break the rock into a series of hexagonal columns (Newcomb, 1961).

Periods of time ranging from less than 100 years to thousands of years elapsed between extrusion of successive lava flows. As a result, parts of some flows are separated by soil zones and, at places, by sand, silt, and clay deposited by streams or in lakes that existed on the land surface before being buried by subsequent lava extrusions. These sedimentary layers, where they occur between lava flows, are commonly referred to as "interflow sediments." Gravel, sand, silt, and clay, partly formed by the present streams and partly of glacial origin, cover the volcanic rocks and the older exposed bedrock in parts of the area.

From the standpoint of the hydraulic characteristics of the volcanic rocks, it is useful to divide the Columbia Lava Plateau region into two parts: (1) the area in southeastern Washington, northeastern Oregon, and the Lewiston area of Idaho, part of which is underlain by volcanic rocks of the Columbia River Group; and (2) the remainder of the area, which also includes the Snake River Plain. The basalt underlying the Snake River Plain is referred to as the Snake River Basalt; that underlying southeastern Oregon and the remainder of this area has been divided into several units, to which names of local origin are applied (Hampton, 1964).

The Columbia River Group is of Miocene to Pliocene age and consists of relatively thick flows that have been deformed into a series of broad folds and offset locally along normal faults. Movement of ground water occurs primarily through the interflow zones near the top of flows and, to a much smaller extent, through fault zones and through joints developed in the dense central and lower parts of the flows. The axes of sharp folds and the offset of the interflow zones along faults form subsurface dams that affect the movement of ground water. Water reaching the interflow zones tends to move down the dip of the flows from fold axes and to collect undip behind faults that are transverse to the direction of movement (Newcomb, 1961). As a result, the basalt in parts of the area is divided into a series of barrier-controlled reservoirs which are only poorly connected hydraulically to adjacent reservoirs.

The water-bearing basalt underlying California, Nevada, southeastern Oregon, and southern Idaho is of Pliocene to Holocene age and consists of small, relatively thin flows that have been affected to a much smaller extent by folding and faulting than has the Columbia River Group. The thin flows contain extensive, highly permeable interflow zones that are relatively effectively interconnected through a dense network of cooling fractures. Structural barriers to ground-water movement, such as those of the Columbia River Group, are of minor importance. This is demonstrated by conditions in the 44,000-square-kilometer area of the Snake River Plan east of Bliss, Idaho, which Nace (1958) thought might be the largest unified ground-water reservoir on the North American continent. (It is probable that this distinction is held by the Floridan aquifer, which underlies an area of 212,000 km2 in Alabama, Florida, Georgia, and South Carolina. See region 11).

The interflow zones form a complex sequence of relatively horizontal aquifers that are separated vertically by the dense central and lower parts of the lava flows and by interlayered clay and silt. Hydrologists estimate that the interflow zones, which range in thickness from about 1 m to about 8 m, account for about 10 percent of the basalt. MacNish and Barker (1976) have estimated, on the basis of studies in the Walla Walla River basin in Washington and Oregon, that the hydraulc conductivity along the flow-contact zones may be a billion times larger than the hydraulic conductivity across the dense zones. The lateral extent of individual aquifers depends on the area covered by the different lava flows, on the presence of dikes and other igneous intrusions, and on faults and folds that terminate the porous zones, especially in the Columbia River Group.

The large differences in hydraulic conductivity between the aquifers and the intervening "confining zones" result in significant differences in hydraulic heads between different aquifers. These differences reflect the head losses that occur as water moves vertically through the system. As a result, heads decrease with increasing depth in recharge areas and increase with increasing depth near the streams that serve as major lines of ground-water discharge. The difference in heads between different aquifers can result in the movement of large volumes of water between aquifers through the open-hole (uncased) sections of wells.

Much of the Columbia Lava Plateau region is in the "rain shadow" east of the Cascades and, as a result, receives only 200 to 1,200 mm of precipitation annually. The areas that receive the least precipitation include the plateau area immediately east of the Cascades and the Snake River Plain. The areas that receive the largest amounts of precipitation include the east flank of the Cascades and the areas adjacent to the Okanogan Highlands and the Rocky Mountains. Recharge to the ground-water system depends on several factors, including the amount and seasonal distribution of precipitation and the permeability of the surficial materials. Most precipitation occurs in the winter and thus coincides with the cooler, nongrowing season when conditions are most favorable for recharge. Mundorff (Columbia-North Pacific Technical Staff, 1970) estimates that recharge may amount to 600 mm in areas underlain by highly permeable young lavas that receive abundant precipitation. Considerable recharge also occurs by infiltration of water from streams that flow onto the plateau from the adjoining mountains. These sources of natural recharge are supplemented in agricultural areas by the infiltration of irrigation water.

Discharge from the ground-water system occurs as seepage to streams, as spring flow, and by evapotranspiration in areas where the water table is at or near the land surface. The famous Thousand Springs and other springs along the Snake River canyon in southern Idaho are, in fact, among the most spectacular displays of ground-water discharge in the world.

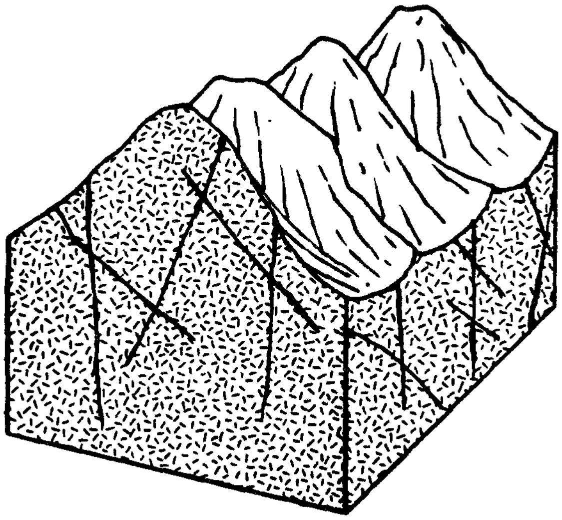
The Columbia Lava Plateau region is mantled by mostly thin soils developed on alluvial and wind-laid deposits that are well suited for agriculture. Because of the arid and semiarid climate in most of the region, many crops require intensive irrigation. In 1970, for example, more than 15,000 km^2 (3.75 million acres) were being irrigated on the Snake River Plain. Water for irrigation is obtained both by diversions from streams and by wells that tap the lava interflow zones. Much of the water applied for irrigation percolates downward into the lava and then moves through the ground-water system to the Columbia and Snake Rivers and to other streams that have deeply entrenched channels. The effect of this "return flow" is graphically indicated by a long-term increase in the flow of the Thousand Springs and other large springs along the Snake River gorge between Milner and King Hill--from about 110 m^3 sec^{-1} in 1902, prior to significant irrigation, to more than 225 m^3 sec^{-1} by 1942, after decades of irrigation on adjacent and upstream parts of the plateau. Prior to the start of irrigation, the water represented by this increased flow reached the Snake River below King Hill through tributary streams and natural ground-water discharge.

The large withdrawal of water in the Columbia Lava Plateau for irrigation, industrial, and other uses has resulted in declines in ground-water levels of as much as 30 to 60 m in several areas. In most of these areas, the declines have been slowed or stopped through regulatory restrictions or other changes that have reduced withdrawals. Declines are still occurring, at rates as much as a few meters per year, in a few areas.

COLUMBIA LAVA PLATEAU

(3A) Mountain Slopes

This hydrogeologic setting is characterized by steep slopes on the side of mountains bordering the plateau, a thin soil cover and fractured bedrock. Steep slopes also occur on cinder cones within the plateau. Ground water is obtained primarily from the fractures in the bedrock which may be sedimentary, metamorphic or igneous origin. The fractures provide localized sources of ground water and well yields are typically limited. Due to the thin soil cover, topography and small storage capacity of the fractures, runoff is significant. Ground-water levels are extremely variable but are typically deep. Due to lack of rainfall, low hydraulic conductivity and steep topography, net recharge is very low.



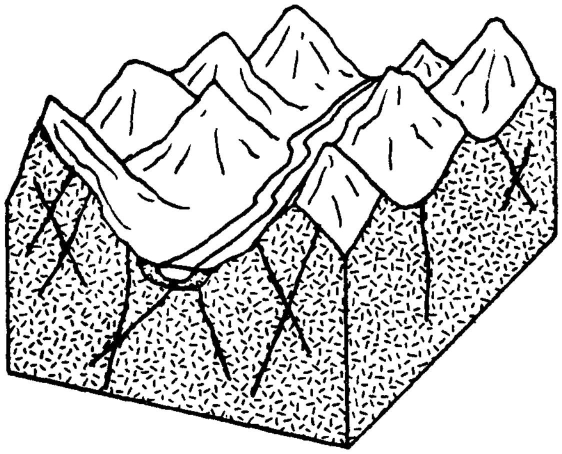
SETTING 3 A Mountain Slopes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	2-4	4	3	12
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Silty Loam	2	4	8
Topography	12-18%	1	3	3
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	86

SETTING 3 A Mountain Slopes		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	2-4	4	3	12
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Silty Loam	5	4	20
Topography	12-18%	3	3	9
Impact Vadose Zone	Metamorphic/Igneous	4	4	16
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	92

COLUMBIA LAVA PLATEAU

(3B) Alluvial Mountain Valleys

This hydrogeologic setting is characterized by thin bouldery alluvium which overlies fractured bedrock of sedimentary, metamorphic or igneous origin. The alluvium, which is derived from the sourrounding steep slopes serves as a localized source of water. Water levels are typically moderate and recharge to the ground water may be of significance. Ground water may also be obtained from the fractures in the underlying bedrock which are typically in direct hydraulic connection with the overlying alluvium.



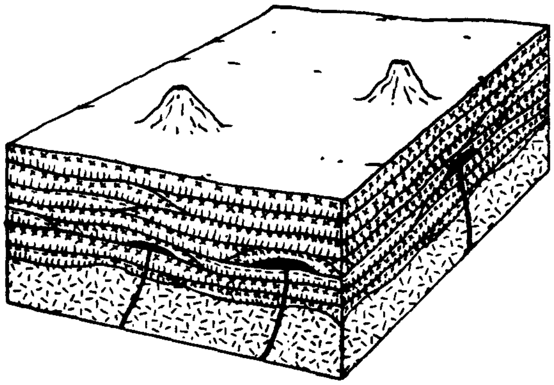
SETTING 3 B Alluvial Mountain Valleys		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Gravel	2	10	20
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	168

SETTING 3 B Alluvial Mountain Valleys		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Gravel	5	10	50
Topography	2-6%	3	9	27
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	202

COLUMBIA LAVA PLATEAU

(3C) Hydraulically Connected Lava Flows

This hydrogeologic setting is characterized by low topographic relief, a thin sandy soil cover and a thick sequence of successive lava flows which is irregularly interbedded with thin unconsolidated deposits. The lava beds are underlain by poorly permeable bedrock of igneous, sedimentary or metamorphic origin. Ground water is obtained primarily from the interflow zones comprised of sequential, thin, lava flows and related sedimentary deposits, cooling fractures, lava tubes and minor structural features. Water levels are extremely variable but are typically deep. Well yields may vary from low to extremely high depending on the characteristics of the underlying lava flows at a particular site. Ground-water recharge may be appreciable because the layers of lava are interconnected hydraulically. This setting is characterized by the deposits that occur in southwestern Idaho (Snake River area), northern Nevada, southeastern Oregon and extreme northeastern California, which are of Pliocene to Holocene age.



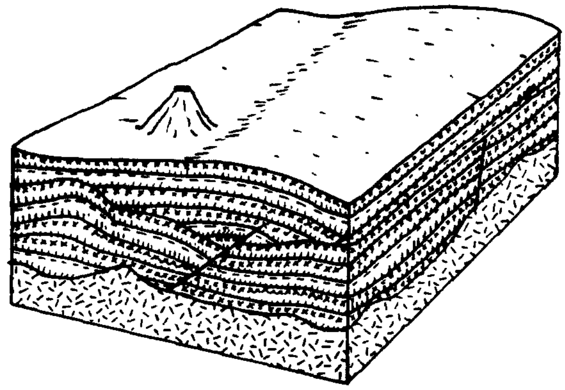
SETTING	3 C Hydraulically Connected Lava Flows	GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	2-4	4	3	12
Aquifer Media	Basalt	3	9	27
Soil Media	Silt Loam	2	4	8
Topography	2-6%	1	9	9
Impact Vadose Zone	Basalt	5	9	45
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	146

SETTING	3 C Hydraulically Connected Lava Flows	PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	2-4	4	3	12
Aquifer Media	Basalt	3	9	27
Soil Media	Silt Loam	5	4	20
Topography	2-6%	3	9	27
Impact Vadose Zone	Basalt	4	9	36
Hydraulic Conductivity	2000+	2	10	20
			Pesticide Drastic Index	157

COLUMBIA LAVA PLATEAU

(3D) Lava Flows Not Connected Hydraulically

This hydrogeologic setting is characterized by low topographic relief, a thin cover of gravel, sand, silt and clay of stream and glacial origin and a sequence of thick lava flows irregularly interbedded with unconsolidated deposits, which have been deformed into a series of folds and normal faults. The lava sequence is underlain by poorly permeable bedrock of igneous, sedimentary or metamorphic origin. Ground water is obtained primarily from the interflow zones of sedimentary deposits and cooling fractures which occur between successive layers of lava. Water levels are extremely variable, but are typically deep. The presence of thick impermeable zones may produce perched water table conditions or disrupt the hydraulic continuity of water bearing zones. The flow of ground water is controlled by locally offset normal faults which form a series of hydraulically poorly connected reservoirs. This setting is characterized by deposits that occur in the Columbia River area in southern Washington, northern Oregon and northern Idaho which are Miocene to Pliocene (?) in age.



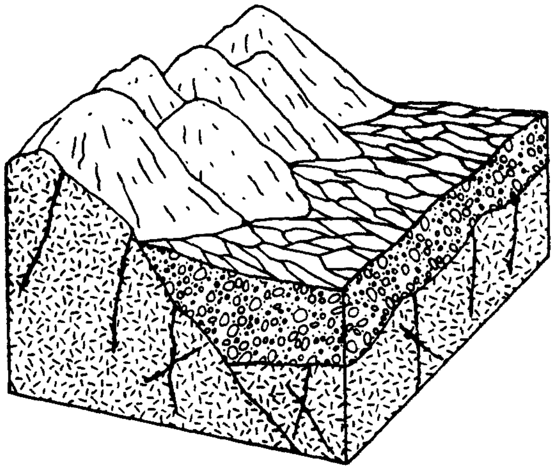
SETTING	3 D Lava Flows Not Connected Hydraulically	GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	2-4	4	3	12
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Bedded LS, SS, SH	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	105

SETTING	3 D Lava Flows Not Connected Hydraulically	PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	2-4	4	3	12
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Sand	5	9	45
Topography	2-6%	3	9	27
Impact Vadose Zone	Bedded LS, SS, SH	4	6	24
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	143

COLUMBIA LAVA PLATEAU

(3E) Alluvial Fans

This hydrogeologic setting is characterized by alluvial sediments which are thickest near the mountain slopes and thin toward the interior basin. Topography is steep to moderate. Fan sediments range from coarse, unsorted debris on the upper slopes grading to well-sorted and stratified gravels, sands and clays. Recharge is a function of precipitation and evaporation, since the permeability of the surface materials is usually high. Ground- water movement is generally unidirectional from the adjacent highlands toward the basin. Depth to ground water is generally moderate to deep. These fans may serve as local sources of water and also as the recharge area for the deposits in the adjacent basin and the lower extremities may serve as discharge areas to local streams.



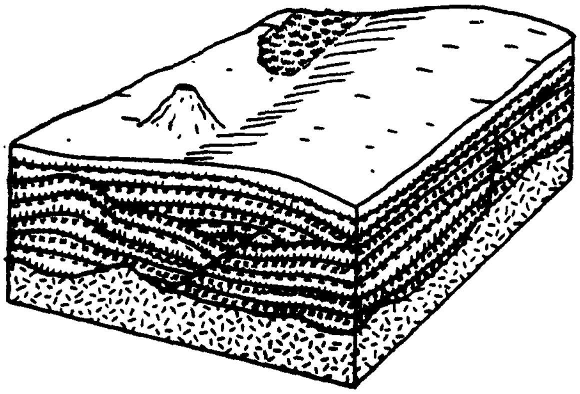
SETTING 3 F Alluvial Fans		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	6-12%	1	5	5
Impact Vadose Zone	S & G w/ sig. Silt and Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	105

SETTING 3 E Alluvial Fans		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	6-12%	3	5	15
Impact Vadose Zone	S & G w/ sig. Silt and Clay	4	6	24
Hydraulic Conductivity	300-700	2	4	8
			Pesticide Drastic Index	123

COLUMBIA LAVA PLEATEAU

(3F) Swamp/Marsh

This hydrogeologic setting is characterized by low topographic relief and very high water levels subject to seasonal drying in smaller basins. Surficial deposits are typically thin with a high organic content and silty or sandy textures. These areas commonly form where fairly impermeable bedrock impedes percolation. Recharge is moderate to low because of limited precipitation and vertical restrictions. These deposits do not serve as aquifers but many provide limited recharge to the underlying bedrock.



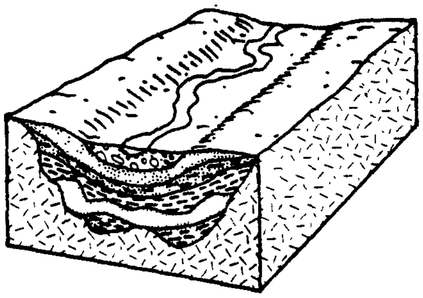
SETTING 3 F Marsh/Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	0-2	4	1	4
Aquifer Media	Basalt	3	9	27
Soil Media	Sand	2	9	18
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	179

SETTING 3 F Marsh/Swamp		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	0-2	4	1	4
Aquifer Media	Basalt	3	9	27
Soil Media	Sand	5	9	45
Topography	0-2	3	10	30
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	2000+	2	10	20
			Pesticide Drastic Index	206

COLUMBIA LAVA PLATEAU

(3G) River Alluvium

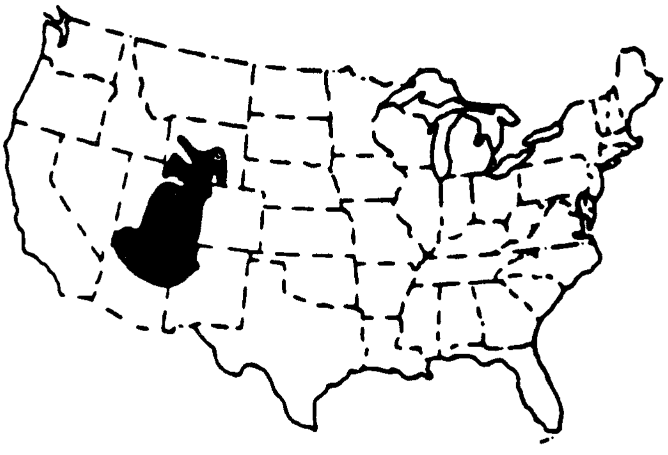
This hydrogeologic setting is characterized by low topography and deposits of alluvium along parts of valley streams. The alluvium yields small to moderate supplies of ground water. Water is obtained from sand and gravel layers which are interbedded with finer-grained alluvial deposits; these are usually in direct hydraulic contact with the stream. Water levels are extremely variable but are commonly moderately shallow. Although precipitation is low, recharge is significant due to the low topography and sandy loam soil cover. The alluvium is underlain by sedimentary or igneous bedrock which may or may not be in direct hydraulic connection with the overlying alluvial deposits.

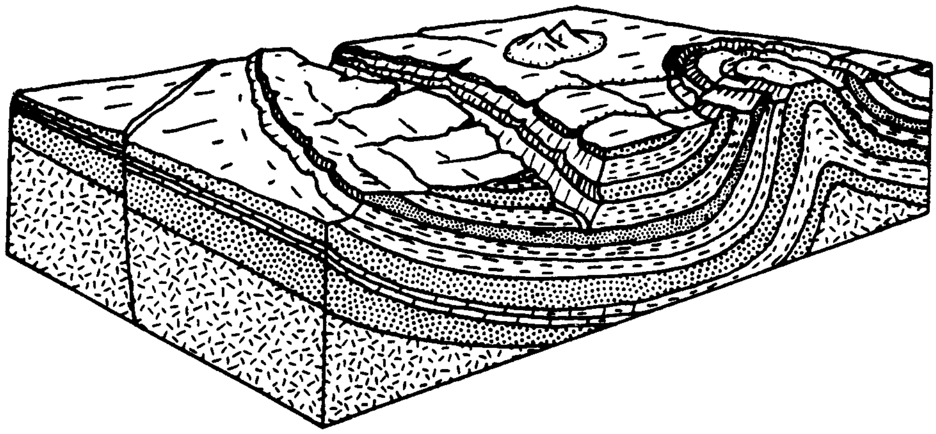


SETTING 3 G River Alluvium		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/big Silt & Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	147

SETTING 3 G River Alluvium		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/big Silt & Clay	4	6	24
Hydraulic Conductivity	300-700	2	4	8
			Pesticide Drastic Index	155

4. COLORADO PLATEAU AND WYOMING BASIN GROUND-WATER REGION





4A	Resistant Ridges
4B	Consolidated Sedimentary Rock
4C	River Alluvium
4D	Alluvium and Dune Sand
4E	Swamp/Marsh

4. COLORADO PLATEAU AND WYOMING BASIN

(Thin soils over consolidated sedimentary rocks)

The Colorado Plateau and Wyoming Basin region occupies an area of 414,000 km^2 in Arizona, Colorado, New Mexico, Utah, and Wyoming. It is a region of canyons and cliffs; of thin, patchy, rocky soils; and of sparse vegetation adapted to the arid and semiarid climate. The large-scale structure of the region is that of a broad plateau standing at an altitude of 2,500 to 3,500 m and underlain by essentially horizontal to gently dipping layers of consolidated sedimentary rocks. The plateau structure has been modified by an irregular alternation of basins and domes, in some of which major faults have caused significant offset of the rock layers.

The region is bordered on the east, north, and west by mountain ranges that tend to obscure its plateau structure. The northern part of the region--the part occupied by the Wyoming Basin--borders the Nonglaciated Central region at the break in the Rocky Mountains between the Laramie Range and the Bighorn Mountains. The region contains small, isolated mountain ranges, the most prominent being the Henry Mountains and the La Sal Mountains in southeastern Utah. It also contains, rather widely scattered over the region, extinct volcanoes and lava fields, the most prominent example being the San Francisco Mountains in north-central Arizona.

The rocks that underlie the region consist principally of sandstone, shale, and limestone of Paleozoic to Cenozoic age. In parts of the region these rock units include significant amounts of gypsum (Calcium sulfate). In the Paradox Basin in western Colorado the rock units include thick deposits of sodium- and potassium-bearing minerals, principally halite (sodium chloride). The sandstones and shales are most prevalent and most extensive in occurrence. The sandstones are the principal sources of ground water in the region and contain water in fractures developed both along bedding planes and across the beds and in interconnected pores. The most productive sandstones are those in which calcium carbonate or other cementing material has been deposited only around the point of contact of the sand grains. Thus, many of the sandstones are only partially cemented and retain significant primary porosity.

Unconsolidated deposits are of relatively minor importance in this region. Thin deposits of alluvium capable of yielding small to moderate supplies of ground water occur along parts of the valleys of major streams, especially adjacent to the mountain ranges in the northern and eastern parts of the region. These deposits are partly of glacial origin. In most of the remainder of the region there are large expanses of exposed bedrock, and the soils, where present, are thin and rocky.

Erosion has produced extensive lines of prominent cliffs in the region. The tops of these cliffs are generally underlain and protected by resistant sandstones. Erosion of the domes has produced a series of concentric, steeply dipping ridges, also developed on the more resistant sandstones.

Recharge of the sandstone aquifers occurs where they are exposed above the cliffs and in the ridges. Average precipitation ranges from about 150 mm in the lower areas to about 1,000 mm in the higher mountains. The heaviest rainfall occurs in the summer in isolated, intense thunderstorms during which some recharge occurs where intermittent streams flow across sandstone outcrops. However, most recharge occurs in the winter during snowmelt periods. Water moves down the dip of the beds away from the recharge areas to discharge along the channels of major streams through seeps and springs and along the walls of canyons cut by the streams.

The condition described in the preceding paragraph, whereby intermittent streams serve as sources of ground-water recharge and perennial streams serve as lines of ground-water discharge, is relatively common in this region and in the Alluvial Basins region to the south and west. Streams into which ground water discharges are referred to as gaining streams. Conversely, streams that recharge ground-water systems are referred to as losing streams. The gaining streams and the losing streams may be different streams. However, in many areas the same stream may be a gaining stream in its headwaters, especially where these drain the wetter mountainous areas, become a losing stream as it flows onto the adjoining lower areas, and, ultimately, become a gaining stream again in its lowermost reaches where it serves as a regional drain.

The quantity of water available for recharge is small, but so are the porosity and the transmissivity of most of the sandstone aquifers. Because of the general absence of a thick cover of unconsolidated rock in the recharge areas, there is relatively little opportunity for such materials to serve as a storage reservoir for the underlying bedrock. The water in the sandstone aquifers is unconfined in the recharge areas and is confined down-dip. Because most of the sandstones are consolidated, the storage coefficient in the confined parts of the aquifers is very small. This small storage coefficient together with the small transmissivities, results in even small rates of withdrawal causing extensive cones of depression around pumping wells.

Springs exist at places near the base of the sandstone aquifers where they crop out along the sides of canyons. Discharge from the springs results in dewatering the upper parts of the aquifers for some distance back from the canyon walls.

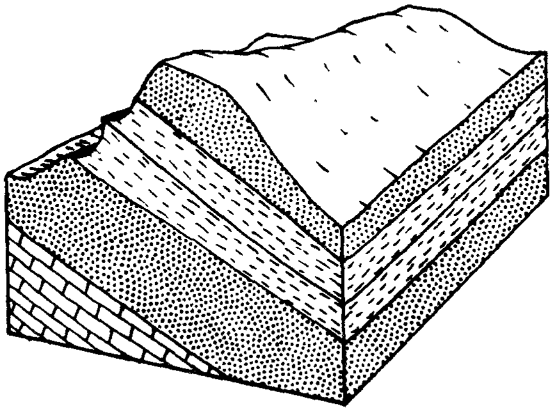
The Colorado Plateau and Wyoming Basin is a dry, sparsely populated region in which most water supplies are obtained from the perennial streams that flow across it from the bordering mountains. Less than 5 percent of the water needs are supplied by ground water, and the development of even small ground-water supplies requires the application of considerable knowledge of the occurrence of both rock units and their structure, and of the chemical quality of the water. Also, because of the large surface relief and the dip of the aquifers, wells even for domestic or small livestock supplies must penetrate to depths of a few hundred meters in much of the area. Thus, the development of ground-water supplies is far more expensive than in most other parts of the country. These negative aspects notwithstanding, ground water in the region can support a substantial increase over the present withdrawals.

As in most other areas of the country underlain by consolidated sedimentary rocks, mineralized (saline) water-that is, water containing more than 1,000 mg/l of dissolved solids--is widespread in occurrence. Most of the shales and siltstones contain mineralized water throughout the region and below altitudes of about 2,000 m. Freshwater--water containing less than 1,000 mg/l of dissolved solids--occurs only in the most permeable sandstones and limestones. Much of the mineralized water is due to the solution of gypsum and halite by water circulating through beds that contain these minerals. Although the aquifers that contain mineralized water are commonly overlain by aquifers containing freshwater, this situation is reversed in a few places where aquifers containing mineralized water are underlain by more permeable aquifers containing freshwater.

COLORADO PLATEAU AND WYOMING BASIN

(4A) Resistant Ridges

This hydrogeologic setting is characterized by moderate to steep slopes, and a very thin soil cover which overlies dipping fractured consolidated sedimentary rocks. The resistant sandstones cap the cliffs and ridges and form hogbacks. These same sandstone units comprise the aquifers that are the principal sources of ground water. The aquifers receive recharge in the areas where the sandstone is exposed at the surface. Recharge is low because of the topography and the lack of precipitation in the area. Water levels are extremely variable, but are typically deep.



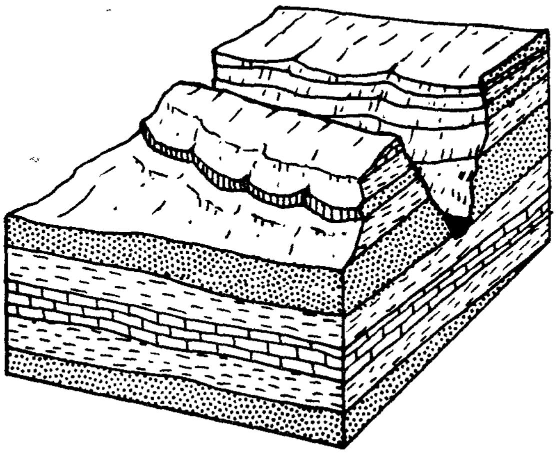
SETTING 4 A Resistant Ridges		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Thin Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Thin or Absent	2	10	20
Topography	12-18%	1	3	3
Impact Vadose Zone	Bedded LS, SS, SH	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	88

SETTING 4 A Resistant Ridges		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Thin Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Thin or Absent	5	10	50
Topography	12-18%	3	3	9
Impact Vadose Zone	Bedded LS, SS, SH	4	6	24
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	117

COLORADO PLATEAU AND WYOMING BASIN

(4B) Consolidated Sedimentary Rocks

This hydrogeologic setting is characterized by alternating layers of moderately-dipping, fractured, consolidated, sedimentary rocks covered by a sandy soil layer which commonly weathers to a sandy loam. The sandstones serve as the principal source of ground water. The water is obtained from fractures developed along bedding planes and from within the pore spaces. Water levels are typically deep and recharge is low because of the lack of precipitation. Intermittent streams often serve as sources of recharge; however, the major source of recharge occurs in the resistant ridges where the bedrock is exposed. The sandstones may also be confined, with small storage values and low yield wells.



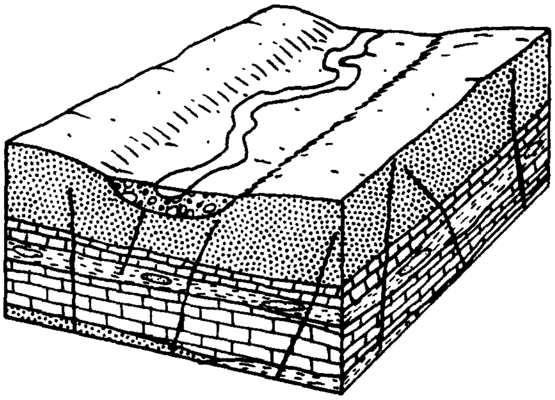
SETTING 4 B Consolidated Sedimentary Rock		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	SH Sequences	3	6	18
Soil Media	Sandy Loam	2	6	12
Topography	6-12%	1	5	5
Impact Vadose Zone	Bedded LS, SS, SH	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	87

SETTING 4 B Consolidated Sedimentary Rock		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	SH Sequences	3	6	18
Soil Media	Sandy Loam	5	6	30
Topography	6-12%	3	5	15
Impact Vadose Zone	Bedded LS, SS, SH	4	6	24
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	108

COLORADO PLATEAU AND WYOMING BASIN

(4C) River Alluvium

This hydrogeologic setting is characterized by low topography and deposits of alluvium along parts of valleys of perennial and intermittent streams. The alluvium yields small to moderate supplies of ground water. Water is obtained from sand and gravel layers which are interbedded with finer- grained alluvial deposits; these are usually in direct hydraulic contact with the perennial or intermittent stream. Water levels are extremely variable but are commonly moderately shallow. Although precipitation is low, recharge is significant due to the low topography and sandy loam soil cover. The alluvium is underlain by consolidated sedimentary rocks which are often in direct hydraulic connection with the overlying deposits.



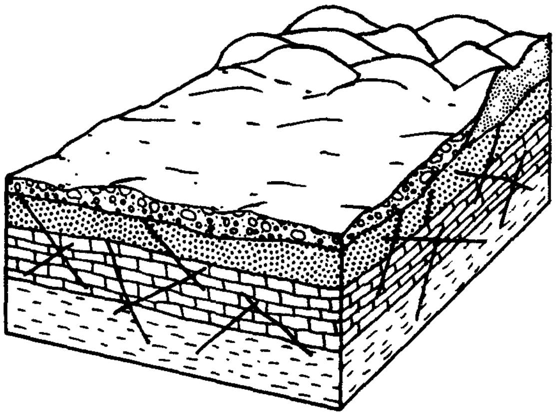
SETTING 4 C River Alluvium		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	S & G w/ sig. Silt and Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	152

SETTING 4 C River Alluvium		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	9	45
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	2-6%	3	9	27
Impact Vadose Zone	S & G w/ sig. Silt and Clay	4	6	24
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	176

COLORADO PLATEAU AND WYOMING BASIN

(4D) Alluvium and Dune Sand

This hydrogeologic setting is characterized by moderate topography derived from unconsolidated alluvial sediments that have formed under various depositional environments. These alluvial deposits vary from lacustrine deposits in the Wyoming Basin area to dune sands in the Navajo area of northern Arizona and northwestern New Mexico. Much of the entire region is covered by thin alluvium. The hydraulic conductivity of the alluvium is high throughout the area, including the sand dunes portion. Recharge is limited by low precipitation and evaporation. The alluvium serves as moderate water supplies in some areas, provides some discharge to streams, and acts as storage for recharge to deeper aquifers.



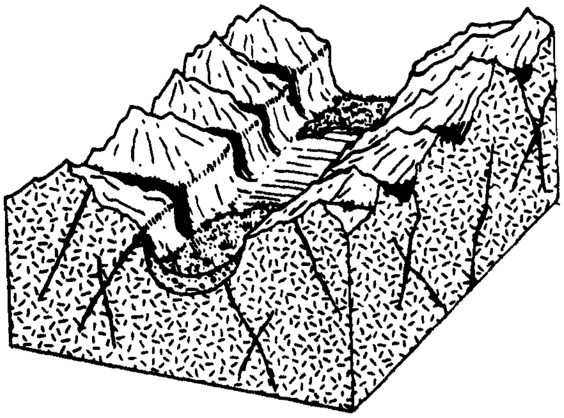
SETTING 4 D Alluvium and Dune Sand		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	S & G w/ sig. Silt and Clay	5	6	30
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	102

SETTING 4 D Alluvium and Dune Sand		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	5	9	45
Topography	6-12%	3	5	15
Impact Vadose Zone	S & G w/ sig. Silt and Clay	4	6	24
Hydraulic Conductivity	100-300	2	2	4
			Pesticide Drastic Index	131

COLORADO PLATEAU AND WYOMING BASIN

(4E) Swamp/Marsh

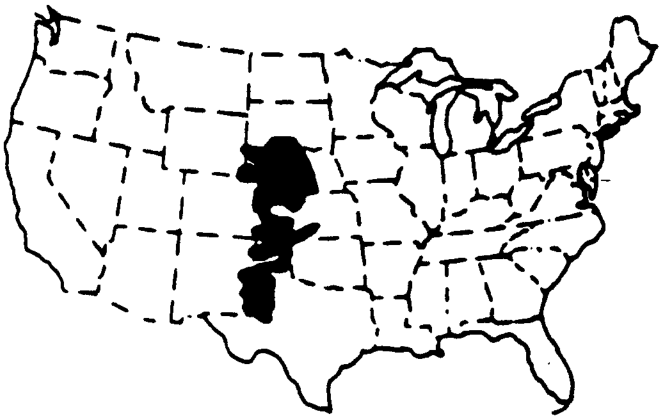
This hydrogeologic setting is characterized by low topographic relief and very high water levels subject to seasonal drying in smaller basins. Surficial deposits have a high organic content and silty or sandy textures. These areas commonly form where fairly impermeable bedrock impedes percolation. Large wetland areas may also be formed where small creeks or other drainage features have been dammed by silt or vegetation. Recharge is potentially high and is dependent primarily on precipitation. The thickness of the unconsolidated deposits varies. Where thick, these deposits may serve as an aquifer. In other areas, the underlying deposits serve as the aquifer with the overlying deposits providing recharge.

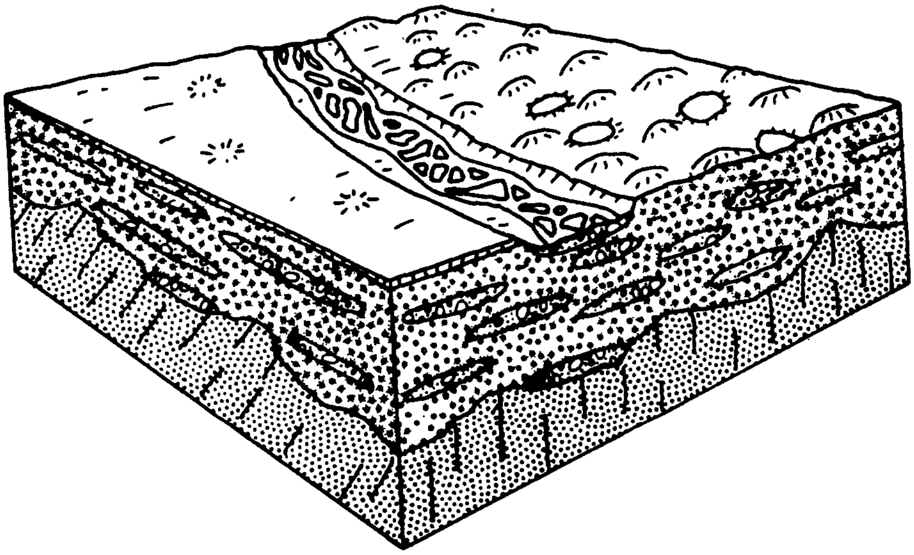


SETTING 4 E Swamp, Marsh		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	0-2	1	10	10
Impact Vadose Zone	S & G w/sig. Silt and Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	176

SETTING 4 E Swamp/Marsh		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	5	9	45
Topography	0-2	3	10	30
Impact Vadose Zone	S & G w/sig. Silt and Clay	4	6	24
Hydraulic Conductivity	300-700	2	4	8
			Pesticide Drastic Index	213

5. HIGH PLAINS GROUND-WATER REGION





5A	Ogallala
5B	Alluvium
5C	Sand Dunes
5D	Playa Lakes
5E	Braided River Deposits
5F	Swamp/Marsh
5Ga	River Alluvium With Overbank Deposits
5Gb	River Alluvium Without Overbank Deposits
5H	Alternating Sandstone, Limestone and Shale Sequences

5. HIGH PLAINS

(Thick alluvial deposits over fractured sedimentary rocks)

The High Plains region occupies an area of 450,000 km^2 extending from South Dakota to Texas. The plains are a remnant of a great alluvial plain built in Miocene time by streams that flowed east from the Rocky Mountains. The plain originally extended from the foot of the mountains to a terminous some hundreds of kilometers east of its present edge. Erosion by streams has removed a large part of the once extensive plain, including all of the part adjacent to the mountains, except in a small area in southeastern Wyoming.

The original depositional surface of the alluvial plain is still almost unmodified in large areas, especially in Texas and New Mexico, and forms a flat, imperceptibly eastward-sloping tableland that ranges in altitude from about 2,000 m near the Rocky Mountains to about 500 m along its eastern edge. The surface of the southern High Plains contains numerous shallow circular depressions, called playas, that intermittently contain water following heavy rains. Some geologists believe these depressions are due to solution of soluble materials by percolating water and accompanying compaction of the alluvium. Other significant topographic features include sand dunes, which are especially prevalent in central and northern Nebraska, and wide, downcut valleys of streams that flow eastward across the area from the Rocky Mountains.

The High Plains region is underlain by one of the most productive and most intensively developed aquifers in the United States. The alluvial materials derived from the Rocky Mountains, which are referred to as the Ogallala Formation, are the dominant geologic unit of the High Plains aquifer. The Ogallala ranges in thickness from a few meters to more than 200 m and consists of poorly sorted and generally unconsolidated clay, silt, sand, and gravel.

Younger alluvial materials of Quaternary age overlie the Ogallala Formation of late Tertiary age in most parts of the High Plains. Where these deposits are saturated, they form a part of the High Plains aquifer; in parts of south-central Nebraska and central Kansas, where the Ogallala is absent, they comprise the entire aquifer. The Quaternary deposits are composed largely of material derived from the Ogallala and consist of alluvial deposits of gravel, sand, silt, and clay and extensive areas of sand dunes. The most extensive area of dune sand occurs in the Sand Hills area north of the Platte River in Nebraska.

Other, older geologic units that are hydrologically connected to the Ogallala thus form a part of the High Plains aquifer include the Arikaree Group of Miocene age and a small part of the underlying Brule Formation. The

Arikaree Group underlies the Ogallala in parts of western Nebraska, southwestern South Dakota, southeastern Wyoming, and northeastern Colorado. It is predominantly a massive, very fine to fine-grained sandstone that locally contains beds of volcanic ash, silty sand, and sandy clay. The maximum thickness of the Arikaree is about 300 m, in western Nebraska. The Brule Formation of Oligocene age underlies the Arikaree. In most of the area in which it occurs, the Brule forms the base of the High Plains aquifer. However, in the southeastern corner of Wyoming and the adjacent parts of Colorado and Nebraska, the Brule contains fractured sandstones hydraulically interconnected to the overlying Arikaree Group; in this area the Brule is considered to be a part of the High Plains aquifer.

In the remainder of the region, the High Plains aquifer is underlain by several formations, ranging in age from Cretaceous to Permian and composed principally of shale, limestone, and sandstone. The oldest of these, of Permian age, underlies parts of northeastern Texas, western Oklahoma, and central Kansas and contains layers of relatively soluble minerals including gypsum, anhydrite, and halite (common salt) which are dissolved by circulating ground water. Thus, water from the rocks of Permian age is relatively highly mineralized and not usable for irrigation and other purposes that require freshwater. The older formations in the remainder of the area contain fractured sandstones and limestones interconnected in parts of the area with the High Plains aquifer. Although these formations yield freshwater, they are not widely used as water sources.

Prior to the erosion that removed most of the western part of the Ogallala, the High Plains aquifer was recharged by the streams that flowed onto the plain from the mountains to the west as well as by local precipitation. The only source of recharge now is local precipitation, which ranges from about 400 mm along the western boundary of the region to about 600 mm along the eastern boundary. Precipitation and ground-water recharge on the High Plains vary in an east-west direction, but recharge to the High Plains also varies in a north-south direction. The average annual rate of recharge has been determined to range from about 5 mm in Texas and New Mexico to about 100 mm in the Sand Hills in Nebraska. This large difference is explained by differences in evaporation and transpiration and by differences in the permeability of the surficial materials.

In some parts of the High Plains, especially in the southern part, the near-surface layers of the Ogallala have been cemented with lime (calcium carbonate) to form a material of relatively low permeability called caliche. Precipitation on areas underlain by caliche soaks slowly into the ground. Much of this precipitation collects in playas that are underlain by silt and clay, which hamper infiltration, with the result that most of the water is lost to evaporation. During years of average or below average precipitation, all or nearly all of the precipitation is returned to the atmosphere by evapotranspiration. Thus, it is only during years of excessive precipitation that significant recharge occurs and this, as noted above, averages only about 5 mm per year in the southern part of the High Plains.

In the Sand Hills area of Nebraska, the lower evaporation and transpiration and the permeable sandy soil results in about 20 percent of the precipitation (or about 100 mm annually) reaching the water table as recharge.

The water table of the High Plains aquifer has a general slope toward the southeast of about 2 to 3 m per km (10 to 15 ft per mile). Gutentag and Weeks (1980) estimate, on the basis of the average hydraulic gradient and aquifer characteristics, that water moves through the aquifer at a rate of about 0.3 m (1 ft) per day.

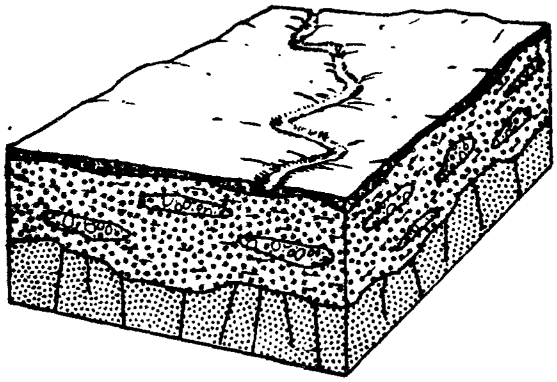
Natural discharge from the aquifer occurs to streams, springs, saline lakes and seeps along the eastern boundary of the plains, and by evaporation and transpiration in areas where the water table is within a few meters of the land surface. However, at present the largest discharge is probably through wells. The widespread occurrence of permeable layers of sand and gravel, which permit the construction of large-yield wells almost any place in the region, has led to the development of an extensive agricultural economy largely dependent on irrigation. Gutentag and Weeks (1980) estimate that in 1977 about $3.7 \times 10^{10} m^3$ (30,000,000 acre-ft) of water was pumped from more than 168,000 wells to irrigate about 65,600 km^2 (16,210,000 acres). Most of this water is derived from ground-water storage, resulting in a long-term continuing decline in ground-water levels in parts of the region of as much as 1 m per year. The lowering of the water table has resulted in a 10 to 50 percent reduction in the saturated thickness of the High Plains aquifer in an area of 130,000 km^2 (12,000 mi^2). The largest reductions have occurred in the Texas panhandle and in parts of Kansas and New Mexico.

The depletion of ground-water storage in the High Plains, as reflected in the decline in the water table and the reduction in the saturated thickness, is a matter of increasing concern in the region. However, from the standpoint of the region as a whole, the depletion does not yet represent a large part of the storage that is available for use. Weeks and Gutentag (1981) estimate, on the basis of a specific yield of 15 percent of the total volume of saturated material, that the available (usable) storage in 1980 was about $4 \times 10^{12} m^3$ (3.3 billion acre-ft). Luckey, Gutentag, and Weeks (1981) estimate that this is only about 5 percent less than the storage that was available at the start of withdrawals. However, in areas where intense irrigation has long been practiced, depletion of storage is severe.

HIGH PLAINS

(5A) Ogallala

This hydrogeologic setting is characterized by moderately flat topography and thick deposits of poorly-sorted, semi-consolidated, clay, silt, sand and gravel that may be underlain by fractured sedimentary rock which is in hydraulic connection with overlying deposits. In some parts of the High Plains, especially in the southern part, shallow zones of the unconsolidated deposits have been cemented with calcium carbonate. The permeability of this caliche layer varies with the degree of cementation, fracturing and clay mineral content. Precipitation averages less than 20 inches per year and recharge is very low throughout most of this water- deficient area. The bedrock and the overlying semi-consolidated deposits both serve as extensive sources of ground water. Water levels are typically deep, but extremely variable. The Ogallala is underlain by bedded, unconsolidated deposits of fractured sandstone, limestone, volcanic ash, silty sand, sandy clay and shales. These formations are hydraulically connected to the Ogallala and the overlying alluvium, from which they derive their recharge.



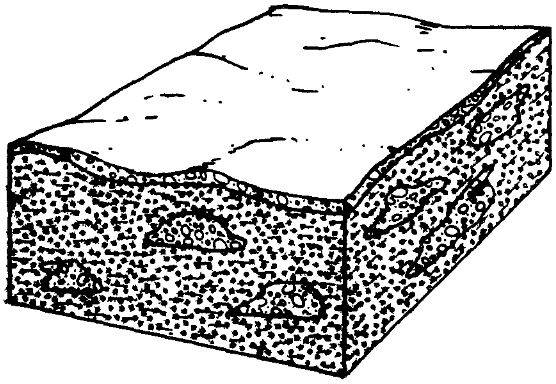
SETTING 5 A Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Shrink/Agg. Clay	2	7	14
Topography	2-6%	1	9	9
Impact Vadose Zone	S & G w/ sig. Silt and Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	109

SETTING 5 A Ogallala		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Shrink/Agg. Clay	5	7	35
Topography	2-6%	3	9	27
Impact Vadose Zone	S & G w/ sig. Silt and Clay	4	6	24
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	136

HIGH PLAINS

(5B) Alluvium

This hydrogeologic setting is characterized by low to moderate relief, and is comprised of gravel, sand, silt and clay alluvial sediments. These deposits are variable in thickness. They form, where saturated, a portion of the High Plains aquifer, and locally all of it where the Ogallala is missing. Water levels are variable, but typically deep. Recharge is limited throughout most of the area by low precipitation. The shallow caliche layer of cemented, unconsolidated deposits also develops in the alluvium in some localities. Similar to the Ogallala, recharge to the deeper sandstones is through the alluvial deposits.



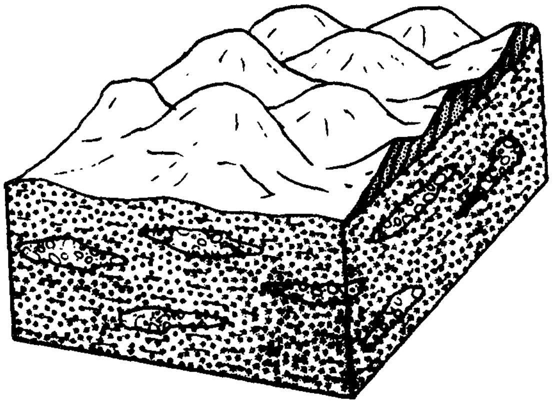
SETTING 5 B Alluvium		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	S & G w/ sig. Silt and Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	107

SETTING 5 B Alluvium		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	0-2%	3	10	30
Impact Vadose Zone	S & G w/ sig. Silt and Clay	4	6	24
Hydraulic Conductivity	300-700	2	4	8
			Pesticide Drastic Index	135

HIGH PLAINS

(5C) Sand Dunes

This hydrogeologic setting is characterized by hilly topography comprised of sand dunes which overlie thick poorly-sorted sand and gravel deposits. The sand dunes are in direct hydraulic connection with the underlying deposits. Because of their relatively low water table, these dunes do not serve as sources of ground water, but serve as local recharge areas. In contrast to other areas of the High Plains, recharge rates are higher due to lower evaporation and permeable sandy soils, but are limited by available precipitation.



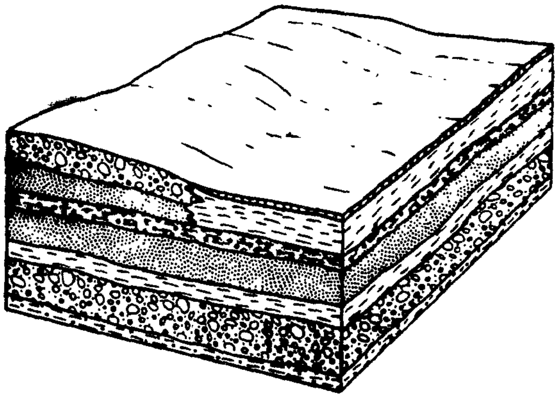
SETTING 5 C Sand Dunes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	150

SETTING 5 C Sand Dunes		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	5	9	45
Topography	2-6%	3	9	27
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	2000+	2	10	20
			Pesticide Drastic Index	177

HIGH PLAINS

(5D) Playa Lakes

This hydrogeologic setting is characterized by low topographic relief and thin layers of clays and other fine-grained sediments which overlie the alluvial deposits. The playa areas serve as a catchment for water during periods of significant runoff. Ground water is obtained from the layers of sand which underlie the finer-grained deposits. Water levels are extremely variable, but are typically deep. The playa beds are significant recharge areas due to the rainfall that collects in them. The rate of recharge, as compared to evaporation, is largely a function of the permeability of the materials forming the bed of the playa, and the precipitation distribution over time.

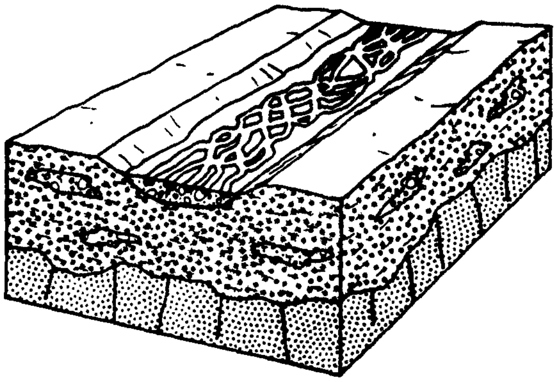


SETTING 5 D Playa Lakes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Shrink/Agg. Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	S & G w/ sig. Silt and Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	110

SETTING 5 D Playa Lakes		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Shrink/Agg. Clay	5	7	35
Topography	0-2%	3	10	30
Impact Vadose Zone	S & G w/ sig. Silt and Clay	4	6	24
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	139

(5E) Braided River Deposits

This hydrogeologic setting is characterized by deposits of alluvium which occur within the flood plain of streams and rivers. The stream is characterized by a low gradient, wide channel and a series of interconnected shallow channels which form a braided pattern. Water levels are typically shallow, and some streams may be intermittent. The river alluvium sometimes serves as a significant source of ground water but is most important as a source of recharge since it overlies more productive semi-consolidated deposits. The underlying deposits are in direct hydraulic connection with the overlying alluvium, so the potential for pollution of the aquifer is high. Although precipitation, which averages less than 20 inches per year is a limiting factor, recharge may be very high due to seasonal or perennial stream flow on these very permeable deposits.

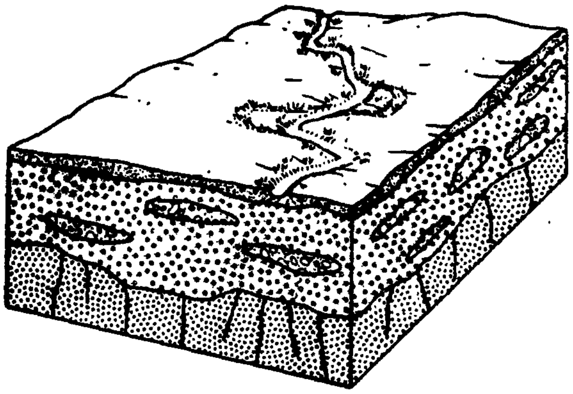


SETTING 5 E Braided River Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	185

SETTING 5 E Braided River Deposits		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	5	9	45
Topography	0-2%	3	10	30
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	216

(5F) Swamp/Marsh

This hydrogeologic setting is characterized by low topographic relief and high water levels in floodplains immediately adjacent to perennial streams. The deposits contain moderate amounts of organic material within the sandy river alluvium. Recharge is potentially high and is dependant primarily on river infiltration. The deposits may serve as aquifers or may recharge the underlying aquifer.



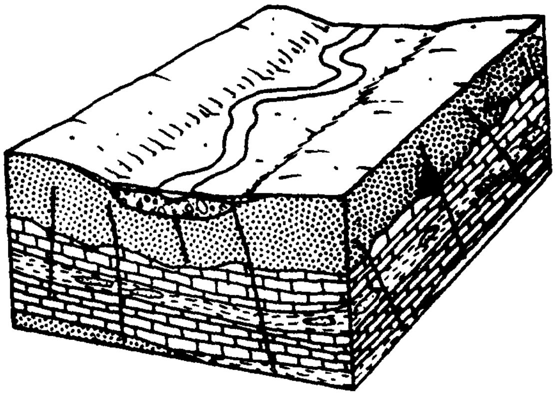
SETTING 5 F Swamp/Marsh		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	198

SETTING 5 F Swamp/Marsh		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	5	9	45
Topography	0-2	3	10	30
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	229

HIGH PLAINS

(5Ga) River Alluvium With Overbank Deposits

This hydrogeologic setting is characterized by low to moderate topography and thin to moderately thick deposits of alluvium along parts of river valleys. The alluvium is underlain by either unconsolidated deposits or fractured bedrock of sedimentary or igneous origin. Water is obtained from sand and gravel layers which are interbedded with finer-grained alluvial deposits. The alluvium may or may not be in direct hydraulic connection with the underlying units. The alluvium typically serves as a significant source of water. The flood plain is covered by varying thicknesses of fine-grained silt and clay, called overbank deposits. The overbank thickness is usually greater along major streams and thinner along minor streams but typically averages approximately 5 to 10 feet. Recharge is limited throughout most of the area by low precipitation. Water levels are typically moderately shallow and may be hydraulically connected to the stream or river.



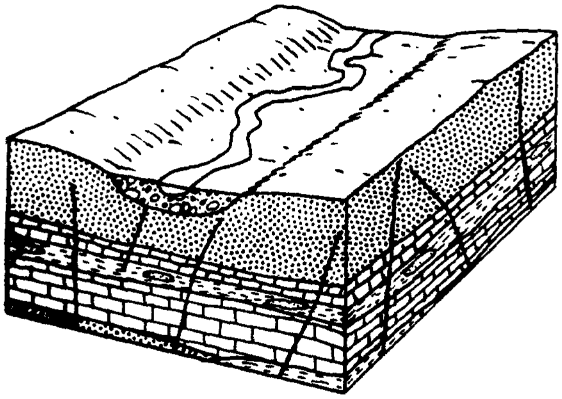
SETTING 5 Ga River Alluvium With Overbank Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	2	4	8
Topography	0-2	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	129

SETTING 5 Ga River Alluvium With Overbank Deposits		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water Table	15-30	5	7	35
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	5	4	20
Topography	0-2	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	4	6	24
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	129

HIGH PLAINS

(5Gb) River Alluvium Without Overbank Deposits

This setting is identical to (5Ga) River Alluvium with Overbank Deposits except that no significant fine-grained floodplain deposits occupy the stream valley. This normally would result in significantly higher recharge except that precipitation is limited in the area. Where irrigation is a factor, recharge will occur more easily in these deposits because of the sandy soils which occur at the surface. Water levels are moderate to shallow where streamflow exists because the hydraulic connection with the surface stream is usually excellent. Alternating recharge/discharge relationships will vary with the stream stage.

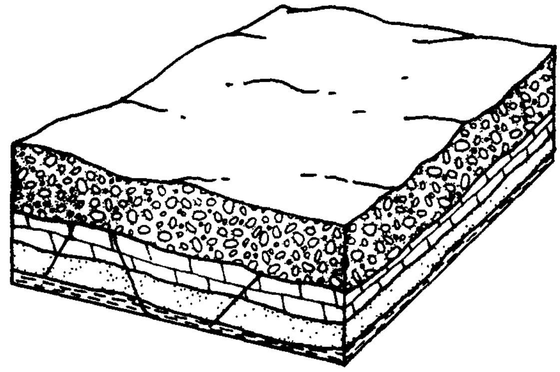


SETTING 5 Gb River Alluvium Without Overbank Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	0-2	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	143

SETTING 5 Gb River Alluvium Without Overbank Deposits		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	0-2	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	4	6	24
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	149

(5H) Alternating Sandstone, Limestone and Shale Sequences

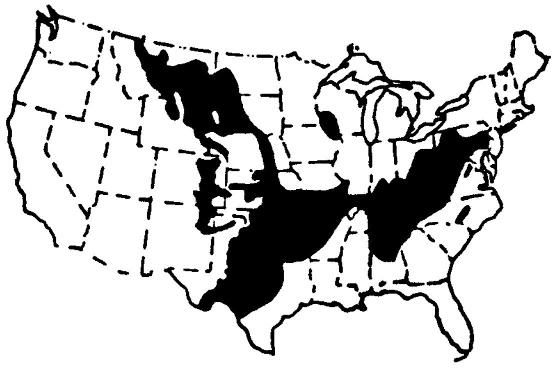
This hydrogeologic setting is characterized by low topographic relief and loamy soils which overlie thick deposits of poorly sorted, semi- consolidated clay, silt, sand and gravel. These unconsolidated deposits are underlain by horizontal or slightly dipping alternating layers of fractured consolidated sedimentary rocks. Precipitation averages less than 20 inches per year and recharge is very low throughout most of this water-deficient area. In areas where the unconsolidated deposits are not saturated, ground water is obtained primarily from fractures along bedding planes or intersecting vertical fractures. Where the unconsolidated deposits contain water, they are typically in direct hydraulic connection with the underlying bedrock.

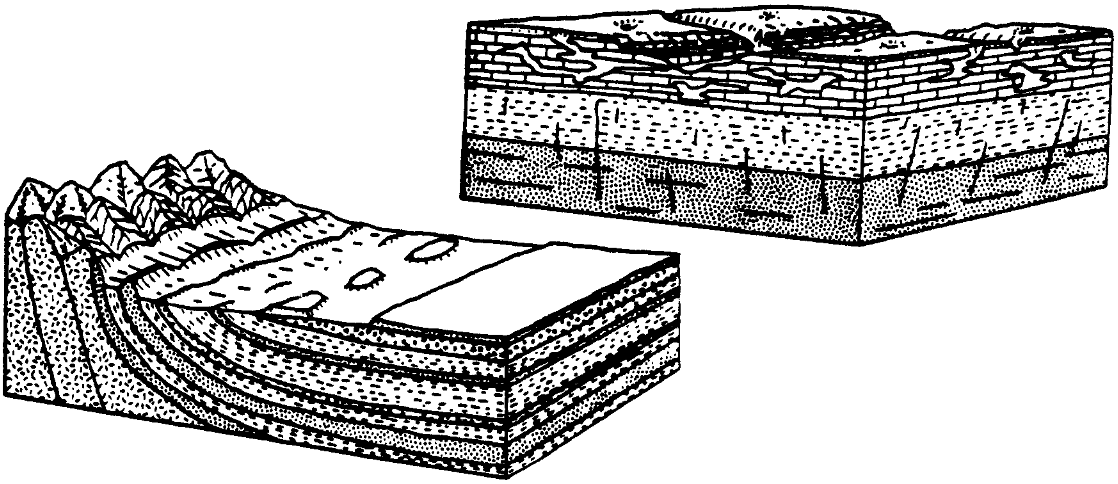


SETTING 5 H Alternating Sandstone, Limestone, Shale Sequences		GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Bedded SS, LS SH Sequences	3	6	18
Soil Media	Low	2	5	10
Topography	0-2	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	81

SETTING 5 H Alternating Sandstone, Limestone, Shale Sequences		PESTICIDE		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	SH Sequences	3	6	18
Soil Media	Loam	5	5	25
Topography	0-2	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	4	6	24
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	88

6. NONGLACIATED CENTRAL GROUND-WATER REGION





6A	Mountain Slopes
6B	Alluvial Mountain Valleys
6C	Mountain Flanks
6Da	Alternating Sandstone, Limestone and Shale - Thin Soil
6Db	Alternating Sandstone, Limestone and Shale - Deep Regolith
6E	Solution Limestone
6Fa	River Alluvium With Overbank Deposits
6Fb	River Alluvium Without Overbank Deposits
6G	Braided River Deposits
6H	Triassic Basins
6I	Swamp/Marsh
6J	Metamorphic/Igneous Domes and Fault Blocks
6K	Unconsolidated and Semi-consolidated Aquifers

6. NONGLACIATED CENTRAL REGION

(Thin regolith over fractured sedimentary rocks)

The nonglaciated Central region is an area of about 1,737,000 km^2 extending from the Appalachian Mountains on the east to the Rocky Mountains on the west. The part of the region in eastern Colorado and northeastern New Mexico is separated from the remainder of the region by the High Plains region. The Nonglaciated Central region also includes the Triassic Basins in Virginia and North Carolina and the "driftless" area in Wisconsin, Minnesota, Iowa, and Illinois where glacial deposits, if present, are thin and of no hydrologic importance. The region is a topographically complex area that ranges from the Valley and Ridge section of the Appalachian Mountains on the east westward across the Great Plains to the foot of the Rocky Mountains. It includes, among other hilly and mountainous areas, the Ozark Plateaus in Missouri and Arkansas. Altitudes range from 150 m above sea level in central Tennessee and Kentucky to 1,500 m along the western boundary of the region.

The region is also geologically complex. Most of it is underlain by consolidated sedimentary rocks that range in age from Paleozoic to Tertiary and consist largely of sandstone, shale, carbonate rocks (limestone and dolomite), and conglomerate. A small area in Texas and western Oklahoma is underlain by gypsum. Throughout most of the region the rock layers are horizontal or gently dipping. Principal exceptions are the Valley and Ridge section of the Wichita and Arbuckle Mountains in Oklahoma, and the Ouachita Mountains in Oklahoma and Arkansas, in all of which the rocks have been folded and extensively faulted. Around the Black Hills and along the eastern side of the Rocky Mountains the rock layers have been bent up sharply toward the mountains and truncated by erosion. The Triassic Basins in Virginia and North Carolina are underlain by moderate to gently dipping beds of shale and sandstone that have been extensively faulted and invaded by narrow bodies of igneous rock. These basins were formed in Triassic time when major faults in the crystalline rocks of the Piedmont resulted in the formation of structural depressions up to several thousand meters deep and more than 25 km wide and 140 km long.

The land surface in most of the region is underlain by regolith formed by chemical and mechanical breakdown of the bedrock. In the western part of the Great Plains the residual soils are overlain by or intermixed with eolian (wind-laid) deposits. The thickness and composition of the regolith depend on the composition and structure of the parent rock and on the climate, land cover, and topography. In areas underlain by relatively pure limestone, the regolith consists mostly of clay and is generally only a few meters thick. Where the limestones contain chert and in areas underlain by shale and sandstone, the regolith is thicker, up to 30 m or more in some areas. The chert and sand form moderately permeable soils, whereas the soils developed on shale are finer grained and less permeable.

The principal water-bearing openings in the bedrock are fractures along which the rocks have been broken by stresses imposed on the Earth's crust at different times since the rocks were consolidated. The fractures generally occur in three sets. The first set, and the one that is probably of greatest importance from the standpoint of ground water and well yields, consists of fractures developed along the contact between different rock layers, in other words, along bedding planes. Where the sedimentary layers making up the bedrock are essentially horizontal, the bedding-plane fractures are more or less parallel to the land surface. The two remaining sets of fractures are essentially vertical and thus cross the bedding planes at a steep angle. The primary difference between the sets of vertical fractures is in the orientation of the fractures in each set. For example, in parts of the region one set of vertical fractures is oriented in a northwest-southeast direction and the other set in a northeast-southwest direction. The vertical fractures facilitate movement of water across the rock layers and thus serve as the principal hydraulic connection between the bedding-plane fractures.

In the parts of the region in which the bedrock has been folded or bent, the occurrence and orientation of fractures are more complex. In these areas the dip of the rock layers and the associated bedding-plane fractures range from horizontal to vertical. Fractures parallel to the land surface, where present, are probably less numerous and of more limited extent than in areas of flat-lying rocks.

The openings developed along most fractures are less than a millimeter wide. The principal exception occurs in limestones and dolomites, which are more soluble in water than most other rocks. Water moving through these rocks gradually enlarges the fractures to form, in time, extensive cavernous openings or cave systems. Many large springs emerge from these openings; one in this region is Big Spring, in Missouri, which has an average discharge of 36.8 m^3sec^{-1}.

Recharge of the ground-water system in this region occurs primarily in the outcrop areas of the bedrock aquifers in the uplands between streams. Precipitation in the region ranges from about 400 mm per year in the western part to more than 1,200 mm in the eastern part. This wide difference in precipitation is reflected in recharge rates, which range from about 5 mm per year in west Texas and New Mexico to as much as 500 mm per year in Pennsylvania and eastern Tennessee. Discharge from the ground-water system is by springs and seepage into streams and by evaporation and transpiration in areas where the water table is within a few meters of land surface.

The yield of wells depends on (1) the number and size of fractures that are penetrated and the extent to which they have been enlarged by solution, (2) the rate of recharge, and (3) the storage capacity of the bedrock and regolith. Yields of wells in most of the region are small, in the range of 0.01 to 1 m^3min^{-1} (about 2.5 to about 250 gallons per minute), making the Nonglaciated Central region one of the least favorable ground-water regions in the country. Even in parts of the areas underlain by cavernous limestone, yields are moderately low because of both the absence of a thick regolith and the large water-transmitting capacity of the cavernous openings which quickly discharge the water that reaches them during periods of recharge.

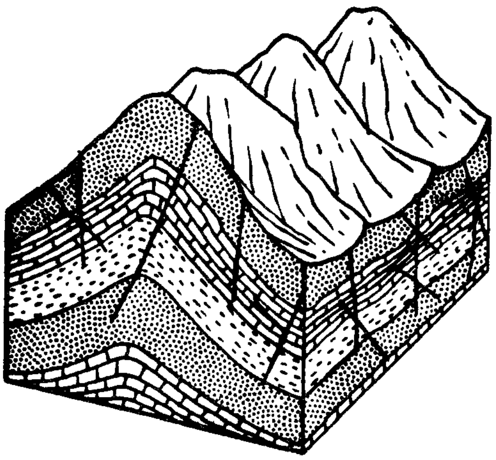
The exceptions to the small well yields are the cavernous limestones of the Edwards Plateau, the Ozark Plateaus, and the Ridge and Valley section. The Edwards Plateau in Texas is bounded on the south by the Balcones Fault Zone, in which limestone and dolomite up to 150 m in thickness has been extensively faulted. The faulting has facilitated the development of solution openings which makes this zone one of the most productive aquifers in the country. Wells of the City of San Antonio are located in this zone; individually, they have yields of more than 60 m^3min^{-1}.

Another feature that makes much of this region unfavorable for ground-water development is the occurrence of salty water at relatively shallow depths. In most of the Nonglaciated Central region, except the Ozark Plateaus, the Ouachita and Arbuckle Mountains, and the Ridge and Valley section, the water in the bedrock contains more than 1,000 mg/l of dissolved solids at depths less than 150 m. Most of the salty water is believed to be connate--that is, it was trapped in the rocks when they emerged from the sea in which they were deposited. Other possible sources include: (1) seawater that entered the rocks during a later time when the land again was beneath the sea and (2) salty water derived from solution of salt beds that underlie parts of the region.

The presence of connate water at relatively shallow depths is doubtless due to several factors, including, in the western part of the area, a semiarid climate and, consequently, a small rate of recharge. Other factors probably include an extremely slow rate of ground-water circulation at depths greater than a few hundred meters.

(6A) Mountain Slopes

This hydrogeologic setting is characterized by relatively steep slopes on the side of mountains or hills, a thin soil cover and fractured bedrock. Ground water is obtained primarily from the fractures in the bedrock which may be of sedimentary, metamorphic or igneous origin but which are commonly alternating sedimentary layers, and also from bedding planes between the sedimentary layers. The fractures provide only localized sources of ground water and well yields are typically limited. Although precipitation may be significant in some areas, due to the steep slopes, thin soil cover and small storage capacity of the fractures, runoff is significant and ground- water recharge is low. Water levels are extremely variable but are commonly moderately deep. Perched ground-water zones are common. These sedimentary rocks may range in attitude from nearly horizontal, as in parts of the western Appalachian Plateau, to steeply dipping, as seen in the Valley and Ridge province, the Wichita, Arbuckle and Ouachita Mountains, the Black Hills, and on the eastern slopes of the Rockies.

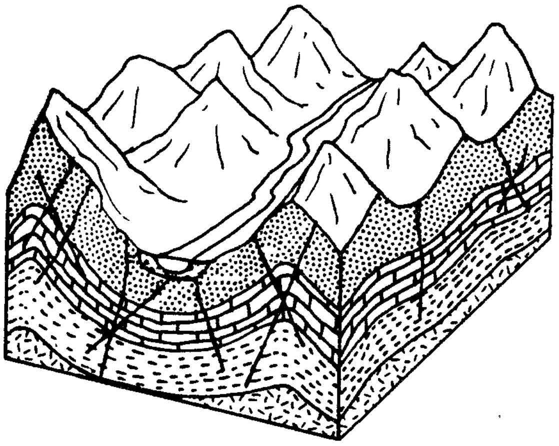


SETTING 6 A Mountain Slopes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	0-2	4	1	4
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Thin or Absent	2	10	20
Topography	12-18%	1	3	3
Impact Vadose Zone	Bedded LS, SS, SH	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	103

SETTING 6 A Mountain Slopes		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	0-2	4	1	4
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Thin or Absent	5	10	50
Topography	12-18%	3	3	9
Impact Vadose Zone	Bedded LS, SS, SH	4	6	24
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	132

(6B) Alluvial Mountain Valleys

This hydrogeologic setting is characterized by thin bouldery alluvium which overlies fractured bedrock of sedimentary, metamorphic or igneous origin but which is commonly comprised of alternating sedimentary layers. The alluvium, which is derived from the surrounding slopes serves as a localized source of water. Water is obtained from sand and gravel layers which are interspersed between finer-grained deposits. Surficial deposits have typically weathered to a sandy loam. Water levels are relatively shallow but may be extremely variable. Ground water may also be obtained from the fractures in the underlying bedrock which are typically in direct hydraulic connection with the overlying alluvium.



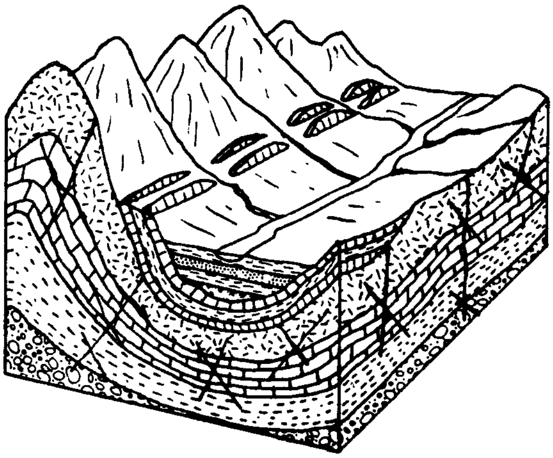
SETTING 6 B Alluvial Mountain Valleys		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	S & G w/ sig. Silt and Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	152

SETTING 6 B Alluvial Mountain Valleys		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	2-6%	3	9	27
Impact Vadose Zone	S & G w/ sig. Silt and Clay	4	6	24
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	176

NON-GLACIATED CENTRAL

(6C) Mountain Flanks

This hydrogeologic setting is characterized by moderate topographic relief and moderately-dipping, fractured, consolidated, sedimentary rocks. Soil cover is usually thicker than on the mountain slopes and typically has weathered to a sandy loam. Although precipitation can be significant, ground-water recharge is only moderate due to the slope. Water levels are typically moderately deep although they are extremely variable. The mountain flanks serve as the recharge area for aquifers which are confined in adjacent areas. Ground water is obtained from the permeable sedimentary rocks or from fractures in the sedimentary rocks. The sedimentary rocks may be underlain by fractured bedrock of igneous, metamorphic or sedimentary origin which yield little water. Sedimentary beds may be either horizontal or dipping, as indicated for the higher mountain slopes (6A), and have a similar geographic distribution.



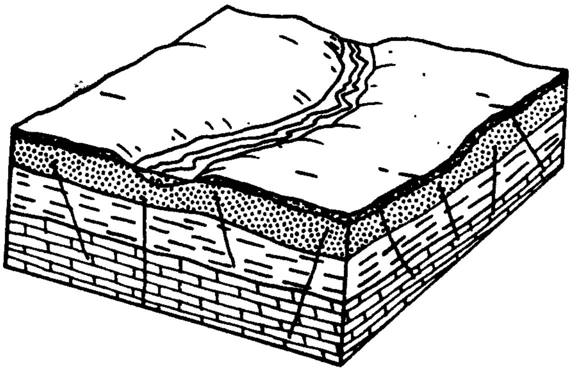
SETTING 6 C Mountain Flanks		GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	30-50	5	5	25
Net Recharge	2-4	4	3	12
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Sandy Loam	2	6	12
Topography	6-12%	1	5	5
Impact Vadose Zone	Bedded LS, SS, SH	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	105

SETTING 6 C Mountain Flanks		PESTICIDE		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	30-50	5	5	25
Net Recharge	2-4	4	3	12
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Sandy Loam	5	6	30
Topography	6-12%	3	5	15
Impact Vadose Zone	Bedded LS, SS, SH	4	6	24
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	126

NON-GLACIATED CENTRAL

(6Da) Alternating Sandstone, Limestone and Shale - Thin Soil

This hydrogeologic setting is characterized by low to moderate topographic relief, relatively thin loamy soils overlying horizontal or slightly dipping alternating layers of fractured consolidated sedimentary rocks. Ground water is obtained primarily from fractures along bedding planes or intersecting vertical fractures. Precipitation varies widely in the region, but recharge is moderate where precipitation is adequate. Water levels are extremely variable but on the average moderately shallow. Shale or clayey layers often form aquitards, and where sufficient relief is present, perched ground water zones of local domestic importance are often developed.

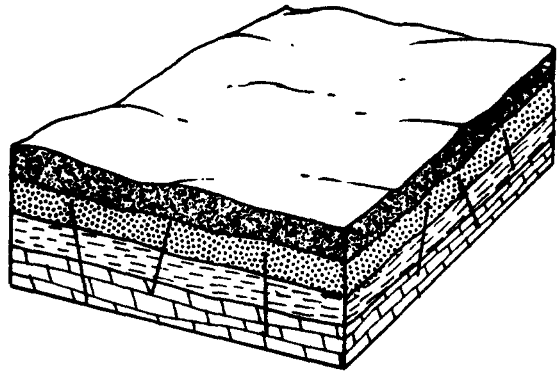


SETTING 6 Da Alternating Sandstone, Limestone, Shale - Thin Soil		GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Thin or Absent	2	10	20
Topography	2-6%	1	9	9
Impact Vadose Zone	Bedded LS, SS, SH	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	139

SETTING 6 Da Alternating Sandstone, Limestone, Shale - Thin Soil		PESTICIDE		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Thin or Absent	5	10	50
Topography	2-6%	3	9	27
Impact Vadose Zone	Bedded LS, SS, SH	4	6	24
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	180

(6Db) Alternating Sandstone, Limestone and Shale - Deep Regolith

This setting is identical to (6Da) Alternating Sandstone, Limestone and Shale - Thin Soil except that the surficial deposits typically have been weathered to form clay loams which grade into weathered bedrock. This weathered zone helps retard the movement of pollutants through the ground to the water table. These thick soil deposits are usually in direct, hydraulic connection with the underlying fractured sedimentary deposits.

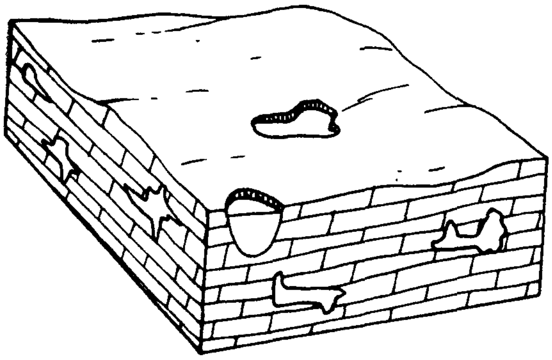


SETTING 6 Db Alternating Sandstone, Limestone, Shale - Deep Regolith		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	Bedded LS, SS, SH	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	125

SETTING 6 Db Alternating Sandstone, Limestone, Shale - Deep Regolith		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	16
Soil Media	Clay Loam	5	3	15
Topography	2-6%	3	9	27
Impact Vadose Zone	Bedded LS, SS, SH	4	6	24
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	145

(6E) Solution Limestone

This hydrogeologic setting is characterized by moderate, but variable, topographic relief and deposits of limestone which have been partially dissolved along bedding and fracture planes to form a network of solution cavities and caves. Soil is usually thin or absent, but where present is commonly a clayey loam. Recharge is usually greater than 10 inches per year because the region receives significant amounts of rainfall which is easily recharged through the solution channels. Runoff return through solution channels into surface watercourses is sometimes very high. Water levels are typically moderately deep. The limestone serves as a significant source of ground water because of the high hydraulic conductivity of the solution channels. Caves related to this setting are widespread, but their greatest concentration occurs in a band 200-400 miles wide extending from central Missouri through western Virginia.



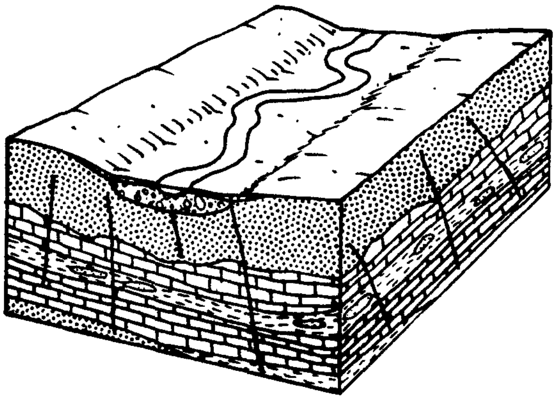
SETTING 6 E Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Thin or Absent	2	10	20
Topography	6-12%	1	5	5
Impact Vadose Zone	Karst Limestone	5	10	50
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	196

SETTING 6 E Solution Limestone		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Thin or Absent	5	10	50
Topography	6-12%	3	5	15
Impact Vadose Zone	Karst Limestone	4	10	40
Hydraulic Conductivity	2000+	2	10	20
			Pesticide Drastic Index	216

NON-GLACIATED CENTRAL

(6Fa) River Alluvium with Overbank Deposits

This hydrogeologic setting is characterized by low topography and deposits of alluvium along parts of stream valleys. Water is obtained from sand and gravel layers which are interbedded with finer-grained alluvial deposits. The floodplain is covered by varying thicknesses of fine-grained silt and clay called overbank deposits. The overbank thickness is usually thicker along major streams (commonly as much as 40 feet), and thinner along minor streams. Precipitation varies widely over the region, but recharge is somewhat reduced because of the impermeable nature of the overbank deposits and subsequent clayey loam soils which typically cover the surface. There is usually substantial recharge, however, due to infiltration from the associated stream, water levels are typically moderately shallow. The alluvium is commonly in direct hydraulic connection with the underlying sedimentary rocks.



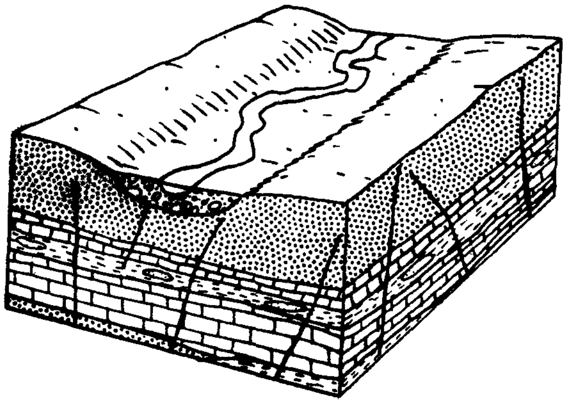
SETTING 6 Fa River Alluvium with Overbank Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Clay Loam	2	3	6
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	126

SETTING 6 Fa River Alluvium with Overbank Deposits		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Clay Loam	5	3	15
Topography	0-2%	3	10	30
Impact Vadose Zone	Silt/Clay	4	3	12
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	164

NON-GLACIATED CENTRAL

(6Fb) River Alluvium without Overbank Deposits

This setting is identical to (6Fa) River Alluvium with Overbank Deposits except that no significant fine-grained floodplain deposits occupy the stream valley. This results in significantly higher recharge where precipitation is adequate and sandy loam soils occur at the surface. Water levels are typically closer to the surface because the fine-grained overbank deposits are not present.



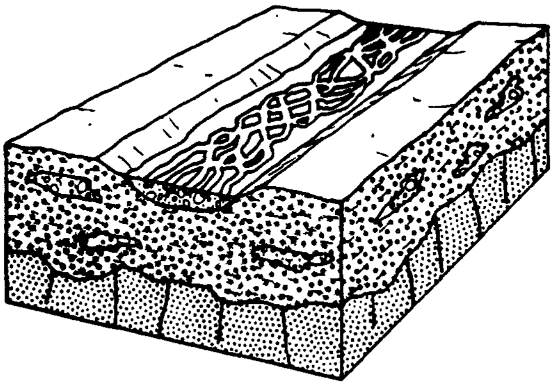
SETTING 6 Fb River Alluvium without Overbank Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	187

SETTING 6 Fb River Alluvium without Overbank Deposits		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	0-2%	3	10	30
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	209

NON-GLACIATED CENTRAL

(6G) Braided River Deposits

This hydrogeologic setting is characterized by deposits of alluvium which occur within the flood plain of streams and rivers. The stream is characterized by a low gradient, wide channel and series of interconnected shallow channels which form a braided pattern. Water levels are typically shallow. This setting is found only in the western portion of this ground- water region. The river alluvium does not serve as a significant source of ground water where it overlies more productive semi-consolidated deposits. However, recharge from the river is substantial and the underlying deposits are in direct hydraulic connection with the overlying alluvium; therefore the potential for pollution of the aquifer is high. Although precipitation commonly averages less than 20 inches per year, recharge is relatively high due to the flat topography and sandy surficial deposits.



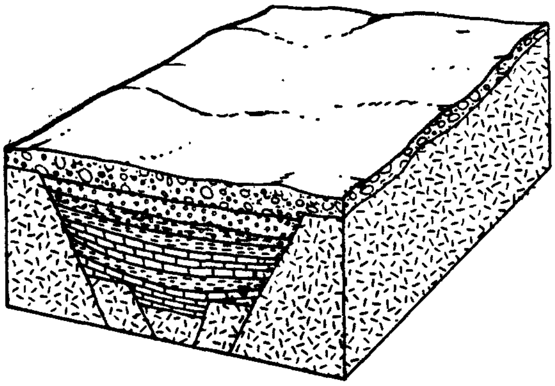
SETTING 6 G Braided River Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	190

SETTING 6 G Braided River Deposits		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	5	9	45
Topography	0-2%	3	10	30
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	221

NON-GLACIATED CENTRAL

(6H) Triassic Basins

This hydrogeologic setting is characterized by moderately dipping, highly faulted beds of sandstone, shale and silty limestone. Conglomeritic deposits occur in some areas. These basins tend to be bounded by high angle faults, with the basins being elongate in the NE-SW directions. The sedimentary beds may be cut by narrow igneous intrusions (dikes, etc.), and are sometimes indurated by the intrusive activity. The Triassic formations are often red in color due to high iron concentrations, but green colors are also common. These deposits may serve as a localized source of water and water levels are variable.



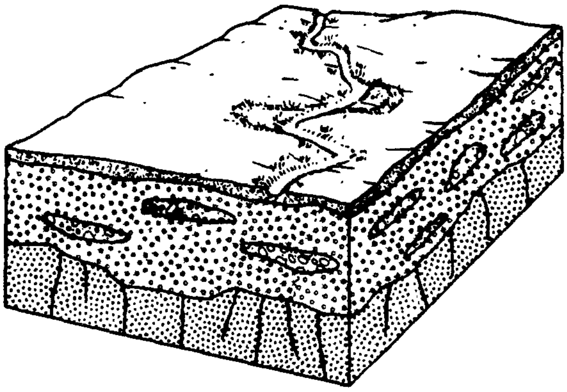
SETTING 6 H Triassic Basins		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	4-7	4	6	24
Aquifer Media	Massive Sandstone	3	6	18
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	Bedded LS, SS, SH	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	106

SETTING 6 H Triassic Basins		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	4-7	4	6	24
Aquifer Media	Massive Sandstone	3	6	18
Soil Media	Sandy Loam	5	6	30
Topography	2-6%	3	9	27
Impact Vadose Zone	Bedded LS, SS, SH	4	6	24
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	135

NON-GLACIATED CENTRAL

(6I) Swamp/Marsh

This hydrogeologic setting is characterized by low topographic relief and high water levels with high organic content in the sandy clay deposits. The high water tables are a result of either restricted vertical conductivity or restricted drainage patterns. Recharge is highly variable but is typically moderate to high where precipitation and/or streamflow permit. These deposits may serve as aquifers or may serve as recharge to the underlying aquifer.



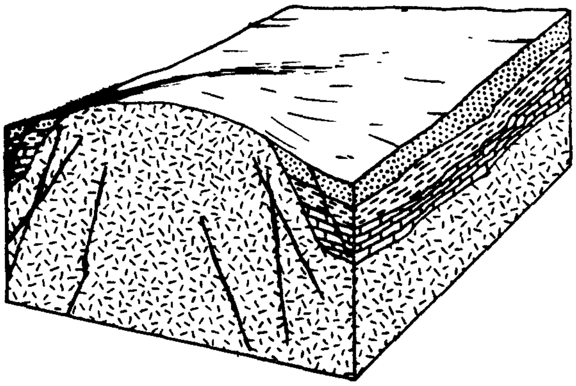
SETTING 6 I Swamp/Marsh		GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	0-5	5	10	50
Net Recharge	4-7	4	6	24
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Clay Loam	2	3	6
Topography	0-2	1	10	10
Impact Vadose Zone	S & G w/sig. Silt and Clay	5	6	30
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	144

SETTING 6 I Swamp/Marsh		PESTICIDE		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	0-5	5	10	50
Net Recharge	4-7	4	6	24
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Clay Loam	5	3	15
Topography	0-2	3	10	30
Impact Vadose Zone	S & G w/sig. Silt and Clay	4	6	24
Hydraulic Conductivity	100-300	2	2	4
			Pesticide Drastic Index	165

NON-GLACIATED CENTRAL

(6J) Metamorphic/Igneous Domes and Fault Blocks

This hydrogeologic setting is characterized by metamorphic and igneous rocks exposed at the surface. The rocks are typically more highly fractured and faulted along the flanks of the domes. The domes are flanked by gently dipping deposits of sedimentary rocks which may also be faulted adjacent to the dome. Soil is typically thin or absent and water levels are extremely variable. Recharge rates are typically low because of excessive surface runoff and low permeabilities. Water yields are extremely variable depending on the degree of folding and faulting but typically are higher along the more fractured flank zones. Where few fractures exist, water yields are very low or non-existent.



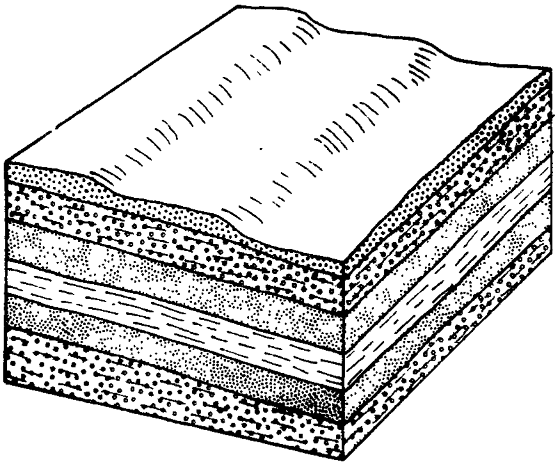
SETTING 6 J Metamorphic/Igneous Domes and Fault Blocks		GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Thin or Absent	2	10	20
Topography	6-12	1	5	5
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	71

SETTING 6 J Metamorphic/Igneous Domes and Fault Blocks		PESTICIDE		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water Table	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Thin or Absent	5	10	50
Topography	6-12	1	5	5
Impact Vadose Zone	Metamorphic/Igneous	4	4	16
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	96

NON-GLACIATED CENTRAL

(6K) Unconsolidated and Semi-Consolidated Aquifers

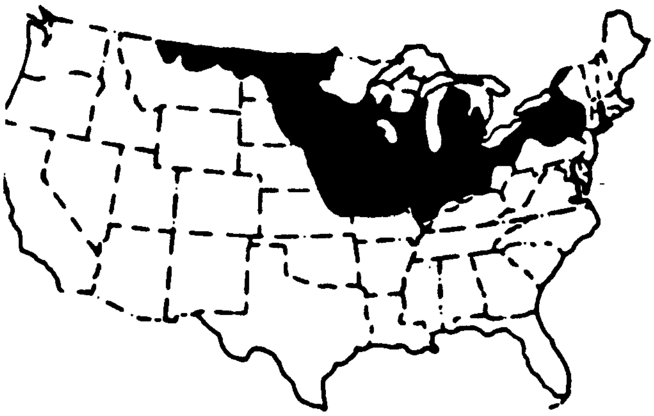
This hydrogeologic setting is characterized by moderately low topographic relief and interbedded deposits which consist primarily of sand, silt and clay. Although soils are typically loamy or sandy, recharge is limited because of only moderate precipitation and high evapotranspiration. Water levels are extremely variable but are typically not less than 50 feet. Hydraulic conductivities are also extremely variable also depending on the amount of fine materials which are interbedded with the sands.

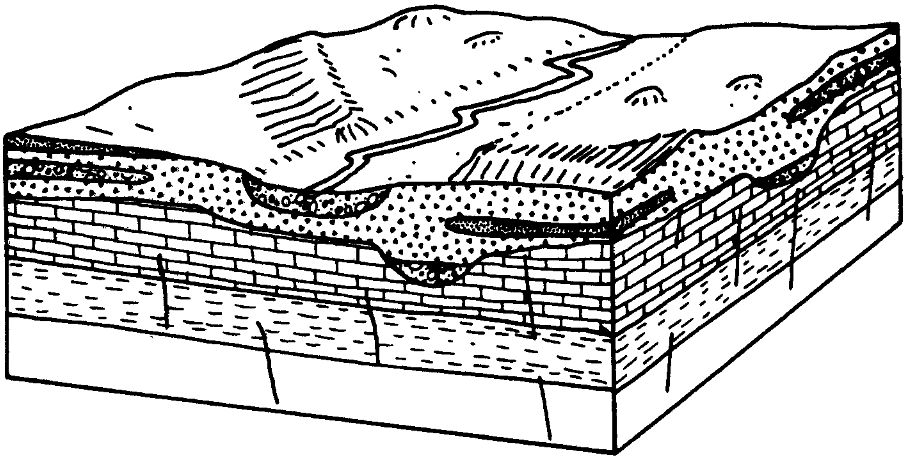


SETTING 6 K Unconsolidated and Semi-Consolidated Aquifers		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig. Silt & Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	101

SETTING 6 K Unconsolidated and Semi-Consolidated Aquifers		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water Table	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	2-6%	1	9	9
Impact Vadose Zone	S&C w/sig. Silt & Clay	4	6	24
Hydraulic Conductivity	300-700	2	4	8
			Pesticide Drastic Index	109

7. GLACIATED CENTRAL GROUND-WATER REGION





7Aa	Glacial Till Over Bedded Sedimentary Rock
7Ab	Glacial Till Over Outwash
7Ac	Glacial Till Over Solution Limestone
7Ad	Glacial Till Over Sandstone
7Ae	Glacial Till Over Shale
7Ba	Outwash
7Bb	Outwash Over Bedded Sedimentary Rock
7Bc	Outwash Over Solution Limestone
7C	Moraine
7D	Buried Valley
7Ea	River Alluvium With Overbank Deposits
7Eb	River Alluvium Without Overbank Deposits
7F	Glacial Lake Deposits
7G	Thin Till Over Bedded Sedimentary Rock
7H	Beaches, Beach Ridges and Sand Dunes
7I	Swamp/Marsh

7. GLACIATED CENTRAL REGION

(Glacial deposits over fractured sedimentary rocks)

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

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

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

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

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

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

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

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

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

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

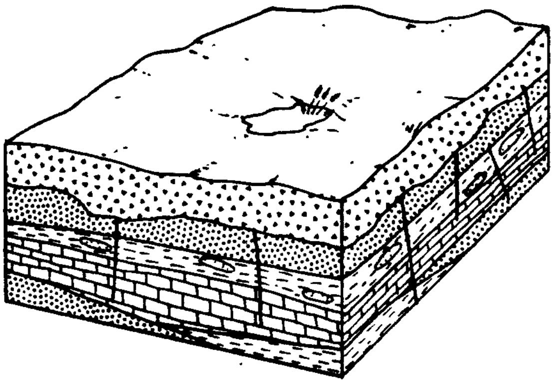
The Glaciated Central region and the Northeast and Superior Uplands region are similar in that the unconsolidated material in both consists of glacial deposits. However, the bedrock in the two regions is different. The bedrock in the Glaciated Central region, as we have already seen, consists of consolidated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

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

GLACIATED CENTRAL

(7Aa) Glacial Till Over Bedded Sedimentary Rocks

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



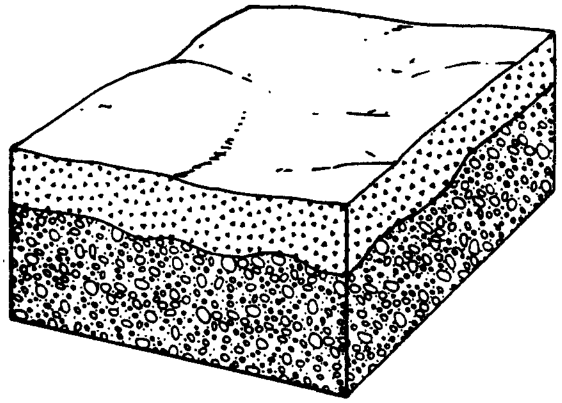
ING 7 Aa Glacial Till Over Bedded Sedimentary Rock		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity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

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

GLACIATED CENTRAL

(7Ab) Glacial Till Over Outwash

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

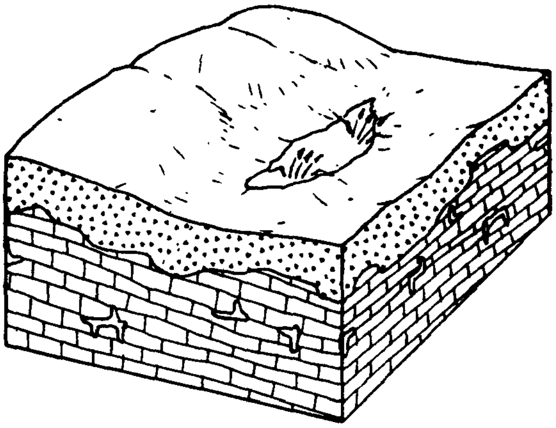


SETTING 7 Ab Glacial Till Over Outwash		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	1000-2000	3	8	24
	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

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

(7Ac) Glacial Till Over Solution Limestone

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

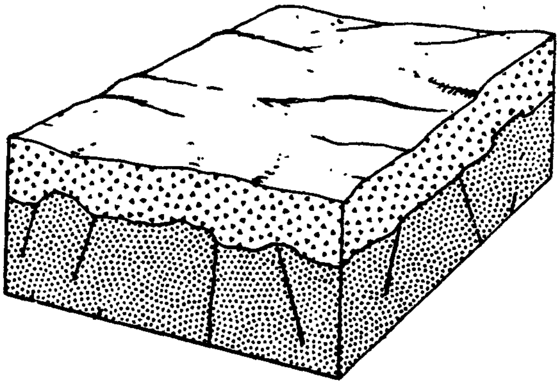


SETTING 7 Ac Glacial Till Over Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	2000+	3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

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

(7Ad) Glacial Till Over Sandstone

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



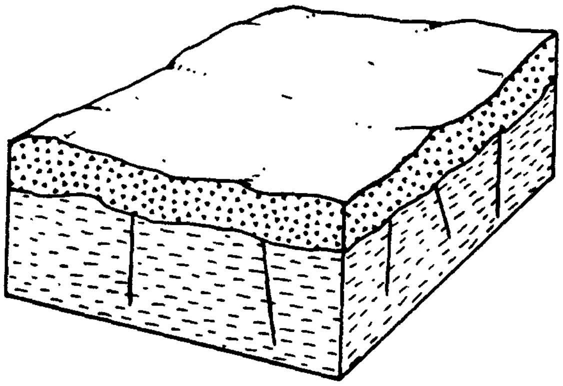
SETTING 7 Ad Glacial Till Over Sandstone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	Massive Sandstone	3	6	18
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	300-700	3	4	12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

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

GLACIATED CENTRAL

(7Ae) Glacial Till Over Shale

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



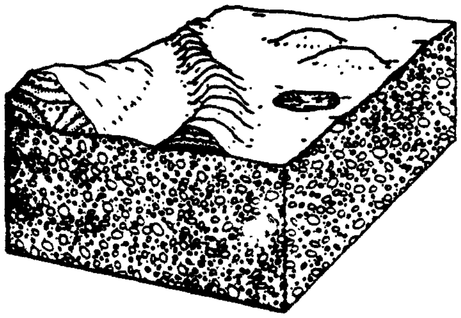
SETTING 7 Ae Glacial Till Over Shale		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	Massive Shale	3	2	6
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index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

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

GLACIATED CENTRAL

(7Ba) Outwash

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



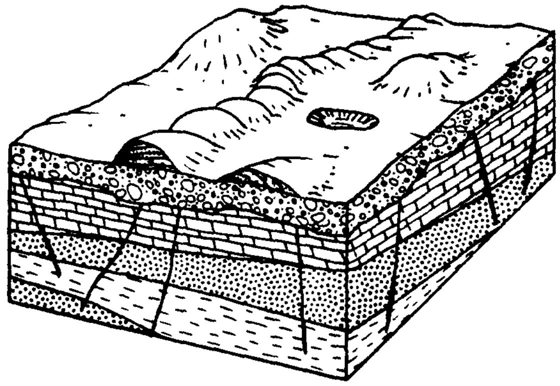
SETTING 7 Ba Outwash		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic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

SETTING 7 Ba Outwash		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	2-6%	3	9	27
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	190

GLACIATED CENTRAL

(7Bb) Outwash Over Bedded Sedimentary Rock

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



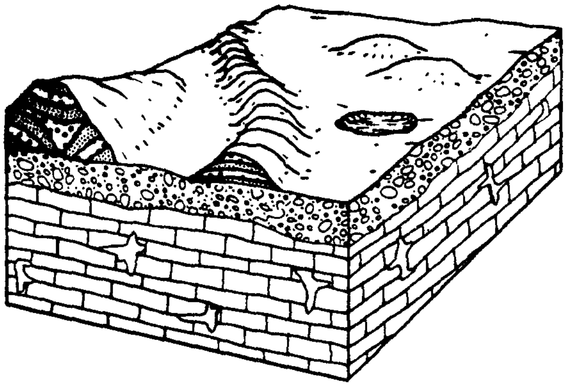
SETTING 7 Bb Outwash Over Bedded Sedimentary Rock		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity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

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

GLACIATED CENTRAL

(7Bc) Outwash Over Solution Limestone

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



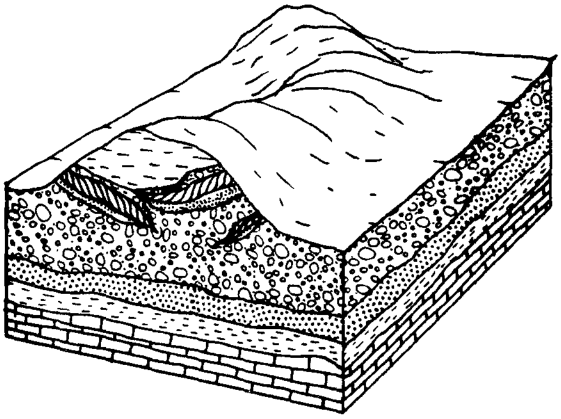
SETTING 7 Bc Outwash Over Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000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

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

GLACIATED CENTRAL

(7C) Moraine

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



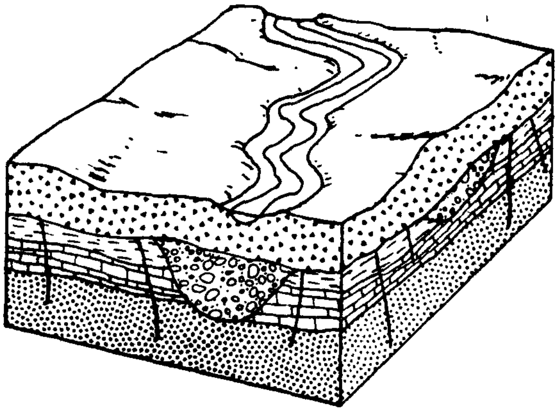
SETTING 7 C Moraine		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	6-12%	1	5	5
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	135

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

GLACIATED CENTRAL

(7D) Buried Valley

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



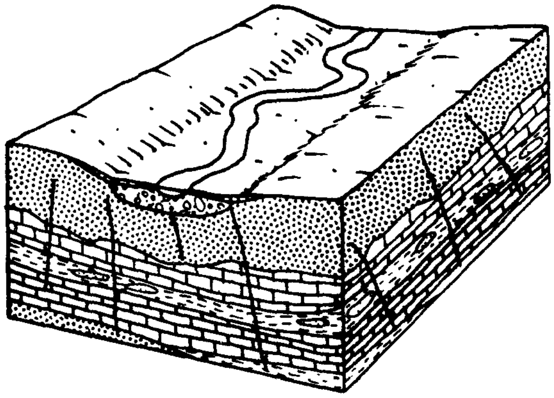
SETTING 7 D Buried Valley		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	S & G w/sig. Silt and Clay	5	6	30
Hydraulic Conductivity	1000-2000	3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

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

GLACIATED CENTRAL

(7Ea) River Alluvium With Overbank Deposits

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



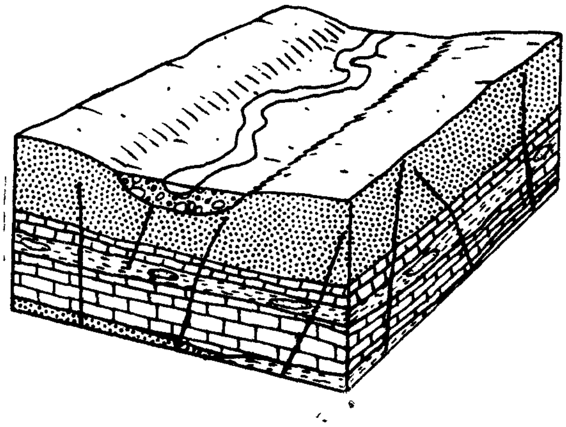
SETTING 7 Ea River Alluvium With Overbank Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	2	4	8
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	700-1000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

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

GLACIATED CENTRAL

(7Eb) River Alluvium Without Overbank Deposits

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



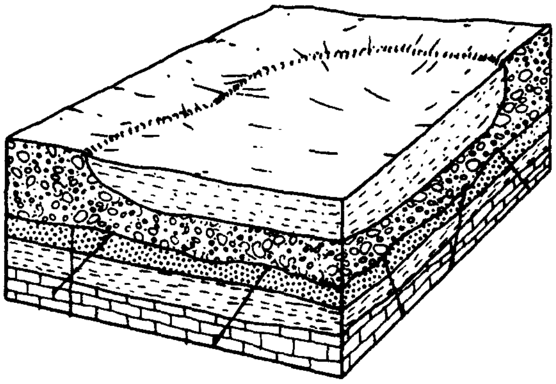
SETTING 7 Eb River Alluvium Without Overbank Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000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

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

GLACIATED CENTRAL

(7F) Glacial Lake Deposits

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



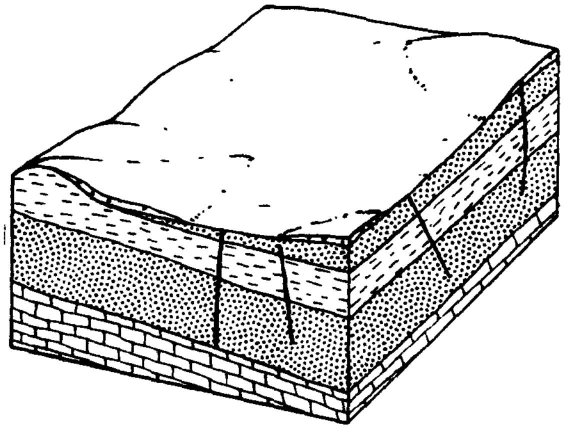
SETTING 7 F Glacial Lake Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	S & G w/ sig. Silt and Clay	5	6	30
Hydraulic Conductivity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

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

GLACIATED CENTRAL

(7G) Thin Till Over Bedded Sedimentary Rock

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

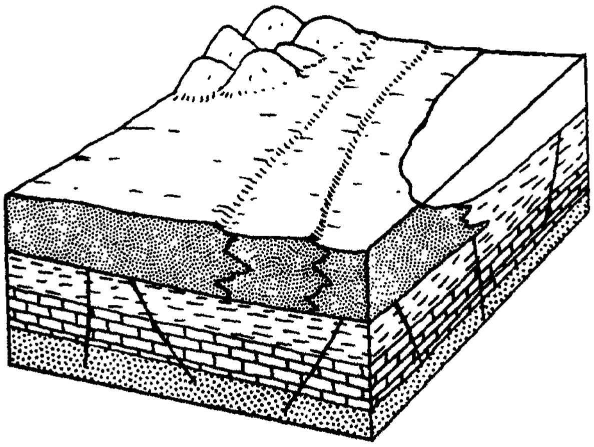


SETTING 7 G Thin Till Over Bedded Sedimentary Rock		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity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

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

(7H) Beaches, Beach Ridges and Sand Dunes

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

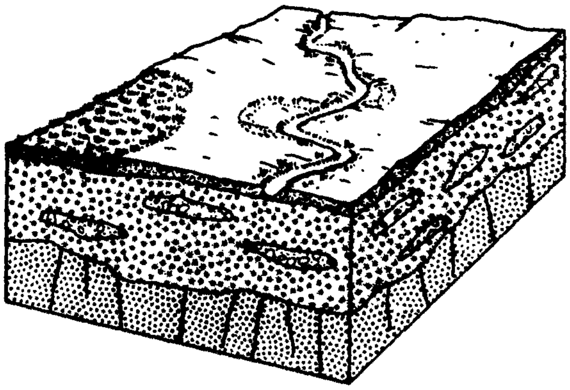


SETTING 7 H Beaches, Beach Ridges and Sand Dunes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000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

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

(7I) Swamp/Marsh

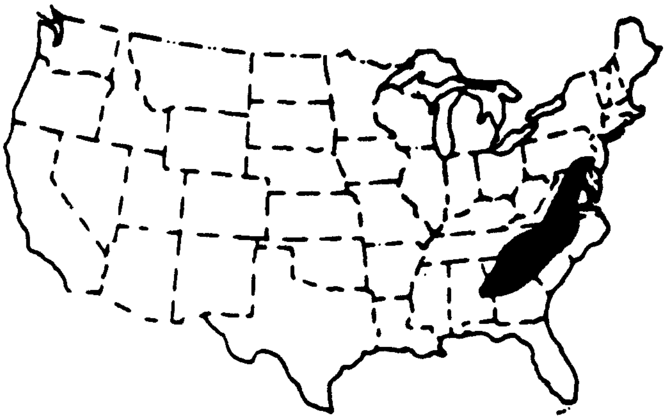
This hydrogeologic setting is characterized by low topographic relief, high water levels and high organic silt and clay deposits. These wetlands occur along the courses of floodplains and in upland areas as a result of vertically restricted drainage. Common features of upland wetlands include those characteristics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

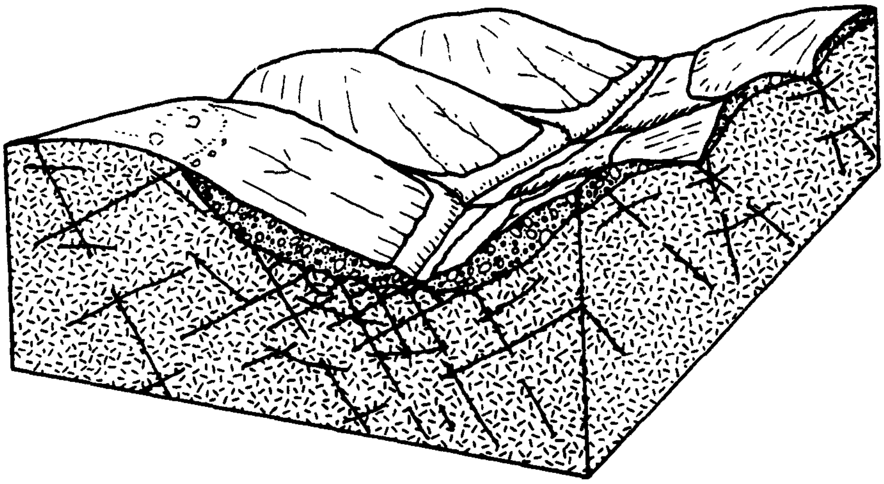


SETTING 7 I Swamp/Marsh		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Muck	2	2	4
Topography	0-2	1	10	10
Impact Vadose Zone	S & G w/sig. Silt and Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic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

SETTING 7 I Swamp/Marsh		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Muck	5	2	10
Topography	0-2	3	10	30
Impact Vadose Zone	S & G w/sig. Silt and Clay	4	6	24
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	174

8. PIEDMONT BLUE RIDGE GROUND-WATER REGION





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

8. PIEDMONT BLUE RIDGE REGION

(Thick regolith over fractured crystalline and metamorphosed sedimentary rocks)

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

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

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

All ground-water systems function both as reservoirs that store water and as pipelines (or conduits) that transmit water from recharge areas to discharge areas. The yield of bedrock wells in the Piedmont and Blue Ridge region depends on the number and size of fractures penetrated by the open hole and on the replenishment of the fractures by seepage into them from the overlying regolith. Thus, the ground-water system in this region can be viewed, from the standpoint of ground-water development, as a terrane in which the reservoir and pipeline functions are effectively separated. Because of its larger porosity, the regolith functions as a reservoir which slowly feeds water downward into the fractures in the bedrock. The fractures serve as an intricate interconnected network of pipelines that transmit water either to springs or streams or to wells.

Recharge of the ground-water system occurs on the areas above the flood plains of streams, and natural discharge occurs as seepage springs that are common near the bases of slopes and as seepage into streams. With respect to recharge conditions, it is important to note that forested areas, which include most of the Blue Ridge and much of the Piedmont, have thick and very permeable soils overlain by a thick layer of forest litter. In these areas, even on steep slopes, most of the precipitation seeps into the soil zone, and most of this moves laterally through the soil in a thin, temporary, saturated zone to surface depressions or streams to discharge. The remainder seeps into the regolith below the soil zone, and much of this ultimately seeps into the underlying bedrock.

Because the yield of bedrock wells depends on the number of fractures penetrated by the well, the key element in selecting well sites is recognizing the relation between the present surface topography and the location of fractures in the bedrock. Most of the valleys, draws, and other surface depressions indicate the presence of more intensely fractured zones in the bedrock which are more susceptible to weathering and erosion than are the intervening areas. Because fractures in the bedrock are the principal avenues along which ground water moves, the best well sites appear to be in draws on the sides of the valleys of perennial streams where the bordering ridges are underlain by substantial thicknesses of regolith. Wells located at such sites seem to be most effective in penetrating open water-bearing fractures and in intercepting ground water draining from the regolith. Chances of success seem to be somewhat less for wells on the flood plains of perennial streams, possibly because the alluvium obscures the topographic expression of bedrock fractures. The poorest sites for wells are on the tops of ridges and mountains where the regolith cover is thin or absent and the bedrock is sparsely fractured.

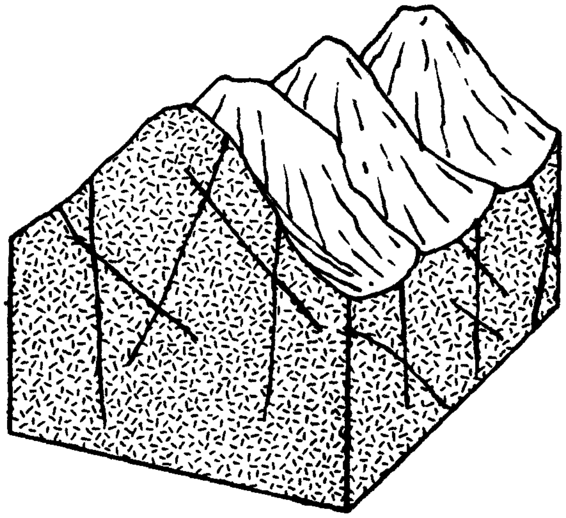
As a general rule, fractures near the bedrock surface are most numerous and have the largest openings, so that the yield of most wells is not increased by drilling to depths greater than about 100 m. Exceptions to this occur in Georgia, South Carolina and North Carolina and some other areas where water-bearing, low-angle faults or fractured zones are present at depths as great as 200 to 300 m.

The Piedmont and Blue Ridge region has long been known as an area generally unfavorable for ground water development. This reputation seems to have resulted both from the small reported yields of the numerous domestic wells in use in the region that were, generally, sited as a matter of convenience and from a failure to apply existing technology to the careful selection of well sites where moderate yields are needed. As water needs in the region increase and as reservoir sites on streams become increasingly more difficult to obtain, it will be necessary to make more intensive use of ground water.

PIEDMONT AND BLUE RIDGE

(8A) Mountain Slopes

This hydrogeologic setting is characterized by steep slopes on the side of mountains, a thin soil cover and fractured bedrock. Ground water is obtained primarily from the fractures in the bedrock which may be of sedimentary, metamorphic or igneous origin, but which is commonly metamorphic or igneous. The fractures provide localized sources of ground water and well yields are typically limited. Although precipitation is abundant, due to the steep slopes, thin soil cover and small storage capacity of the fractures, runoff is significant and ground-water recharge is only moderate. Water levels are extremely variable but are commonly deep.



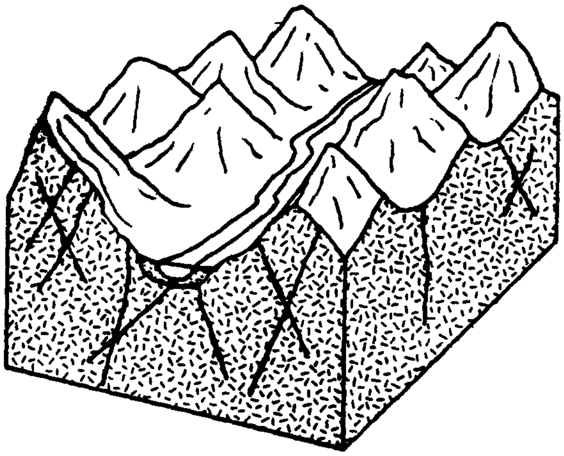
SETTING 8 A Mountain Slopes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	2-4	4	3	12
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Thin or Absent	2	10	20
Topography	18+	1	1	1
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	75

SETTING 8 A Mountain Slopes		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	2-4	4	3	12
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Thin or Absent	5	10	50
Topography	18+	3	1	3
Impact Vadose Zone	Metamorphic/Igneous	4	4	16
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	102

PIEDMONT AND BLUE RIDGE

(8B) Alluvial Mountain Valleys

This hydrogeologic setting is characterized by thin, bouldery alluvium which overlies fractured bedrock of sedimentary, metamorphic or igneous origin. The alluvium, which includes both mass-wastage and water-sorted debris, is derived from the surrounding slopes, and serves as a localized source of water. Water is obtained from sand and gravel layers which are interspersed between finer-grained deposits. Surficial deposits have typically weathered to a loam. Water levels are usually relatively shallow but are extremely variable. Ground water is also obtained from the fractures in the underlying bedrock, which are typically in direct hydraulic connection with the overlying alluvium.



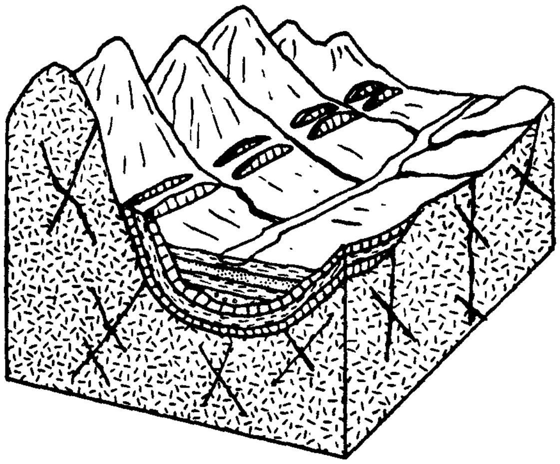
SETTING 8 B Alluvial Mountain Valleys		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Loam	2	5	10
Topography	2-6%	1	9	9
Impact Vadose Zone	S & G w/ sig. Silt and Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	162

SETTING 8 B Alluvial Mountain Valleys		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Loam	5	5	25
Topography	2-6%	3	9	27
Impact Vadose Zone	S & G w/ sig. Silt and Clay	4	6	24
Hydraulic Conductivity	300-700	2	4	8
			Pesticide Drastic Index	185

PIEDMONT AND BLUE RIDGE

(8C) Mountain Flanks

This hydrogeologic setting is characterized by moderate topographic relief and moderately-dipping, fractured, consolidated sedimentary rocks. Soil cover is usually thicker than on the mountain slopes and typically has weathered to a sandy loam or loam. Although precipitation is abundant, ground-water recharge is moderate due to the soil cover and slope. Water levels are typically moderately-deep although they are extremely variable. The mountain flanks serve as the recharge area for aquifers which are typically confined in adjacent valley areas.



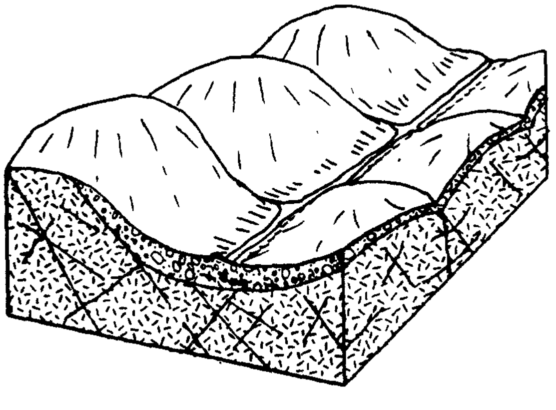
SETTING 8 C Mountain Flanks		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	2-4	4	3	12
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Loam	2	5	10
Topography	6-12%	1	5	5
Impact Vadose Zone	Bedded LS, SS, SH	5	6	30
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	106

SETTING 8 C Mountain Flanks		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	2-4	4	3	12
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Loam	5	5	25
Topography	6-12%	3	5	15
Impact Vadose Zone	Bedded LS, SS, SH	4	6	24
Hydraulic Conductivity	100-300	2	2	4
			Pesticide Drastic Index	123

PIEDMONT AND BLUE RIDGE

(8D) Regolith

This hydrogeologic setting is characterized by moderate to low slopes covered by regolith and underlain by fractured bedrock of igneous, sedimentary or metamorphic origin. The regolith is typically clay-rich but may also serve as a source of ground water for low-yield wells. The regolith functions as a reservoir for ground-water recharge to the bedrock which is in direct hydraulic connection with the overlying regolith. The bedrock typically yields larger amounts of ground water than the regolith when the well intersects fractures in the bedrock.



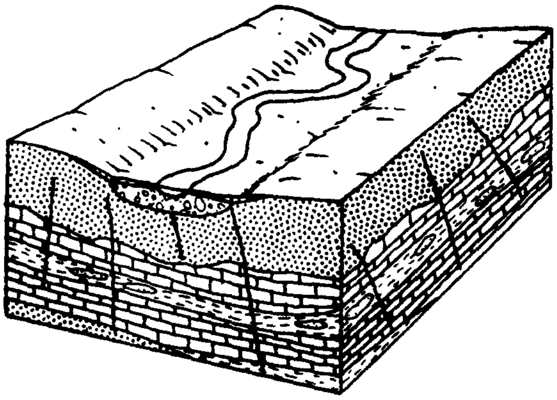
SETTING 8 D Regolith		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	4-7	4	6	24
Aquifer Media	Weathered Meta./Ig.	3	4	12
Soil Media	Clay Loam	2	3	6
Topography	6-12%	1	5	5
Impact Vadose Zone	Silt/Clay	5	1	5
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	100

SETTING 8 D Regolith		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	4-7	4	6	24
Aquifer Media	Weathered Meta./Ig.	3	4	12
Soil Media	Clay Loam	5	3	15
Topography	6-12%	3	5	15
Impact Vadose Zone	Silt/Clay	4	1	4
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	117

PIEDMONT AND BLUE RIDGE

(8E) River Alluvium

This hydrogeologic setting is characterized by low topography and deposits of varying thickness of alluvium along parts of stream valleys. The alluvium is underlain by fractured igneous, metamorphic or consolidated sedimentary rocks. Water is obtained from sand and gravel which is overlain and interbedded with finer-grained alluvial deposits. Surficial deposits usually weather to a sandy loam. The sand and gravel within the alluvium serves as the principal aquifer, but the alluvium also serves as the source of ground-water recharge for the underlying aquifer. Precipitation is abundant and recharge is moderately high, limited only by the loamy surficial deposits. Water levels are extremely variable, but are typically moderately shallow.



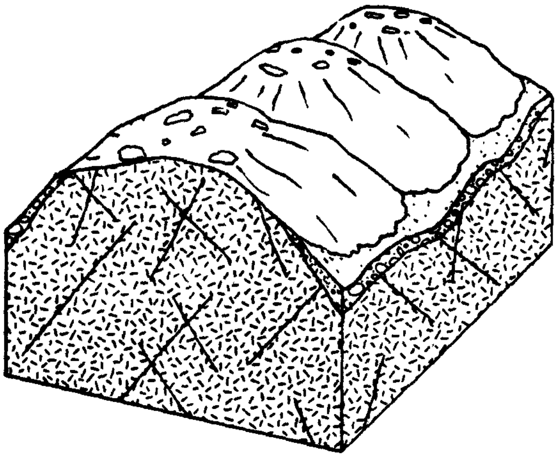
SETTING 8 E River Alluvium		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	S & G w/ sig. Silt and Clay	5	6	30
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	176

SETTING 8 E River Alluvium		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	2-6%	3	9	27
Impact Vadose Zone	S & G w/ sig. Silt and Clay	4	6	24
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	198

PIEDMONT AND BLUE RIDGE

(8F) Mountain Crests

This hydrogeologic setting is characterized by moderate to steep topography on the crests of mountains with thin soil cover and exposed fractured bedrock. Ground water is obtained primarily from the fractures in the bedrock which may be of sedimentary, metamorphic or igneous origin but which is commonly metamorphic or igneous. The fractures provide localized sources of ground water and well yields are typically limited. Although precipitation is abundant, due to the slopes, thin soil cover and small storage capacity of the fractures, runoff is significant and ground-water recharge is low. Water levels are extremely variable but commonly deep.

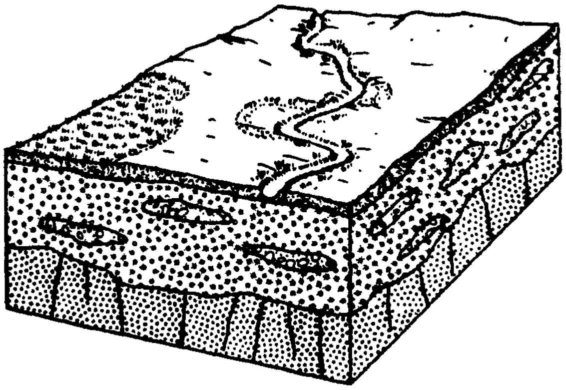


SETTING 8 F Mountain Crests		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Thin or Absent	2	10	20
Topography	2-6%	1	9	9
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	70

SETTING 8 F Mountain Crests		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Thin or Absent	5	10	50
Topography	2-6%	3	9	27
Impact Vadose Zone	Metamorphic/Igneous	4	4	16
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	113

(8G) Swamp/Marsh

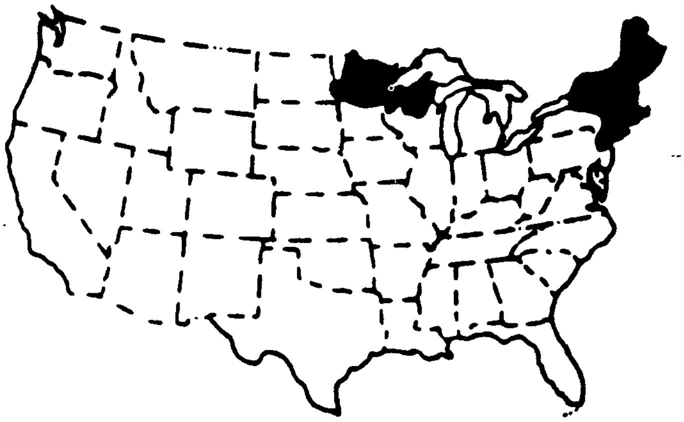
This hydrogeologic setting is characterized by low topographic relief, high water levels and high organic silt and clay deposits. These wetlands occur along the courses of floodplains and in upland areas as a result of vertically restricted drainage. Recharge is commonly low to moderate as a result of low topography and low conductivities even though rainfall is high. These areas may be discharge zones or may alternate as recharge and discharge zones as seasons change.

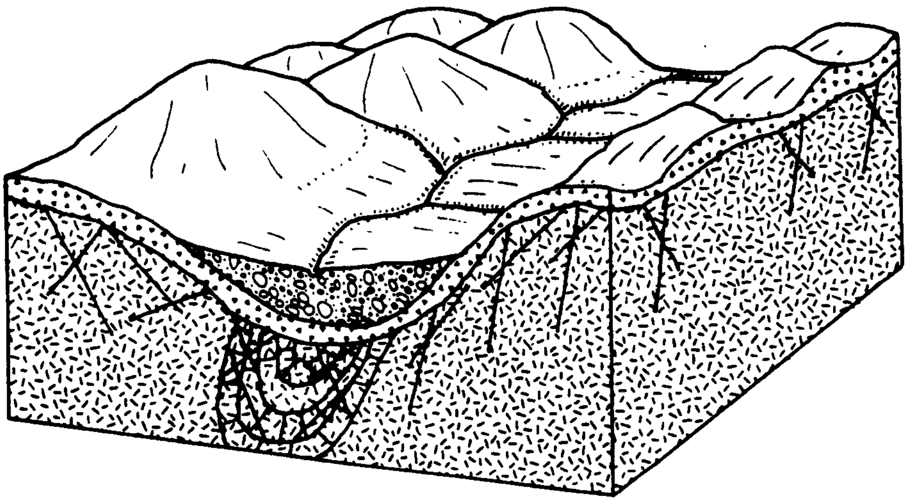


SETTING 8 G Swamp/Marsh		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	4-7	4	6	24
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Muck	2	2	4
Topography	0-2	1	10	10
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	120

SETTING 8 G Swamp/Marsh		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	4-7	4	6	24
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Muck	5	2	10
Topography	0-2	3	10	30
Impact Vadose Zone	Metamorphic/Igneous	4	4	16
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	141

9. NORTHEAST AND SUPERIOR UPLANDS GROUND-WATER REGION





9A	Mountain Slopes
9B	Alluvial Mountain Valleys
9C	Mountain Flanks
9Da	Glacial Till Over Crystalline Bedrock
9Db	Glacial Till Over Outwash
9E	Outwash
9F	Moraine
9Ga	River Alluvium With Overbank Deposits
9Gb	River Alluvium Without Overbank Deposits
9H	Swamp/Marsh
9I	Bedrock Uplands
9J	Glacial Lake/Glacial Marine Deposits
9K	Beaches, Beach Ridges and Sand Dunes

9. NORTHEAST AND SUPERIOR UPLANDS

(Glacial deposits over fractured crystalline rocks)

The Northeast and Superior Uplands region is made up of two separate areas totaling about 415,000 km^2. The Northeast Upland encompasses the Adirondack Mountains, the Lake Champlain valley, and nearly all of New England. The parts of New England not included are the Cape Cod area and nearby islands, which are included in the Atlantic and Gulf Coastal Plain region, and the Triassic lowland along the Connecticut River in Connecticut and Massachusetts, which is included in the Glaciated Central region. The Superior Upland encompasses most of the northern parts of Minnesota and Wisconsin adjacent to the western end of Lake Superior. The Northeast and Superior Uplands are characterized by rolling hills and low mountains. Land-surface altitudes in the Northeast Upland range from sea level to more than 1,500 m on some of the peaks in the Adirondacks and White Mountains. In contrast to the mountainous areas in the Northeast, the Superior Upland is in an area of rolling hills whose summits reach altitudes of only 300 to 600 m.

Bedrock in the region ranges in age from Precambrian to Paleozoic and consists mostly of granite, syenite, anorthosite, and other intrusive igneous rocks and metamorphosed sedimentary rocks consisting of gneiss, schist, quartzite, slate, and marble. Most of the igneous and metamorphosed sedimentary rocks have been intensely folded and cut by numerous faults.

The bedrock is overlain by unconsolidated deposits laid down by ice sheets that covered the areas one or more times during the Pleistocene and by gravel, sand, silt, and clay laid down by meltwater streams and in lakes that formed during the melting of the ice. The thickness of the glacial deposits ranges from a few meters on the higher mountains, which also have large expanses of barren rock, to more than 100 m in some valleys. The most extensive glacial deposit is till, which was laid down as a nearly continuous blanket by the ice, both in valleys and on the uplands. In most of the valleys and other low areas, the till is covered by glacial outwash consisting of interlayered sand and gravel, ranging in thickness from a few meters to more than 20 m, that was deposited by streams supplied by glacial meltwater. In several areas, including parts of the Champlain valley and the lowlands adjacent to Lake Superior, the unconsolidated deposits consist of clay and silt deposited in lakes that formed during the melting of the ice sheets.

Ground-water supplies are obtained in the region from both the glacial deposits and the underlying bedrock. The largest yields come from the sand and gravel deposits, which in parts of the valleys of large streams are as much as 60 m thick. Other sand and gravel deposits, not thick or productive enough to be included in the Alluvial Valleys region, occur locally in most valley and lowland areas in the Northeast and Superior Uplands region and serve as important sources of water.

Water occurs in the bedrock in fractures similar in origin, occurrence, and hydraulic characteristics to those in the Piedmont and Blue Ridge region. In fact, the primary difference in ground-water conditions between the Piedmont and Blue Ridge region and the Northeast and Superior Uplands region is related to the materials that overlie the bedrock. In the Piedmont and Blue Ridge, these consist of unconsolidated material derived from weathering of the underlying bedrock. In the Northeast and Superior Uplands the overlying materials consist of glacial deposits which, having been transported either by ice or by streams, do not have a composition and structure controlled by that of the underlying bedrock. These differences in origin of the regolith between the Northeast and Superior Uplands and the Piedmont and Blue Ridge are an important consideration in the development of water supplies, as is discussed in the following paragraphs.

Recharge from precipitation generally begins in the fall after plant growth stops. It continues intermittently over the winter during thaws and culminates during the period between the spring thaw and the start of the growing season. Precipitation on the Northeast Upland, about 1,200 mm per year, is twice that on the Superior Upland, with the result that recharge, both to the glacial deposits and to the underlying bedrock, is largest in the Northeast. The glacial deposits in the region serve as a storage reservoir for the fractures in the underlying bedrock, in the same way the saprolite functions in the Piedmont and Blue Ridge region. The major difference is that the glacial deposits on hills and other upland areas are much thinner than the saprolite in similar areas in the Piedmont and Blue Ridge and, therefore, have a much smaller ground-water storage capacity.

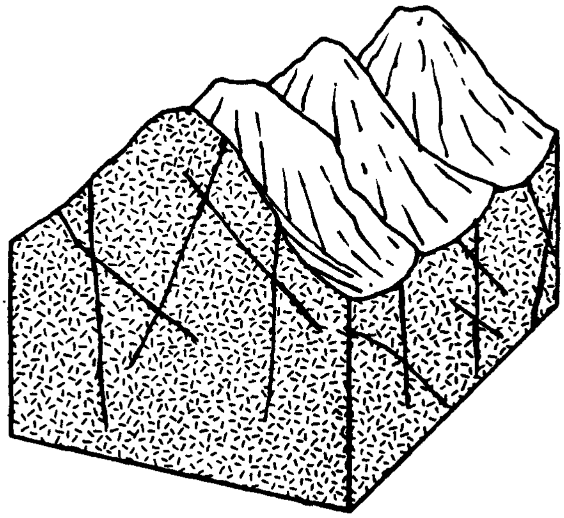
Water supplies in the Northeast and Superior Uplands region are obtained from open-hole drilled wells in bedrock, from drilled and screened or open-end wells in sand and gravel, and from large-diameter bored or dug wells in till. The development of water supplies from bedrock, especially in the Superior Upland, is more uncertain than from the fractured rocks in the Piedmont and Blue Ridge region because the ice sheets that advanced across the region removed the upper, more fractured part of the rock and also tended to obscure many of the fracture-caused depressions in the rock surface with the layer of glacial till. Thus, use of surface depressions in this region to select sites of bedrock wells is not as satisfactory as in the Piedmont and Blue Ridge.

Most of the rocks that underlie the Northeast and Superior Uplands are relatively insoluble, and, consequently, the ground water in both the glacial deposits and the bedrock generally contains less than 500 mg/l of dissolved solids. Two of the most significant water-quality problems confronting the region, especially the Northeast Upland section, are acid precipitation and pollution caused by salts used to de-ice highways. Much of the precipitation now falling on the Northeast (in 1982) has a pH in the range of 4 to 6 units. Because of the low buffering capacity of the soils derived from the rocks underlying the area, there is relatively little opportunity for the pH to be increased. One of the results of this is the gradual elimination of living organisms from many lakes and streams. The effect on ground-water quality, which will develop much more slowly, has not yet been determined. The second problem--that of de-icing salts--affects ground-water quality adjacent to streets and roads maintained for winter travel.

NORTHEAST AND SUPERIOR UPLANDS

(9A) Mountain Slopes

This hydrogeologic setting is characterized by steep slopes on the side of mountains, a thin soil cover and fractured bedrock. Ground water is obtained primarily from the fractures in the bedrock which may be of sedimentary, metamorphic or igneous origin but which is commonly metamorphic or igneous. The fractures provide localized sources of ground water, and well yields are typically limited. Although precipitation is abundant, due to the steep slopes, thin soil cover and small storage capacity of the fractures, runoff is significant and ground-water recharge is moderate. Water levels are extremely variable but are commonly deep.



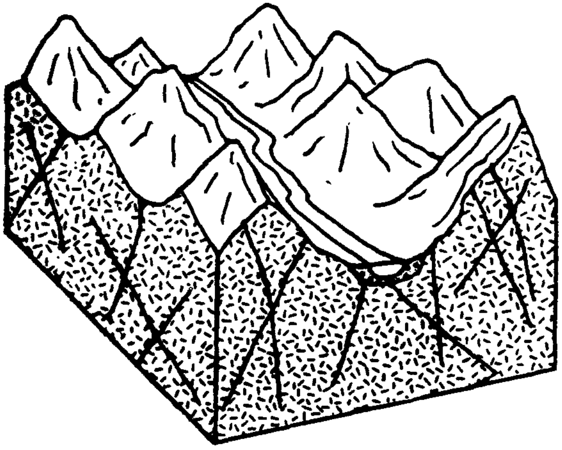
SETTING 9 A Mountain Slopes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	2-4	4	3	12
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Thin or Absent	2	10	20
Topography	18+	1	1	1
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	75

SETTING 9 A Mountain Slopes		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	2-4	4	3	12
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Thin or Absent	5	10	50
Topography	18+	3	1	3
Impact Vadose Zone	Metamorphic/Igneous	4	4	16
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	102

NORTHEAST AND SUPERIOR UPLANDS

(9B) Alluvial Mountain Valleys

This hydrogeologic setting is characterized by thin, bouldery alluvium which overlies fractured bedrock of sedimentary, metamorphic or igneous origin but which are commonly alternating sedimentary layers. The alluvium, which is derived from the surrounding slopes serves as a localized source of water. Water is obtained from sand and gravel layers which are interspersed between fine-grained deposits. Surficial deposits have typically weathered to a sandy loam. Water levels are relatively shallow but may be extremely variable. Ground water may also be obtained from the fractures in the underlying bedrock which are usually in direct hydraulic connection with the overlying alluvium.



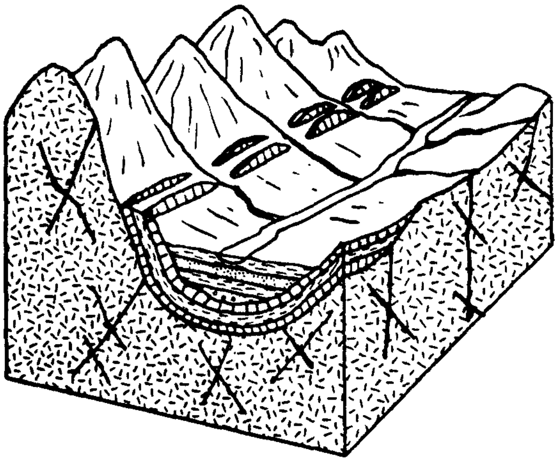
SETTING 9 B Alluvial Mountain Valleys		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	16
			Drastic Index	180

SETTING 9 B Alluvial Mountain Valleys		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	2-6%	3	9	27
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	202

NORTHEAST AND SUPERIOR UPLANDS

(9C) Mountain Flanks

This hydrogeologic setting is characterized by moderate topographic relief and moderately dipping, fractured, consolidated sedimentary rocks. Soil cover is usually thicker than on the mountain slopes and typically has weathered to a sandy loam. Although precipitation can be significant, ground-water recharge is moderate due to the slope. Water levels are typically moderately deep, although they are extremely variable. The mountain flanks serve as the recharge area for aquifers which are confined in adjacent lowland areas. Ground water is obtained from the permeable sedimentary rocks or from fractures and bedding planes in the sedimentary rocks. The sedimentary rocks may be underlain by fractured bedrock of igneous, metamorphic or sedimentary origin which yield little water.



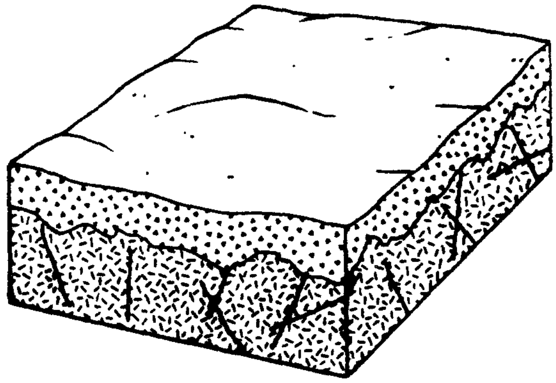
SETTING 9 C Mountain Flanks		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	2-4	4	3	12
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Sandy Loam	2	6	12
Topography	12-18%	1	3	3
Impact Vadose Zone	Bedded LS, SS, SH	5	6	30
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	106

SETTING 9 C Mountain Flanks		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	2-4	4	3	12
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Sandy Loam	5	6	30
Topography	12-18%	3	3	9
Impact Vadose Zone	Bedded LS, SS, SH	4	6	24
Hydraulic Conductivity	100-300	2	2	4
			Pesticide Drastic Index	122

NORTHEAST AND SUPERIOR UPLANDS

(9Da) Glacial Till Over Crystalline Bedrock

This hydrogeologic setting is characterized by moderately low topographic relief and varying thicknesses of glacial till overlying severely fractured, folded and faulted bedrock of igneous and metamorphic origin with minor occurrences of bedded sedimentary rocks. The till is principally unsorted deposits which may be interbedded with localized deposits of sand and gravel. Although ground water occurs in both the glacial deposits and fractured bedrock, the bedrock is typically the principal aquifer. The glacial till serves as a recharge source. Although precipitation is abundant, recharge is only moderately high because of the low permeability of the glacial till and the surficial deposits which typically weather to loam. Depth to water is extremely variable depending in part on the thickness of the glacial till, but is typically moderately shallow.



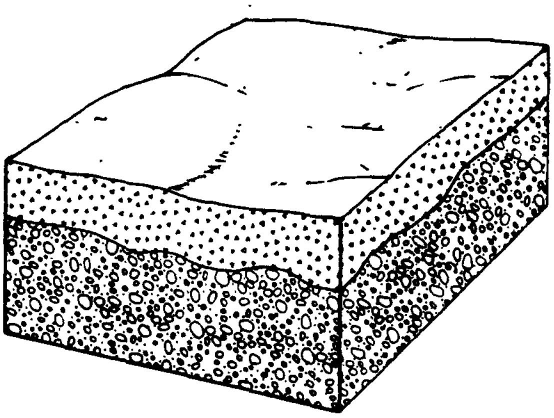
SETTING 9 Da Glacial Till Over Crystalline Bedrock		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Loam	2	5	10
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	113

SETTING 9 Da Glacial Till Over Crystalline Bedrock		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Loam	5	5	25
Topography	2-6%	3	9	27
Impact Vadose Zone	Silt/Clay	4	3	12
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	142

NORTHEAST AND SUPERIOR UPLANDS

(9Db) Glacial Till Over Outwash

This hydrogeologic setting is characterized by low topography and outwash materials which are covered by varying thicknesses of glacial till. The till is principally unsorted deposits which may be interbedded with localized deposits of sand and gravel. Surficial deposits have usually weathered to a loam. Although ground water occurs in both the glacial till and in the underlying outwash, the outwash typically serves as the principal aquifer because the fine grained deposits have been removed by glacial meltwater. The outwash is in direct hydraulic connection with the glacial till and the glacial till serves as a source of recharge for the underlying outwash. Precipitation is abundant in the region but recharge is moderate because of the relatively low permeability of the overlying glacial till. Depth to water is extremely variable depending in part on the thickness of the glacial till, but averages around 30 feet.



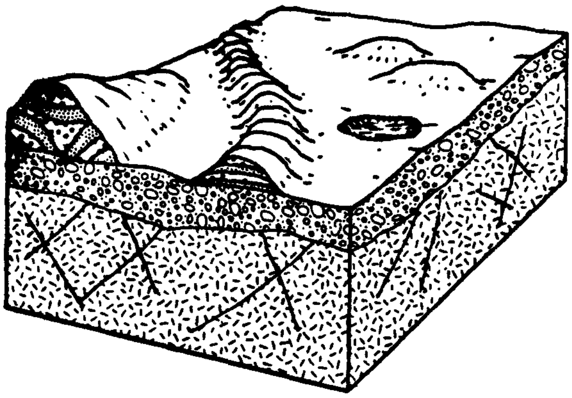
SETTING 9 Db Glacial Till Over Outwash		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Loam	2	5	10
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	139

SETTING 9 Db Glacial Till Over Outwash		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Loam	5	5	25
Topography	2-6%	3	9	27
Impact Vadose Zone	Silt/Clay	4	3	12
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	161

NORTHEAST AND SUPERIOR UPLANDS

(9E) Outwash

This hydrogeologic setting is characterized by moderate topographic relief and varying thickness of outwash which overlie fractured bedrock of sedimentary, metamorphic or igneous origin. The outwash consists of water- washed deposits of sand and gravel which often serve as the principal aquifers in the area, and which typically have a sandy loam surficial layer. The outwash also serves as a source of recharge to the underlying bedrock. Recharge is abundant and ground-water recharge is high. Water levels are extremely variable, but are relatively shallow.



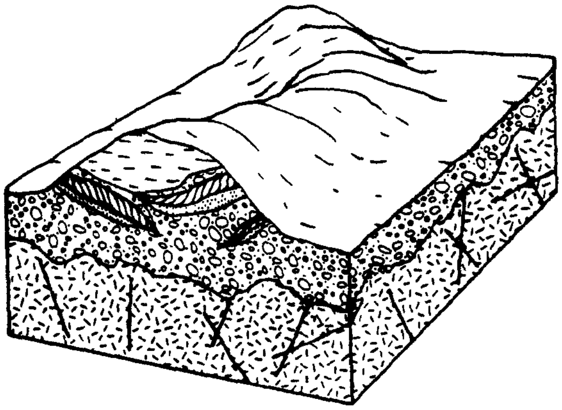
SETTING 9 E Outwash		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	190

SETTING 9 E Outwash		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	2-6%	3	9	27
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	210

NORTHEAST AND SUPERIOR UPLANDS

(9F) Moraine

This hydrogeologic setting is characterized by moderate topography and varying thicknesses of mixed glacial deposits which overlie fractured bedrock of sedimentary, igneous or metamorphic origin. This setting is similar to (9E) Outwash in that the sand and gravel within the morainal deposits is well-sorted and serves as the principal aquifer in the area. These deposits also serve as a source of recharge for the underlying bedrock. Moraines also contain sediments that are typically unsorted and unstratified; these deposits contain more fines than outwash deposits, are less permeable and characteristically more like glacial till. Moraines are typically mounds or ridges of till which were deposited along the margin of a stagnant or retreating glacier. Surficial deposits often weather to a sandy loam. Precipitation is abundant throughout the region and ground-water recharge is moderately high. Water levels are extremely variable, based in part on the thickness of the glacial till, but are typically fairly shallow.



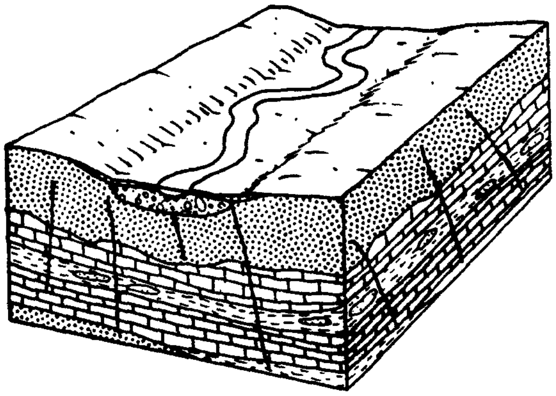
SETTING 9 F Moraine		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	6-12%	1	5	5
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	166

SETTING 9 F Moraine		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	6-12%	3	5	15
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	180

NORTHEAST AND SUPERIOR UPLANDS

(9Ga) River Alluvium With Overbank Deposits

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

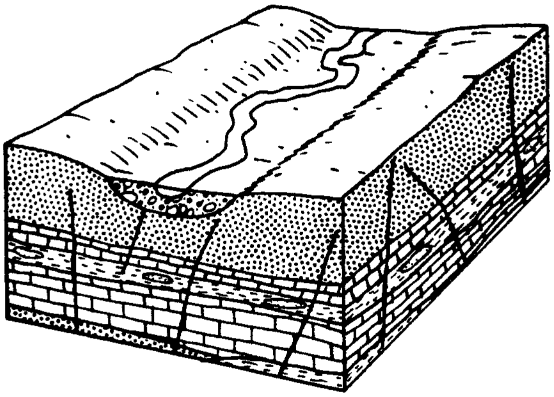


SETTING 9 Ga River Alluvium With Overbank Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Clay Loam	2	3	6
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	146

SETTING 9 Ga River Alluvium With Overbank Deposits		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Clay Loam	5	3	15
Topography	0-2%	3	10	30
Impact Vadose Zone	Silt/Clay	4	3	12
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	164

(9Gb) River Alluvium Without Overbank Deposits

This hydrogeologic setting is identical to (9Ga) River Alluvium With Overbank Deposits except that no significant fine-grained floodplain deposits occupy the stream valley. This results in significantly higher recharge where precipitation is adequate and sandy soils occur at the surface. Water levels are moderate to shallow in depth. Hydraulic contact with the surface stream is usually excellent, with alternating recharge/discharge relationships varying with stream stage. These deposits serve as a good source of recharge to the underlying fractured bedrock.

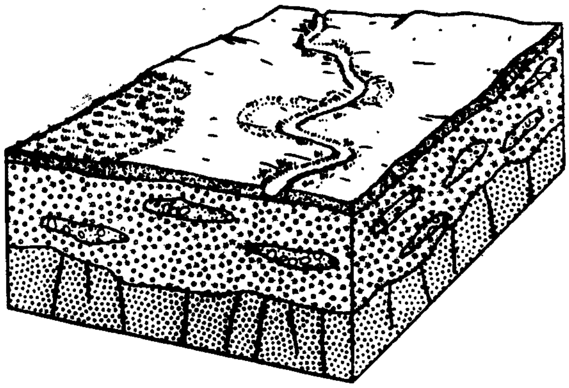


SETTING 9 Gb River Alluvium Without Overbank Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	191

SETTING 9 Gb River Alluvium Without Overbank Deposits		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	0-2%	3	10	30
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	213

(9H) Swamp/Marsh

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



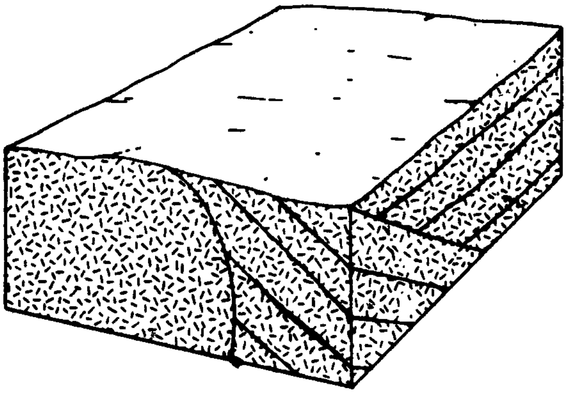
SETTING 9 H Swamp/Marsh		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	4-7	4	6	24
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Muck	2	2	4
Topography	0-2	1	10	10
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	120

SETTING 9 H Swamp/Marsh		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	4-7	4	6	24
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Muck	5	2	10
Topography	0-2	3	10	30
Impact Vadose Zone	Metamorphic/Igneous	4	4	16
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	141

NORTHEAST AND SUPERIOR UPLANDS

(9I) Bedrock Uplands

This hydrogeologic setting is characterized by moderately low topographic relief and exposed fractured, folded and faulted bedrock of igneous and low-grade metamorphic origin with minor occurrences of bedded sedimentary rocks. Recharge is primarily controlled by precipitation but is limited by the hydraulic conductivity of the rock. Where present, soils are commonly sandy. These areas typically serve as limited aquifers.



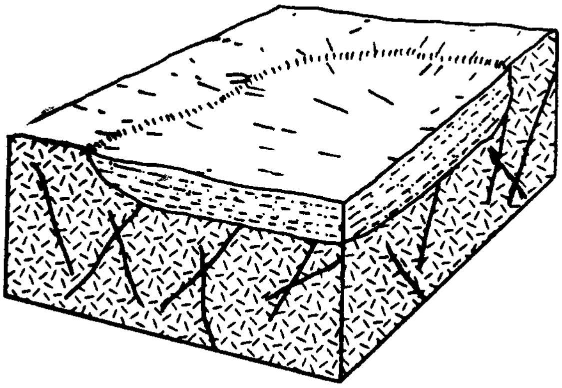
SETTING 9 I Bedrock Uplands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Sand	2	9	18
Topography	2-6	1	9	9
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	118

SETTING 9 I Bedrock Uplands		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Sand	5	9	45
Topography	2-6	3	9	27
Impact Vadose Zone	Metamorphic/Igneous	4	4	16
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	158

NORTHEAST AND SUPERIOR UPLANDS

(9J) Glacial Lake/Glacial Marine Deposits

This hydrogeologic setting is characterized by relatively flat to gently rolling topography and varying thicknesses of fine-grained sediments that overly sequences of fractured igneous and metamorphic rocks. The deposits are composed of fine-grained silts and clays interlayered with fine sand that settled out in glacial lakes and submerged coastal areas and exhibit alternating layers relating to seasonal fluctuations. Due to their fine- grained nature, these deposits range in permeabilities reflecting variations in sand content.



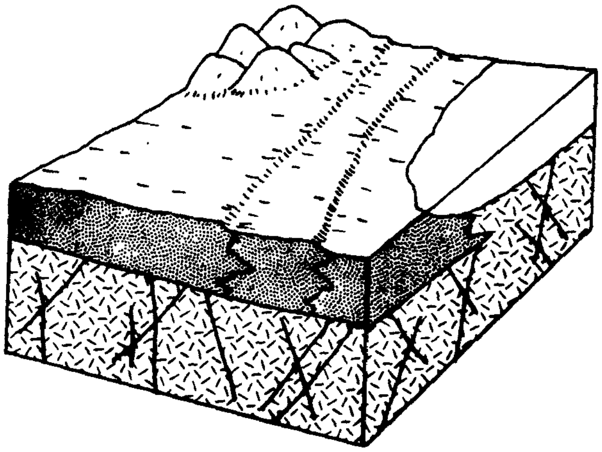
SETTING 9 J Glacial Lake/Glacial Marine Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Loam	2	5	10
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	120

SETTING 9 J Glacial Lake/Glacial Marine Deposits		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Loam	5	5	25
Topography	2-6%	3	9	27
Impact Vadose Zone	S&G w/sig Silt & Clay	4	6	24
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	146

NORTHEAST AND SUPERIOR UPLANDS

(9K) Beaches, Beach Ridges and Sand Dunes

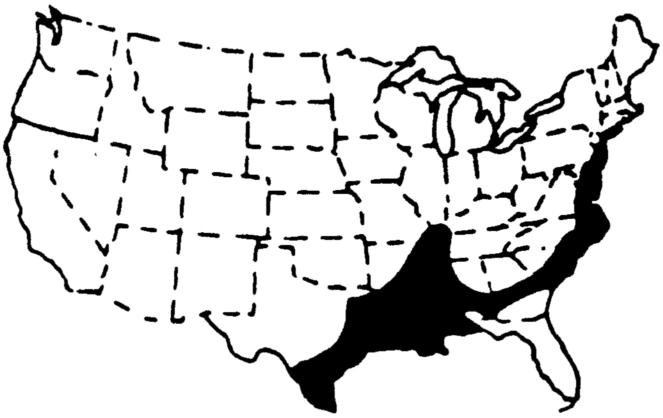
This hydrogeologic setting is characterized by a low relief, sandy surface soil that is predominantly silica sand, extremely high infiltration rates and low sorptive capacity in the thin vadose zone. The water table is very shallow beneath the beaches boarding the coastal areas. The water table is slightly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

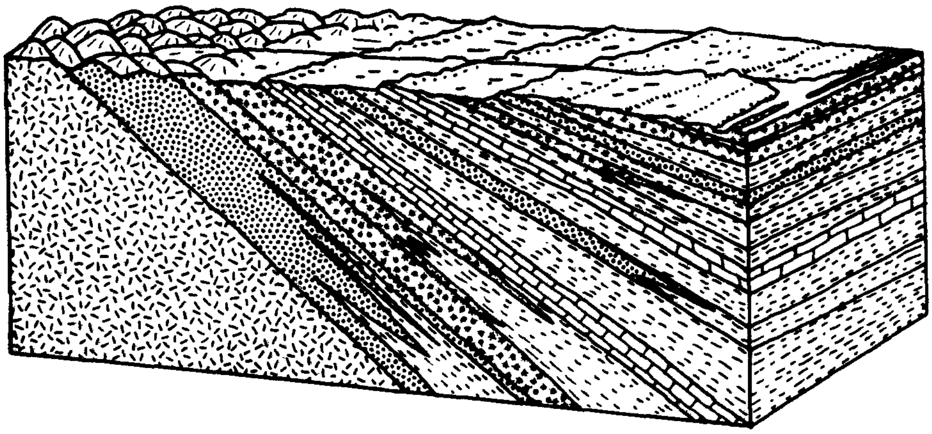


SETTING 9 K Beaches, Beach Ridges and Sand Dunes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	161

SETTING 9 K Beaches, Beach Ridges and Sand Dunes		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Sand	5	9	45
Topography	0-2%	3	10	30
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	1-100	2	1	2
			Pesticide Drastic Index	199

10. ATLANTIC AND GULF COASTAL PLAIN GROUND-WATER REGION





10Aa	Regional Aquifers
10Ab	Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer
10Ba	River Alluvium With Overbank Deposits
10Bb	River Alluvium Without Overbank Deposits
10C	Swamp

10. ATLANTIC AND GULF COASTAL PLAIN

(Complexly interbedded sand, silt, and clay)

The Atlantic and Gulf Coastal Plain region is an area of about 844,000 km^2 extending from Cape Cod, Massachusetts, on the north to the Rio Grande in Texas on the south. This Region does not include Florida and parts of the adjacent States; although those areas are a part of the Atlantic and Gulf Coastal Plain physiographic province, they together form a separate ground-water region. (See region 11, "Southeast Coastal Plain").

The Atlantic and Gulf Coastal Plain region ranges in width from a few kilometers near its northern end to nearly a thousand kilometers in the vicinity of the Mississippi River. The great width near the Mississippi reflects the effect of a major downwarped zone in the Earth's crust that extends from the Gulf of Mexico to about the confluence of the Mississippi and Ohio Rivers. This area is referred to as the Mississippi embayment.

The topography of the region ranges from extensive, flat, coastal swamps and marshes 1 to 2 m above sea level to rolling uplands, 100 to 250 m above sea level, along the inner margin of the region.

The region is underlain by unconsolidated sediments that consist principally of sand, silt, and clay transported by streams from the adjoining uplands. These sediments, which range in age from Jurassic to the present, range in thickness from less than a meter near the inner edge of the region to more than 12,000 m in southern Louisiana. The greatest thicknesses are along the seaward edge of the region and along the axis of the Mississippi embayment. The sediments were deposited on floodplains and as deltas where streams reached the coast and, during different invasions of the region by the sea, were reworked by waves and ocean currents. Thus, the sediments are complexly interbedded to the extent that most of the named geologic units into which they have been divided contain layers of the different types of sediment that underlie the region. These named geologic units (or formations) dip toward the coast or toward the axis of the Mississippi embayment, with the result that those that crop out at the surface form a series of bands roughly parallel to the coast or to the axis of the embayment. The oldest formations crop out along the inner margin of the region, and the youngest crop out in the coastal area.

Within any formation the coarsest grained materials (sand, at places interbedded with thin gravel layers) tend to be most abundant near source areas. Clay and silt layers become thicker and more numerous downdip.

Although sand, silt, and clay, as noted above, are the principal types of material underlying the Atlantic and Gulf Coastal Plain, there are also a small amount of gravel interbedded with the sand, a few beds composed of mollusk shells, and a small amount of limestone present in the region. The most important limestone is the semi-consolidated Castle Hayne Limestone of Eocene age which underlies an area of about 26,000 km^2 in eastern North Carolina, is more than 200 m thick in much of the area, and is the most productive aquifer in North Carolina. A soft, clayey limestone (the chalk of the Selma Group) of Late Cretaceous age underlies parts of eastern Mississippi and western Alabama, but instead of being an aquifer it is an important confining bed.

From the standpoint of well yields and ground-water use, the Atlantic and Gulf Coastal Plain is one of the most important regions in the country. Recharge to the ground-water system occurs in the interstream areas, both where sand layers crop out and by percolation downward across the interbedded clay and silt layers. Discharge from the system occurs by seepage to streams, estuaries, and the ocean. Movement of water from recharge areas to discharge areas is controlled, as in all ground-water systems, by hydraulic gradients, but in this region the pattern of movement is complicated by down-dip thickening of clay which hampers upward discharge. As a result, movement down the dip of the permeable layers becomes increasingly slow with increasing distance from the outcrop areas. This causes many flow lines to converge on the discharge areas located on major streams near the downdip part of outcrop areas. These areas of concentrated ground-water discharge are referred to as "artesian-water gaps" by LeGrand and Pettyjohn (1981).

Wells that yield moderate to large quantities of water can be constructed almost anywhere in the region. Because most of the aquifers consist of unconsolidated sand, wells require screens; where the sand is fine-grained and well sorted, the common practice is to surround the screens with a coarse sand or gravel envelope.

Withdrawals near the outcrop areas of aquifers are rather quickly balanced by increases in recharge and (or) reductions in natural discharge. Withdrawals at significant distances downdip do not appreciably affect conditions in the outcrop area and thus must be partly or largely supplied from water in storage in the aquifers and confining beds.

The reduction of storage in an aquifer in the vicinity of a pumping well is reflected in a decline in ground-water levels and is necessary in order to establish a hydraulic gradient toward the well. If withdrawals are continued for long periods in areas underlain by thick sequences of unconsolidated deposits, such as the Atlantic and Gulf Coastal Plain, the lowered ground-water levels in the aquifer may result in drainage of water from layers of silt and clay. The depletion of storage in fine-grained beds results in subsidence of the land surface. Subsidence in parts of the Houston area totaled about 9 m as of 1978. Subsidence near pumping centers in the Atlantic Coastal Plain has not yet been confirmed but is believed to be occurring, though at a slower rate than along the Texas Gulf Coast.

The depletion of storage in confining beds is permanent, and subsidence of the land surface that results from such depletion is also permanent. On the other hand, depletion of storage in aquifers may not be fully permanent, depending on the availability of recharge. In arid and semiarid regions, recharge rates are extremely small, and depletion of aquifer storage is, for practical purposes, permanent. Depletion of storage in aquifers in these regions is referred to as mining. In humid regions, recharge is sufficient to replace aquifer storage rather quickly, once withdrawals are stopped, so that depletion of aquifer storage in these areas is not considered to be mining. The important point is that depletion of storage in the confining layers of silt and clay in both arid and humid regions is permanent but is not normally considered to be ground-water mining. The term "mining" is applied by most ground-water hydrologists only to areas in which aquifer storage is being permanently depleted.

Depletion of storage in the aquifers underlying large areas of the Atlantic and Gulf Coastal Plain is reflected in long-term declines in ground-water levels. These declines suggest that withdrawals in these areas are exceeding the long-term yield of the aquifers.

This is a water-management problem that will become more important as rates of withdrawal and the lowering of water levels increase. Solutions to this problem include (1) concentrating withdrawals as close as possible to outcrop (recharge) areas, (2) dispersing withdrawals in regions remote from the outcrop areas over the widest possible area, and (3) increasing withdrawals from surficial aquifers to the maximum possible extent.

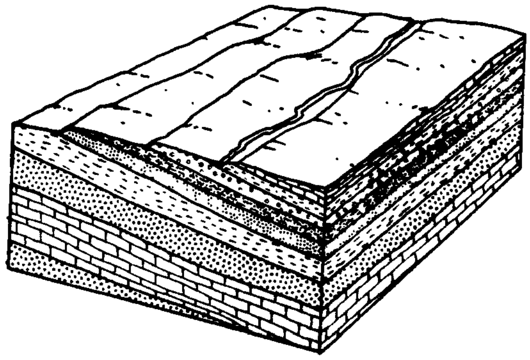
Another problem that affects ground-water development in the region concerns the presence of saline water in the deeper parts of most aquifers. The occurrence of saline water is controlled by the circulation of freshwater which, as noted previously, becomes increasingly slow down the dip of the aquifers. Thus, in some of the deeper aquifers, the interface between freshwater and saltwater is inshore, but in parts of the region, including parts of Long Island, New Jersey, and Mississippi, the interface in the most intensively developed aquifers is a significant distance offshore. Pumping near the interfaces has resulted in problems of saltwater encroachment locally.

Another significant feature of the ground-water system in this region is the presence of "geopressured" zones at depths of 1,800 to 6,100 m in Texas and Louisiana which contain water at a temperature of 80°C to more than 273°C. Water in these zones contains significant concentrations of natural gas, and the water in some zones is under pressures sufficient to support a column of water more than 4,000 m above land surface. Because the elevated temperature, natural gas, and high pressures are all potential energy sources, these zones are under intensive investigation.

ATLANTIC AND GULF COASTAL PLAIN

(10Aa) Regional Aquifer

This hydrogeologic setting is characterized by moderately low topographic relief and gently dipping, complexly interbedded unconsolidated and semi-consolidated deposits which consist primarily of sand, silt and clay. Outcrops of these deposits form a series of bands roughly parallel to the coast or to the axis of the Mississippi Embayment. The outcrop areas and overlying semi-permeable beds are the principal sources of recharge to the formations which serve as regional aquifers. Precipitation is abundant and recharge is moderately high in the outcrop areas but low regionally to deep zones. Surficial deposits typically weather to a sandy loam. Large quantities of water are obtained from the sand and gravel and sand deposits within the aquifer. Water levels are extremely variable and typically are shallower toward the shoreline. When ground water is heavily pumped near the shoreline, these aquifers are very susceptible to salt-water intrusion. Since the shallow aquifers are very vulnerable to pollution due to their permeable nature, and the deeper aquifers are recharged from the shallow ones, the entire system is somewhat susceptible to ground-water pollution. The degree of vulnerability varies according to the nature of the deposits and the amount of recharge.



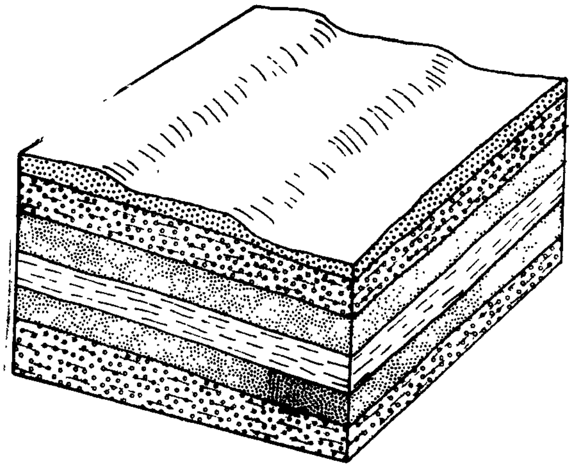
SETTING 10 Aa Confined Regional Aquifers		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt and Clay	5	3	15
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	82

SETTING 10 Aa Confined Regional Aquifers		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	0-2%	3	10	30
Impact Vadose Zone	Silt and Clay	4	3	12
Hydraulic Conductivity	300-700	2	4	8
			Pesticide Drastic Index	113

ATLANTIC AND GULF COASTAL PLAIN

(10Ab) Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer

This setting is very similar to (10Aa) Confined Regional Aquifers except that the principal aquifer is the shallow surficial deposits which serve as a local source of water and typically provide recharge for the regional aquifer. Water is obtained from the surficial sand and gravel which may be separated from the underlying regional aquifer by a confining layer. This confining layer typically "leaks" providing recharge to the deeper zones. Surficial deposits are sandy loams. Water levels tend to be quite shallow, especially near the coast. Precipitation is abundant and recharge to the ground water is high. These deposits are very vulnerable to ground-water pollution due to their permeable nature.



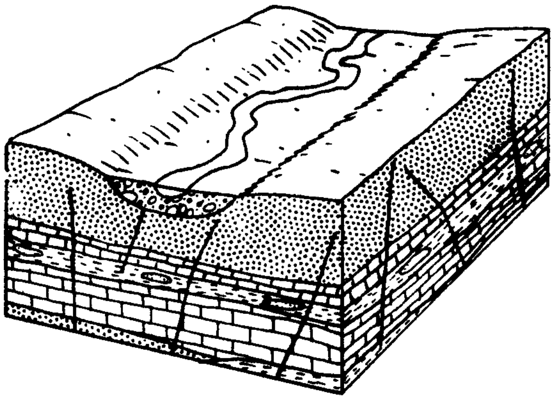
SETTING 10 Ab Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	184

SETTING 10 Ab Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	2-6%	3	9	27
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	206

ATLANTIC AND GULF COASTAL PLAIN

(10Ba) River Alluvium with Overbank Deposits

This hydrogeologic setting is characterized by low topography and thin to moderately thick deposits of alluvium along parts of river valleys. The alluvium is underlain by consolidated and semi-consolidated sedimentary rocks. Water is obtained from sand and gravel layers which are interbedded with finer-grained alluvial deposits. The floodplain is covered by varying thicknesses of fine-grained, silty deposits called overbank deposits. The overbank thickness is usually greater along major streams (as much as 40 feet) and thinner along minor streams. Precipitation in the region is abundant, but recharge is somewhat reduced because of the silty overbank deposits and subsequent silty soils which typically cover the surface. Water levels are typically moderately shallow. The alluvium may serve as a significant source of water and may be in direct hydraulic connection with the underlying sedimentary rocks. The alluvium may also serve as a source of recharge to the underlying bedrock.



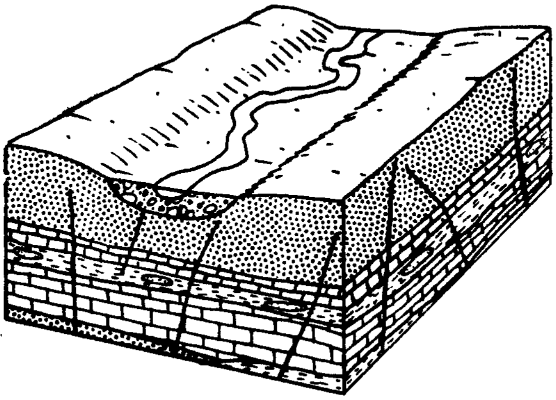
SETTING 10 Ba River Alluvium With Overbank Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	2	4	8
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	142

SETTING 10 Ba River Alluvium With Overbank Deposits		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	5	4	20
Topography	0-2%	3	10	30
Impact Vadose Zone	Silt/Clay	4	3	12
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	165

ATLANTIC AND GULF COASTAL PLAIN

(10Bb) River Alluvium without Overbank Deposits

This setting is identical to (10Ba) River Alluvium with Overbank Deposits except that no significant fine-grained floodplain deposits occupy the stream valley. This results in significantly higher recharge and sandy soils at the surface. Water levels are typically shallow in depth and throughout much of this region there is an abundance of coarse-grained material. Hydraulic connection with the surface stream is usually excellent, with alternating recharge/discharge relationships varying with stream stage. These deposits provide a good source of recharge to the underlying consolidated and semi-consolidated bedrock.

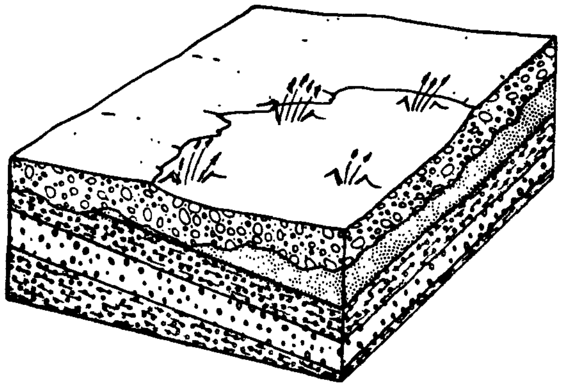


SETTING 10 Bb River Alluvium Without Overbank Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	S & G w/ sig. Silt and Clay	5	6	30
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	187

SETTING 10 Bb River Alluvium Without Overbank Deposits		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	5	9	45
Topography	0-2%	3	10	30
Impact Vadose Zone	S & G w/ sig. Silt and Clay	4	6	24
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	220

(10C) Swamp

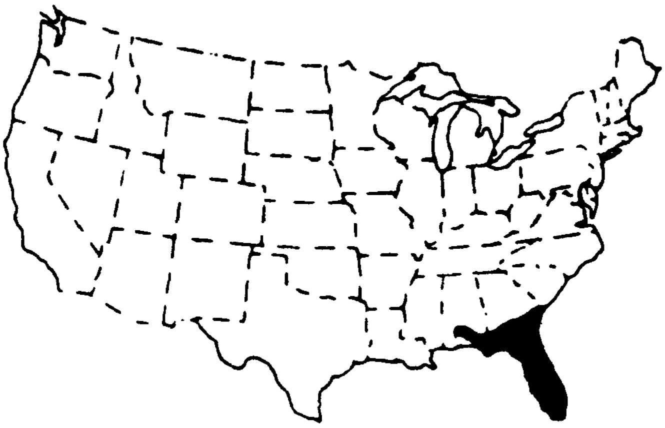
This hydrogeologic setting is characterized by low topographic relief and deposits of sand, and sand and gravel, which overlie consolidated and semi-consolidated sedimentary rocks. Precipitation is abundant and potential recharge is high. Water levels are typically at or near the surface during the majority of the year. Surficial deposits are typically sand mixed with organic material. The surficial sands are usually in hydraulic connection with the underlying aquifers and may serve as a source of recharge. However, a swamp is frequently a ground-water discharge zone and in this case would not be especially vulnerable to pollution. It should also be noted that a slight reversal in gradient would easily convert the swamp into a ground-water recharge zone. Thus, it is potentially highly vulnerable to ground-water pollution.

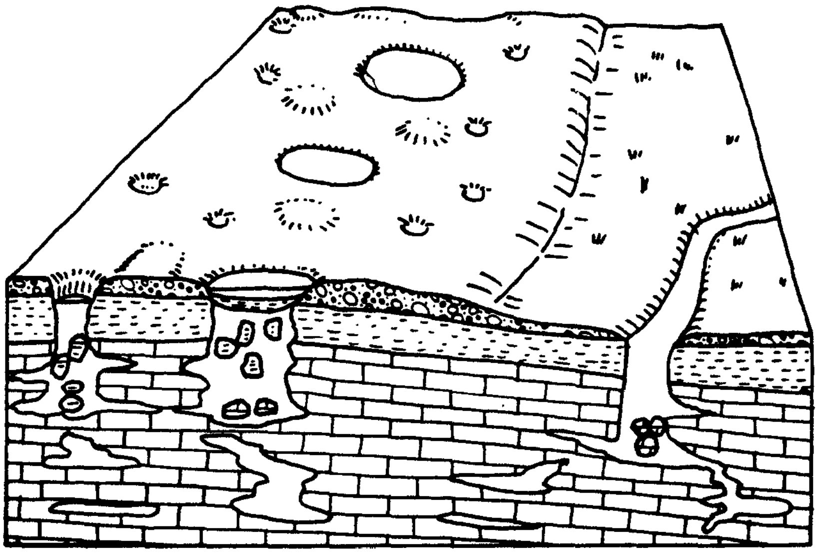


SETTING 10 C Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	202

SETTING 10 C Swamp		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	5	9	45
Topography	0-2%	3	10	30
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	233

11. SOUTHEAST COASTAL PLAIN GROUND-WATER REGION





11A	Solution Limestone and Shallow Surficial Aquifers
11B	Coastal Deposits
11C	Swamp
11D	Beaches & Bars

11. SOUTHEAST COASTAL PLAIN

(Thick layers of sand and clay over semi-consolidated carbonate rocks)

The Southeast Coastal Plain is an area of about 212,000 km^2 in Alabama, Florida, Georgia, and South Carolina. It is a relatively flat, low-lying area in which altitudes range from sea level at the coast to about 100 m down the center of the Florida peninsula and as much as 200 m on hills in Georgia near the interior boundary of the region. Much of the area, including the Everglades in southern Florida, is a nearly flat plain less than 10 m above sea level.

The land surface of the Southeast Coastal Plain is underlain by unconsolidated deposits of Pleistocene age consisting of sand, gravel, clay, and shell beds and, in southeastern Florida, by semiconsolidated limestone. From the coast up to altitudes of nearly 100 m, the surficial deposits are associated with marine terraces formed when the Coastal Plain was inundated at different times by the sea. In most of the region the surficial deposits rest on formations, primarily of middle to late Miocene age, composed of interbedded clay, sand, and limestone. The most extensive Miocene deposit is the Hawthorn Formation. The formations of middle to late Miocene age and, where those formations are absent, the surficial deposits overlie semiconsolidated limestones and dolomites that are as much as 1,500 m thick. These carbonate rocks range in age from early Miocene to Paleocene and are generally referred to collectively as Tertiary limestones.

The Tertiary limestone that underlies the Southeast Coastal Plain constitutes one of the most productive aquifers in the United States and is the feature that justifies treatment of the region separately from the remainder of the Atlantic and Gulf Coastal Plain. The aquifer, which is known as the Floridan aquifer, underlies all of Florida and southeast Georgia and small areas in Alabama and South Carolina. The Floridan aquifer consists of layers several meters thick composed largely of loose aggregations of shells of foraminifers and fragments of echinoids and other marine organisms interbedded with much thinner layers of cemented and cherty limestone. The Floridan, one of the most productive aquifers in the world, is the principal source of ground-water supplies in the southeast Coastal Plain region.

In southern Florida, south of Lake Okeechobee, and in a belt about 30 km wide northward along the east coast of Florida to the vicinity of St. Augustine, the water in the Floridan aquifer contains more than 100 mg/l of chloride. In this area, most water supplies are obtained from surficial aquifers, the most notable of which underlies the southeastern part of Florida and which in the Miami area consists of 30 to 100 m of cavernous limestone and sand referred to as the Biscayne aquifer. The Biscayne is an unconfined aquifer which is recharged by local precipitation and by infiltration of water from canals that drain water from impoundments (conservation areas) developed in the Everglades. It is the principal source of water for municipal, industrial, and irrigation uses and can yield as much as $5 m^3 min^{-1}$ (1,300 gal min^{-1}) to small-diameter wells less than 25 m deep finished with open holes only 1 to 2 m in length.

The surficial aquifers in the remainder of the region are composed primarily of sand, except in the coastal zones of Florida where the sand is interbedded with shells and thin limestones. These surficial aquifers serve as sources of small ground-water supplies throughout the region and are the primary sources of ground water where the water in the Floridan aquifer contains more than about 259 mg/l of chloride.

The Floridan aquifer, as noted above, is the principal source of ground water in the region. Ground water in the upper part of the aquifer is unconfined in the principal recharge areas in Georgia and in west-central Florida. In the remainder of the region, water in the aquifer is confined by clay in the Hawthorn Formation and in other beds that overlie the aquifer. Recharge occurs where the potentiometric surface of the Floridan aquifer is lower than the water table in the overlying surficial aquifer. The principal recharge areas include a broad area along the west side of Florida extending from the central part of the peninsula to south-central Georgia and an area extending from west-central Florida through southeast Alabama into southwest Georgia. In these areas, recharge rates are estimated to exceed 120 mm yr^{-1} (5 in. yr^{-1}). Recharge occurs by infiltration of precipitation directly into the limestone, where it is exposed at the land surface, and by seepage through the permeable soils that partly mantle the limestone in the outcrop areas. Considerable recharge also occurs in the higher parts of the recharge areas through permeable openings in the confining beds, where these beds have been breached by the collapse of caverns in the limestone during the process of sinkhole formation. Thus, the land surface in most of Florida north of Lake Okeechobee is marked by thousands of closed depressions ranging in diameter from a few meters to several kilometers. The larger depressions, which represent a more advanced stage of solution of the limestone and collapse of the overlying material, are occupied by lakes generally referred to as sinkhole lakes.

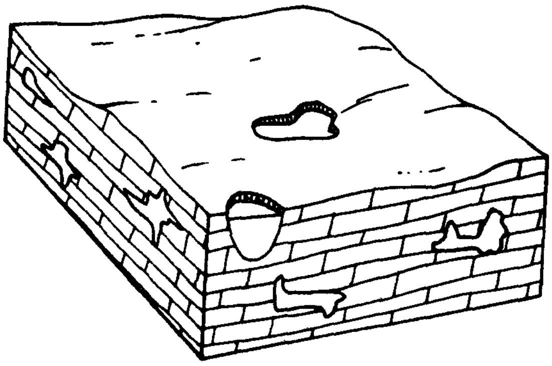
Discharge from the Floridan aquifer occurs through springs and by seepage to streams. Considerable discharge also occurs by diffuse seepage across the overlying confining beds in areas where the potentiometric surface of the aquifer stands at a higher altitude than the water table. In most of these areas, which include the southern third of the Florida peninsula, the east coast area and major stream valleys of Florida, and the coastal zone and major stream valleys of Georgia and South Carolina, wells open to the aquifer will flow at the land surface. Such wells are called "flowing artesian wells." The most spectacular discharge from the Floridan aquifer is through sinkholes exposed along streams and offshore. Florida has 27 springs of the first magnitude at which the average discharge exceeds 2.83 $m^3 sec^{-1}$ (100 $ft^3 sec^{-1}$). The largest is Silver Springs, which has an average discharge of 23.2 m^3sec^{-1} (530 million gallons per day) and reached a maximum discharge of 36.5 m^3sec^{-1} on September 28, 1960. Heath and Conover (1981) estimate that the combined discharge from Florida's springs is 357 m^3sec^{-1} (8 billion gallons per day).

The marked difference in ground-water conditions between the Southeast Coastal Plain and the Atlantic and Gulf Coastal Plain and the Atlantic and Gulf Coastal Plain regions is apparent in the response of ground-water levels to withdrawals. In the Atlantic and Gulf region most large withdrawals are accompanied by a pronounced continuing decline in ground-water levels. In the Southeast Coastal Plain, on the other hand, large withdrawals have significantly lowered ground-water levels in only a few areas.

SOUTHEAST COASTAL PLAIN

(11A) Solution Limestone and Shallow Surficial Aquifers

This hydrogeologic setting is characterized by low to moderate topographic relief and deposits of limestone which have been partially dissolved to form a network of solution cavities and caves. Surficial deposits typically consist of sands which may serve as localized aquifers. The underlying limestone typically serves as the principal aquifer due to the high yields. The shallow surficial aquifer may not be present in all areas. Precipitation is abundant and recharge is high. Water levels are variable but are usually moderate in the limestone and shallow in the overlying surficial sands. These sands also serve as an important source of recharge for the limestones. Due to the presence of a shallow water table and direct recharge to the limestone these surficial sands are very vulnerable to pollution. Near the coast, these aquifers are very susceptible to salt water intrusion.



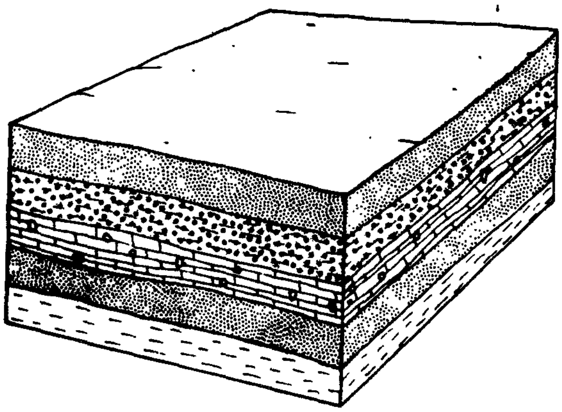
SETTING 11 A Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Karst Limestone	5	10	50
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	218

SETTING 11 A Solution Limestone		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	5	9	45
Topography	2-6%	3	9	27
Impact Vadose Zone	Karst Limestone	4	10	40
Hydraulic Conductivity	2000+	2	10	20
			Pesticide Drastic Index	243

SOUTHEAST COASTAL PLAIN

(11B) Coastal Deposits

This hydrogeologic setting is characterized by flat topography and unconsolidated deposits of carbonate, sand, gravel, clay and shell beds which overlie semi-consolidated carbonate rocks. The surficial deposits serve as direct sources of ground water and also serve as recharge for the underlying carbonate rocks where the gradient is downward toward the carbonates. The carbonates serve as a source of ground water but may contain saline water in some areas. Precipitation is abundant and recharge is high. Water levels may vary, but are typically close to the surface.



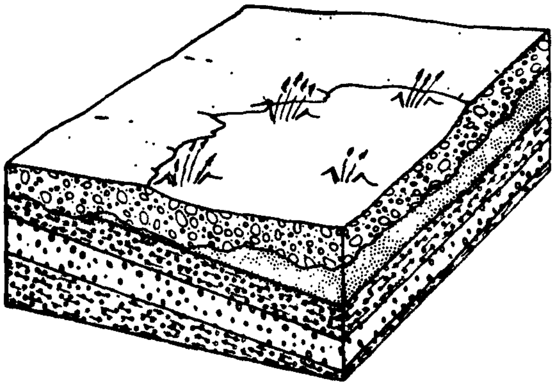
SETTING 11 B Coastal Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	191

SETTING 11 B Coastal Deposits		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	5	9	45
Topography	0-2%	3	10	30
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	224

SOUTHEAST COASTAL PLAIN

(11C) Swamp

This hydrogeologic setting is characterized by flat topographic relief, very high water levels and deposits of limestone which have partially been dissolved to form a network of solution cavities and caves. Soils are typically sand and recharge may be high due to the abundant precipitation. The limestone typically serves as the major regional aquifer. These swamps also serve as discharge areas, but due to their environmental vulnerability, and possible gradient reversal, they should be regarded as areas of maximum (potential) recharge. Water levels are typically at or above the surface during the majority of the year.



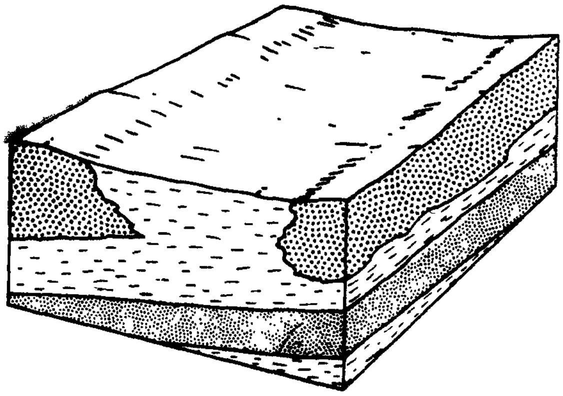
SETTING 11 C Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Karst Limestone	5	10	50
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	224

SETTING 11 C Swamp		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	5	9	45
Topography	0-2%	3	10	30
Impact Vadose Zone	Karst Limestone	4	10	40
Hydraulic Conductivity	2000+	2	10	20
			Pesticide Drastic Index	251

SOUTHEAST COASTAL PLAIN

(11D) Beaches and Bars

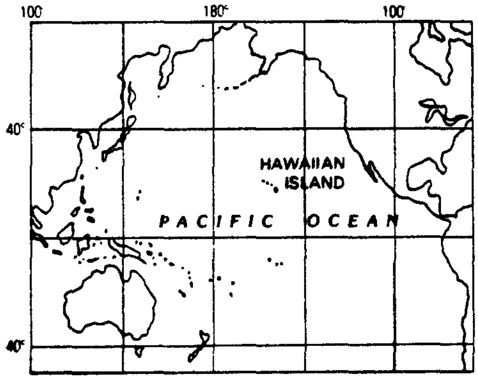
This hydrogeologic setting is characterized by moderate to flat topographic relief and unconsolidated deposits of water-washed sands. These sands are well-sorted and very permeable, and may serve as localized sources of ground water. These deposits also serve as a source of recharge to the underlying unconsolidated coastal deposits. Precipitation is abundant and recharge is high. Water levels may vary, but are typically shallow. These areas are highly susceptible to pollution due to their high permeabilities.

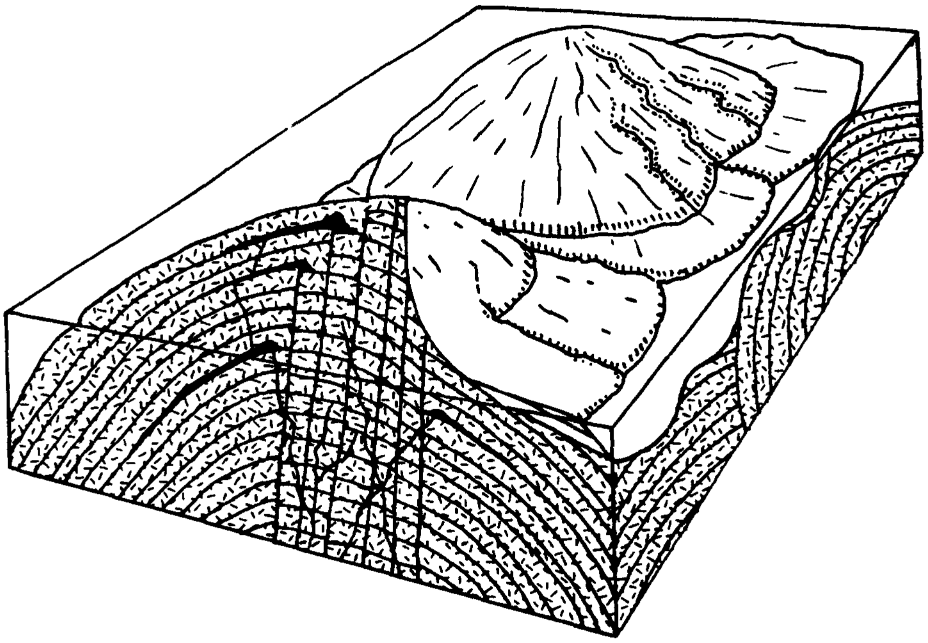


SETTING 11 D Beaches and Bars		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	190

SETTING 11 D Beaches and Bars		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	5	9	45
Topography	2-6%	3	9	27
Impact Vadose Zone	Sand and Gravel	4	8	36
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	225

12. HAWAIIAN ISLANDS GROUND-WATER REGION





12A	Mountain Slopes
12B	Alluvial Mountain Valleys
12C	Volcanic Uplands
12D	Coastal Beaches

12. HAWAIIAN ISLANDS

(Lava flows segmented in part by dikes, interbedded with ash deposits, and partly overlain by alluvium)

The Hawaiian Islands region encompasses the State of Hawaii and consists of eight major islands occupying an area of 16,707 km^2 in the Pacific Ocean 3,700 km southeast of California. The islands are the tops of volcanoes that rise from the ocean floor and stand at altitudes ranging from a few meters to more than 4,000 m above sea level. Each island was formed by lava that issued from one or more eruption centers. The islands have a hilly to mountainous appearance resulting from erosion that has carved valleys into the volcanoes and built relatively narrow plains along parts of the coastal areas.

Each of the Hawaiian Islands is underlain by hundreds of distinct and separate lava flows, most of which are composed of basalt. The lavas issued in repeated outpourings from narrow zones of fissures, first below sea level, then above it. The lavas that extruded below the sea are relatively impermeable. Those formed above sea level tend to be highly permeable, with interconnected openings that formed as the lava cooled, cavities and openings that were not filled by the overlying flow, and lava tubes (tunnels). The central parts of the thicker flows tend to be more massive and less permeable; the most common water-bearing openings are joints and faults that formed after the lava solidified. Thin layers of ash and weathered volcanic rock occur irregularly between some of the flows that formed above sea level. The lava flows in valleys and parts of the coastal plains are covered by a thin layer of alluvium consisting of coral (limestone) fragments, sand-size fragments of basalt, and clay.

The fissures through which the lava erupted tend to cluster near eruption centers. Flows from the fissures moved down depressions on the adjacent slopes to form layers of lava that dip at angles of 4 to 10 degrees toward the margins of the volcanoes. The result, prior to modification by erosion, is a broad, roughly circular, gently convex mountain similar in shape to a warrior's shield. Thus, volcanoes of the Hawaiian type are referred to as shield volcanoes. When eruption along a fissure ceases, the lava remaining in the fissure solidifies to form a dike.

All of the islands have sunk, to some extent, as a result of a downward flexing of the Earth's crust caused by the weight of the volcanoes. This has resulted in flows that formed above sea level being depressed below sea level. The upper parts of these flows contain freshwater that serves as an important source of water.

In mineral composition and nature of the water-bearing openings, the lavas that form the Hawaiian Islands are very similar to those in the Columbia Plateau region. Thus, from these two standpoints, these regions could be combined into one. There is, however, one important difference that justifies their treatment as separate regions. This difference relates to the presence of seawater around and beneath the islands, which significantly affects the occurrence and development of water supplies.

From the standpoint both of description and of development, it is useful to divide the ground-water system of the Hawaiian Islands into three parts. The first part consists of the higher areas of the islands in the vicinity of the eruption centers. The rocks in these areas are formed into a complex series of vertical compartments surrounded by dikes developed along eruption fissures. The ground water in these compartments is referred to as dike-impounded water. The second, and by far the more important, part of the system consists of the lava flows that flank the eruption centers and that contain fresh ground water floating on saline ground water. These flank flows are partially isolated hydraulically from the vertical compartments developed by the dikes that surround the eruption centers. The fresh ground water in these flows is referred to as basal ground water. In parts of the coastal areas the basal water is confined by the overlying alluvium. The third part of the system consists of fresh water perched, primarily in lava flows, on soils, ash, or thick impermeable lava flows above basal ground water.

The ground-water system is recharged by precipitation which ranges annually from about 160 mm to more than 11,000 mm. This wide range in precipitation reflects the effect of the islands on the moist northeast trade winds. As the moisture-laden winds are deflected upward by the mountains, precipitation falls on the higher elevations. Precipitation is heaviest on mountains below 1,000 m and lightest in the coastal areas on the leeward side of the islands and at elevations above 1,000 m on the islands of Maui and Hawaii. The average annual precipitation on the islands is estimated to be about 1,800 mm. Because of the highly permeable nature of the volcanic soils, it is estimated that about 30 percent of the precipitation recharges the ground-water system.

Some discharge of dike-impounded ground water doubtless occurs through fractures in the dikes into the flanking lava flows. This movement must be small, however, because water stands in the compartments at levels hundreds of meters above sea level and the principal discharge occurs as springs on the sides and at the heads of valleys where erosion has removed parts of the dikes. Both the basal ground water and the perched ground water in the lava flows surrounding the dike-bounded compartments is recharged by precipitation and by streams leaving the dike-bounded area. Discharge is to streams and to springs and seeps along the coast.

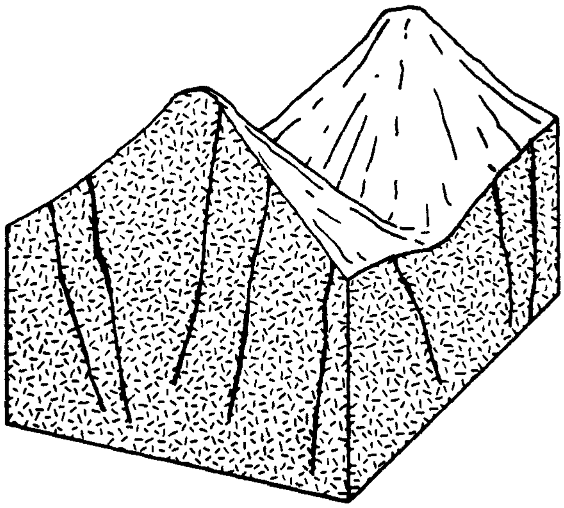
The basal water is the principal source of ground water on the islands. Because the freshwater is lighter (less dense) than seawater, it floats as a lens-shaped body on the underlying seawater. The thickness of the freshwater zone below sea level essentially depends on the height of the freshwater head above sea level. Near the coast the zone is thin, but several kilometers inland from the coast on the larger islands it reaches thicknesses of at least a few hundred meters. In parts of the coastal zone, and especially on the leeward side of the islands, the basal ground water is brackish.

Forty-six percent of the water used in Hawaii in 1975, or 3.1 x $10^6 m^3 day^{-1}$, was ground water. It is obtained through horizontal tunnels and through both vertical and inclined wells. Tunnels are used to obtain supplies of basal water near the coast where the freshwater zone is thin. Tunnels are also used to tap dike-impounded water. These tunnels encounter large flows of water when the principal impounding dike is penetrated and it is necessary to drain most of the water in the saturated zone above the tunnel before construction can be completed. Thereafter, the yield of the tunnel reflects the rate of recharge to the compartment tapped by the tunnel. To avoid a large initial waste of water and to preserve as much storage as possible, the Honolulu Board of Water Supply has begun to construct inclined wells to obtain dike-impounded water. Vertical wells are used to obtain basal water and perched ground water in inland areas where the thickness of the freshwater zone permits the use of such wells.

HAWAII

(12A) Mountain Slopes

This hydrogeologic setting is characterized by steep slopes composed of volcanic lava flows, breccia and related extrusive magmatic rocks. Soils are thin, but highly permeable where present. Rubble alluvial deposits are common. Because of the steep topography and elevation the water table is typically deep. Water occurs in the fractures and vesicular zones of the basaltic lava flows, and along the relatively horizontal inter-flow zones. Overall, hydraulic conductivity is moderately high, due to the density of fracture zones. Perched water table zones are common, where water in an inter-flow zone between successive lava flows is delayed from moving downward by a dense layer of clayey material or basalt. The dense layer acts as an aquitard. Rainfall is high, and with permeable surface material recharge is also high.



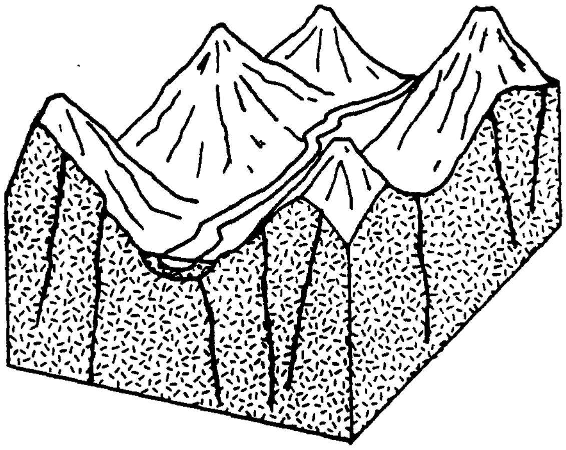
SETTING 12 A Mountain Slopes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	10+	4	9	36
Aquifer Media	Basalt	3	9	27
Soil Media	Thin or Absent	2	10	20
Topography	18+%	1	1	1
Impact Vadose Zone	Basalt	5	9	45
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	164

SETTING 12 A Mountain Slopes		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	10+	4	9	36
Aquifer Media	Basalt	3	9	27
Soil Media	Thin or Absent	5	10	50
Topography	18+%	3	1	3
Impact Vadose Zone	Basalt	4	9	36
Hydraulic Conductivity	2000+	2	10	20
			Pesticide Drastic Index	177

HAWAII

(12B) Alluvial Mountain Valleys

This hydrogeologic setting is characterized by narrow, steep-walled valleys, with moderate to steep seaward slope. The valleys contain alluvial material varying typically from zero to a few tens of feet in thickness. Waterfalls and related features are common near the ocean. The alluvium consists of basaltic debris and associated weathered products. Soils are moderately developed, thin and quite permeable. Rainfall is high, recharge is high, and vegetation is lush. The alluvium below stream grade is generally saturated at a shallow level, and may be hydraulically connected to the permanent water table or perched zones. Hydraulic conductivity of both the alluvium and underlying aquifers is high.



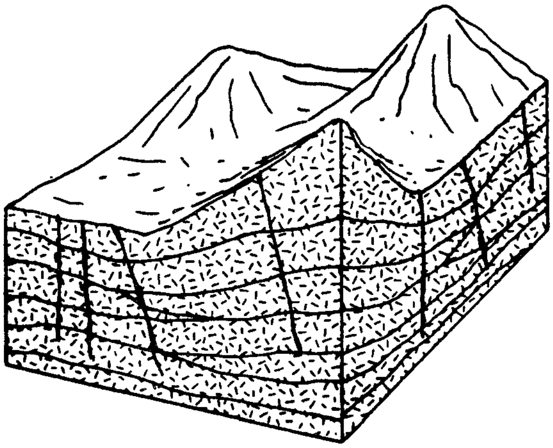
SETTING 12 B Alluvial Mountain Valleys		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	12-18%	1	3	3
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	184

SETTING 12 B Alluvial Mountain Valleys		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	12-18%	3	3	9
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	192

HAWAII

(12C) Volcanic Uplands

This hydrogeologic setting is characterized by moderately rolling topography, at medium elevations, and rich, dark, soils developed from the basaltic bedrock. The soils are permeable, rainfall is high and recharge is high. Bedrock is composed primarily of alternating extrusive basaltic lava flows and interlayered weathered zones formed between flows. Ground water occurs at moderate to deep depths, and aquifer yield is controlled by fracture zones, vesicular zones (both primarily cooling features) and the inter-flow weathered zones. Hydraulic conductivity is high. As with other settings in Hawaii, heavy pumping stresses often result in salt-water intrusion. This is a reflection of the fact that each island is surrounded by and underlain by salt water, with the fresh water occurring in a lenticular body that floats on the salt water. Ground-water yield is therefore limited quite specifically to the amount of water recharged annually.



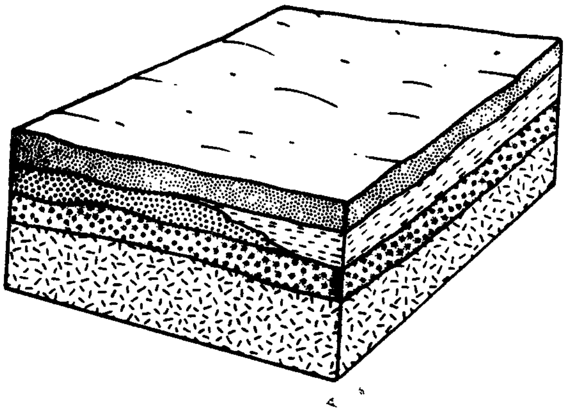
SETTING 12 C Volcanic Uplands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	10+	4	9	36
Aquifer Media	Basalt	3	9	27
Soil Media	Sandy Loam	2	6	12
Topography	6-12%	1	5	5
Impact Vadose Zone	Basalt	5	9	45
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	165

SETTING 12 C Volcanic Uplands		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	10+	4	9	36
Aquifer Media	Basalt	3	9	27
Soil Media	Sandy Loam	5	6	30
Topography	6-12%	3	5	15
Impact Vadose Zone	Basalt	4	9	36
Hydraulic Conductivity	2000+	2	10	20
			Pesticide Drastic Index	174

HAWAII

(12D) Coastal Beaches

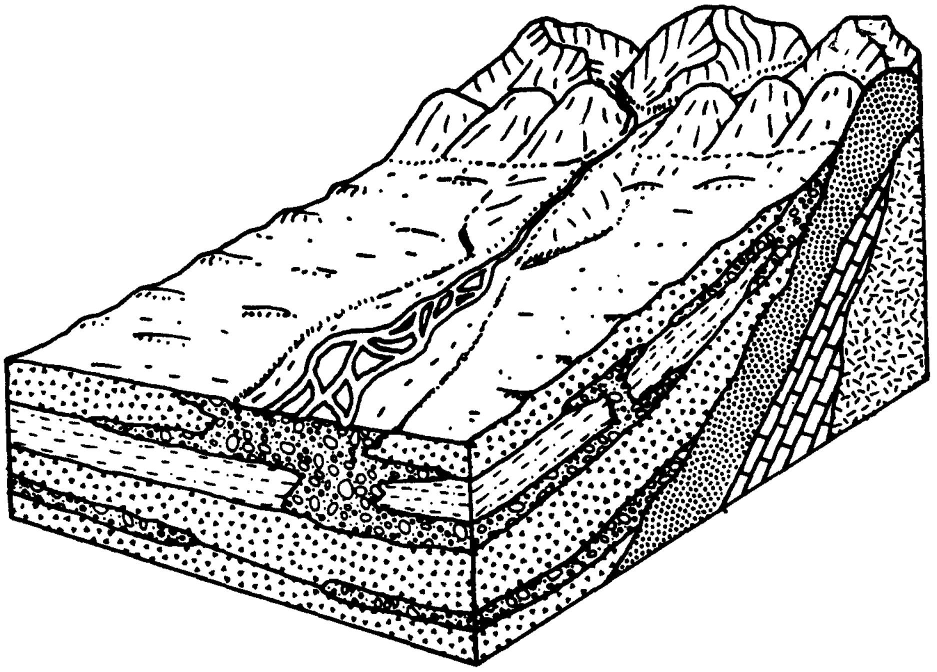
This hydrogeologic setting is characterized by low to moderate topography, near sea level, with sandy materials at the surface. The sandy soils are very permeable and direct recharge from rainfall is high where ground-water levels permit. Because of their location these settings are often discharge areas where ground water is lost into the ocean. Management of this area is essential to the maximum utilization of the ground-water resources of the islands. It should be noted that all discharge areas are potential recharge areas, and therefore potentially vulnerable to pollution.



SETTING 12 D Coastal Beaches		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	201

SETTING 12 D Coastal Beaches		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	5	9	45
Topography	2-6%	3	9	27
Impact Vadose Zone	Sand and Gravel	4	8	32
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	230

13. ALASKA GROUND-WATER REGION



13A	Alluvium
13B	Glacial and Glaciolacustrine Deposits of the Interior Valleys
13C	Coastal Lowland Deposits
13D	Bedrock of the Uplands and Mountains

13. ALASKA

(Glacial and alluvial deposits, occupied in part by permafrost, and overlying crystalline, metamorphic, and sedimentary rocks)

The Alaska region encompasses the State of Alaska, which occupies an area of 1,519,000 km^2 at the northwest corner of North America. Physiographically, Alaska can be divided into four divisions--from south to north, the Pacific Mountain System, the Intermontane Plateaus, the Rocky Mountain System, and the Arctic Coastal Plain. The Pacific Mountain System is the Alaskan equivalent of the Coast Range, Puget Sound Lowland, and Cascade provinces of the Washington-Oregon area. The Intermontane Plateaus is a lowland area of plains, plateaus, and low mountains comparable to the area between the Cascades-Sierra Nevada and the Rocky Mountains. The Rocky Mountain System is a continuation of the Rocky Mountains of the United States and Canada, and the Arctic Coastal Plain is the geologic equivalent of the Great Plains of the United States and Canada. The coastal areas and lowlands range in altitude from sea level to about 300 m, and the higher mountains reach altitudes of 1,500 to 3,000 m. Mt. McKinley in the Pacific Mountain System is the highest peak in North America, with an altitude of about 6,300 m.

As would be expected of any area its size, Alaska is underlain by a diverse assemblage of rocks. The principal mountain ranges have cores of igneous and metamorphic rocks ranging in age from Precambriam to Mesozoic. These are overlain and flanked by younger sedimentary and volcanic rocks. The sedimentary rocks include carbonates, sandstones, and shales. In much of the region the bedrock is overlain by unconsoliated deposits of gravel, sand, silt, clay, and glacial till.

Climate has a dominant effect on hydrologic conditions in Alaska. Mean annual air temperatures range from -12°C in the Rocky Mountain System and the Arctic Coastal Plain to about 5°C in the coastal zone adjacent to the Gulf of Alaska. The present climate and the colder climates that existed intermittently in the past have resulted in the formation of permafrost, or perennially frozen ground. Permafrost is present throughout the State except in a narrow strip along the southern and southeastern coasts. In the northern part of the Seward Peninsula, in the western and northern parts of the Rocky Mountain System, and in the Arctic Coastal Plain, the permafrost extends to depths as great as 600 m and is continuous except beneath deep lakes and in the alluvium beneath the deeper parts of the channels of streams. South of this area and north of the coastal strip, the permafrost is discontinuous and depends on exposure, slope, vegetation, and other factors. The permafrost is highly variable in thickness in this zone but is generally less than 100 m thick.

Much of the water in Alaska is frozen for at least a part of each year: that on the surface as ice in streams and lakes or as snow or glacier ice and that below the surface as winter frost and permafrost. Approximately half of Alaska, including the mountain ranges and adjacent parts of the lowlands, was covered by glaciers during the Pleistocene. About 73,000 $km2$, or one-twentieth of the region, is still occupied by glaciers, most of which are in the mountain ranges that border the Gulf of Alaska. Precipitation, which ranges from about 130 mm yr^{-1} in the Rocky Mountain System and the Arctic Coastal Plain to about 7,600 mm yr^{-1} along the southeast coast, falls as snow for 6 to 9 months of the year and even year-round in the high mountain regions. The snow remains on the surface until thawing conditions begin, in May in southern and central Alaska and in June in the arctic zone. During the period of subfreezing temperatures, there is no overland runoff, and many streams and shallow lakes not receiving substantial ground-water discharge are frozen solid.

From the standpoint of ground-water availability and well yields, Alaska is divided into three zones. In the zone of continuous permafrost, ground water occurs beneath the permafrost and also in small, isolated, thawed zones that penetrate the permafrost beneath large lakes and deep holes in the channels of streams. In the zone of discontinuous permafrost, ground water occurs below the permafrost and in sand and gravel deposits that underlie the channels and floodplains of major streams. In the zone of discontinuous permafrost, water contained in silt, clay, glacial till, and other fine-grained deposits usually is frozen. Thus, in this zone the occurrence of ground water is largely controlled by hydraulic conductivity. In the zone not affected by permafrost, which includes the Aleutian Islands, the western part of the Alaska Peninsula, and the southern and southeastern coastal areas, ground water occurs both in the bedrock and in the relatively continuous layer of unconsolidated deposits that mantle the bedrock.

Relatively little is known about the occurrence and availability of ground water in the bedrock. Permafrost extends into the bedrock in both the zones of continuous and discontinuous permafrost, but springs that issue from carbonate rocks in the Rocky Mountain System indicate the presence of productive water-bearing openings. Small supplies of ground water have also been developed from sandstones, from volcanic rocks, and from faults and fractures in the igneous and metamorphic rocks.

Recharge of the aquifers in the Alaska region occurs when the ground is thawed in the areas not underlain by permafrost. This period generally lasts only from June through September. Because the ground, even in nonpermafrost areas, is still frozen when most snowmelt runoff occurs, relatively little recharge occurs in interstream areas by infiltration of water across the unsaturated zone. Instead, most recharge occurs through the channels of streams where they flow across the alluvial fans that fringe the mountainous areas and in alluvial deposits for some distance downstream. Because of the large hydraulic conductivty of the sand and gravel in these areas, the rate of infiltration is large. Seepage investigations along Ship Creek near Anchorage indicate channel losses of 0.07 $m^3sec^{-1}km^{-1}$, which gives an infiltration rate through the wetted perimeter of about 0.4 m day^{-1}.

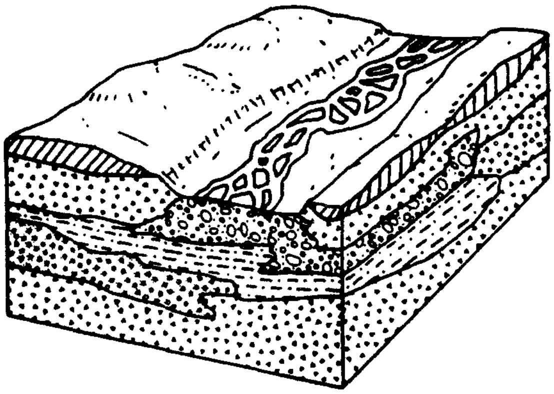
Discharge from aquifers occurs in the downstream reaches of streams and through seeps and springs along the coast. The winter flow of most Alaskan streams is sustained by ground-water discharge. In the interior and northern regions, this discharge is evidenced by the buildup of ice (referred to locally as "icings") in the channels of streams and on the adjacent flood plains.

Unlike the 12 regions which comprise the contiguous United States, both Alaska and Hawaii are political subdivisions, not discrete ground-water regions. Hawaii can be treated as a single region because of its smaller size and relative geologic simplicity. Alaska, however, due to its size and complexity includes several major ground-water regions. For purposes of this document, these regions are considered hydrogeologic settings.

ALASKA

(13A) Alluvium

This hydrogeological setting includes floodplains, terraces and alluvial fans of both major valleys and upland and mountain valleys. Braided streams are present in the major valley floodplains. Heavy silt/rock flour loading in streams results in substantial silt and clay deposition along with the alluvial sands and gravels. Ground-water levels are usually shallow near the streams, into which the ground water discharges, and considerably deeper along the higher terraces. Recharge to the ground water is seasonal, following snow melt and thawing of frozen areas. Except for the south coastal area, precipitation is light to moderate and usually in the form of snow. Topography is moderate, with a unidirectional downstream ground-water movement. Hydraulic conductivities are moderate to very high in the cleaner portions of the sand and gravel aquifers.



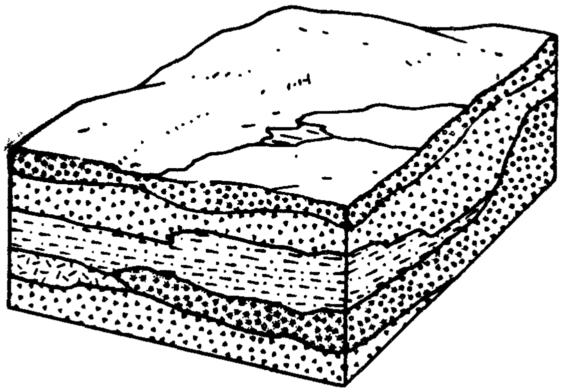
SETTING 13 A Alluvium		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	S & G w/ sig. Silt and Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	140

SETTING 13 A Alluvium		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	2-6%	1	9	27
Impact Vadose Zone	S & G w/ sig. Silt and Clay	4	6	24
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	164

ALASKA

(13B) Glacial and Glaciolacustrine Deposits of the Interior Valleys

This hydrogeological setting is characterized by tills and associated outwash deposits, as well as glacier-related lake deposits of interbedded sand, silt and clay. Ground-water levels are relatively shallow. Surface soils are typically organic sandy loams with moderate conductivity. Recharge is moderate to low, primarily limited by the period of thaw and annual precipitation. Topography is moderate, and the hydraulic conductivity of the outwash aquifers is generally high.



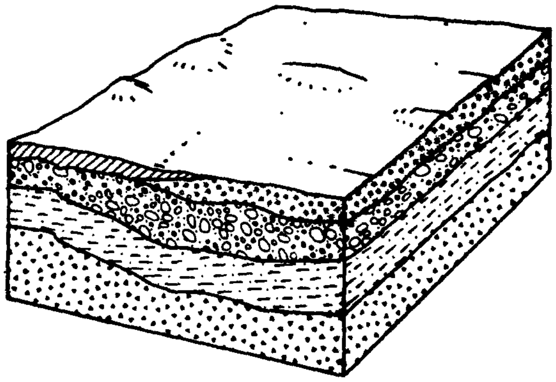
SETTING 13 B Glacial & Glaciolacustrine Deposits: Interior Valleys		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	3	15
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	141

SETTING 13 B Glacial & Glaciolacustrine Deposits: Interior Valleys		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	2-6%	3	9	27
Impact Vadose Zone	Silt/Clay	4	3	12
Hydraulic Conductivity	1000-2000	2	8	16
			Pesticide Drastic Index	166

ALASKA

(13C) Coastal-Lowland Deposits

This hydrogeologic setting includes coastal plains, deltaic deposits of major streams, beaches and nearshore bars and spits, and deposits of deep alluvial coastal basins and valleys. Permafrost severely affects the northernmost portions of this setting, which is within the permanent permafrost zone. Where not permanently frozen, recharge rates are seasonally high, particularly along streams which are hydraulically connected to the ground-water. Ground-water depths are at or near the elevation of the surface streams, and topographic slopes are low to moderate. The primary aquifers in this setting are the alluvial sands and gravels that are interbedded with silts and clays. Thick sequences of all types of materials are common.



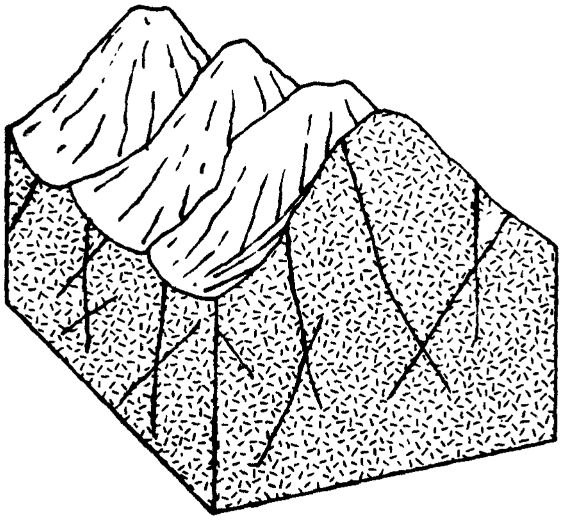
SETTING 13 C Coastal Lowland Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	S & G w/ sig. Silt and Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	140

SETTING 13 C Coastal Lowland Deposits		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	5	6	30
Topography	2-6%	3	9	27
Impact Vadose Zone	S & G w/ sig. Silt and Clay	4	6	24
Hydraulic Conductivity	700-1000	2	6	12
			Pesticide Drastic Index	164

ALASKA

(13D) Bedrock of the Uplands and Mountains

This hydrogeologic setting is characterized by deposits of carbonate rocks, limestone, sandstone, volcanics and other igneous and metamorphic rocks. These formations underlie a thin veneer of alluvium beneath a large portion of the state. Water levels within this setting are variable, but generally deep. Exceptions to this are discharge zones along the flanks of many mountains. The most notable example of this are springs discharging from carbonate rocks along the flanks of mountains. Recharge is limited by precipitation, topography and predominant permafrost. Soils are generally thin and poorly developed. Aquifer conductivities vary from low in some of the fractured metamorphics to very high in the solution-dissolved carbonates.



SETTING 13 D Bedrock of the Uplands and Mountains		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Thin or Absent	2	10	20
Topography	12-18%	1	3	3
Impact Vadose Zone	Bedded LS, SS, SH	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	92

SETTING 13 D Bedrock of the Uplands and Mountains		PESTICIDE		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Bedded SS, LS, SH Sequences	3	6	18
Soil Media	Thin or Absent	5	10	50
Topography	12-18%	3	3	9
Impact Vadose Zone	Bedded LS, SS, SH	4	6	24
Hydraulic Conductivity	300-700	2	4	8
			Pesticide Drastic Index	118

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APPENDIX A

PROCESSES AND PROPERTIES AFFECTING CONTAMINANT FATE AND TRANSPORT

Most potential ground-water contaminants are released at or slightly above the water table as a result of various industrial, agricultural and other human activities. The attenuation of contaminants as they travel through the unsaturated zone and ground-water system is affected by a variety of naturally occurring physical processes and chemical reactions that often cause the contaminant to change its physical state or chemical form. This change may result in removal of the contaminant from the ground-water system. The extent of these reactions is dependent on hydrogeochemical conditions present in the ground water such as pH, redox-potential and solid surface area. However, the chemical processes within dynamic ground-water systems are complex, and are highly dependent on site-specific aquifer and soil characteristics as well as the effects of individual contaminants in the system (Cherry et al., 1984). Therefore, although the importance of these chemical reactions in attenuation of contaminants is widely recognized, prediction of the amount of attenuation of a contaminant in any environment is still very difficult.

Attenuation includes those mechanisms that lessen the severity or amounts of contaminants. The components which affect attenuation are the physical and chemical processes and properties including density, solubility, sorption, biodegradation, oxidation-reduction, dilution, hydrolysis, dispersion, viscosity, mechanical filtration, ion exchange, volatilization and buffering or neutralization. The degree of attenuation that occurs is dependent on: 1) the time that the contaminant is in contact with the material through which it passes, 2) the grain size, and physical and chemical characteristics of the material through which it passes, and 3) the distance which the contaminant has traveled. For most materials, the longer the time, the greater the surface area and the greater the distance of travel, the greater the degree of attenuation. Movement of ground water is slower in rocks with high surface areas, such as found in a fine-grained porous medium, than in rocks where water movement is primarily through fault and fracture channels or solution openings. Additionally, flow velocity decreases with lower gradients and increasing depth; subsequently ground water is in prolonged contact with rock materials (Matthess and Harvey, 1982).

Another factor affecting attenuation includes surface area in the aquifer media. The greater the surface area of the material through which the contaminant passes, the greater the potential for sorption of the contaminant. Likewise, the greater the reactivity of the material through which the contaminant passes, the greater the potential for attenuation.

The many physical processes and chemical reactions present in a ground-water system may work individually or in combination to provide varying degrees of attenuation depending on the hydrogeochemical conditions and the particular contaminant. The following discussion addresses each physical and chemical process and describes the respective impact on contaminants.

DENSITY

The density of any substance is defined as mass per unit volume. The movement of a contaminant in an aquifer is directly affected by the density of the fluid with respect to the density of the ground water. Low density contaminants float on top of the water table; high density contaminants sink to the bottom of the aquifer.

Once a contaminant has entered an aquifer, it will be transported as a function of density in the direction of ground-water flow. Under the ideal condition of a homogeneous aquifer media, the contaminant will begin to disperse forming an elliptical plume (Pye et al., 1983; Todd, 1980). Movement and dispersion of the plume is affected by the density of the contaminant, the character of the geologic formation through which the contaminant passes and the reactive nature of the contaminant. In a uniform geologic formation, the more dense the contaminant, the greater will be the downward migration of that contaminant and the slower the contaminant will travel in relation to the velocity of ground-water flow.

SOLUBILITY

As a contaminant is introduced into an aquifer, the contaminant is generally partially dissolved in water, forming either miscible or immiscible solutions. A potential contaminant may also remain insoluble, depending on the chemical characteristics of the contaminant. The solubility of a substance is defined as the mass of a substance that will dissolve in a unit volume of solute under specified chemical conditions (Freeze and Cherry, 1979). The solubility of a constituent in water is dependent on variations in temperature, pressure, pH, redox potential (Eh) and the relative concentrations of other substances in solution. The interactions of these chemical parameters make it difficult to predict the solubilities of many substances in ground water (Davis and DeWiest, 1966; Snoeyink and Jenkins, 1980).

Substances are dissolved in water, or become soluble, because the water molecule exhibits a charge which attracts other molecules in solution. When the attractive forces that hold a substance together are less than or equal to the attractive force of the water molecule, the substance will dissolve. Conversely, those substances that are held together by attractive forces stronger than the attraction of the water molecule do not dissolve to any appreciable degree in water, thus forming immiscible liquids or solids. A good example is oil and water; the two substances do not mix because the oil is only slightly soluble in water. Substances that have been dissolved may be reprecipitated as a consequence of equilibria shifts and deposited in the void spaces of the aquifer. In addition, immiscible fluids may be transformed through similar changes in solubility.

The chemical reaction which transforms a dissolved substance to a solid form is precipitation. The precipitation of a dissolved substance may be initiated by changes in pressure, temperature, pH, concentration, or oxidation-reduction. In addition, the introduction of another substance that changes the equilibrium concentrations in the solution, or which reacts chemically with the dissolved substance may cause precipitation. The resultant solid is deposited in the void spaces of the aquifer, thereby reducing the space available for transport of the ground water.

Several types of contaminants can be effectively removed from the ground water through precipitation. Calcium salt solutions have been shown to effectively precipitate free fluorides (Tolman, et al., 1978). Alkalis and/or sulfides may precipitate heavy metals. Stover and Kincannon (1983) have conducted successful experiments with regulated pH conditions, demonstrating the precipitation of metals using lime. Since oxidation-reduction reactions may change the chemical state of a substance by rendering it insoluble, this reaction has proven effective in changing dissolved chromium to a less soluble state thereby removing it from the ground water (Tolman et al., 1978; Fuller and Artiola, 1978). The FMC Corporation (1983) has conducted extensive studies using hydrogen peroxide to oxidize various sulfide compounds and initiate precipitation. Vapors escaping from a contaminated site may cause heavy metals to be transported and re-deposited. Each of these chemical reactions provides a method of changing the solubility of a substance, thereby removing the contaminant from the ground water and precipitating it in the void spaces of the aquifer. Even though the contaminant has changed form, the precipitate may be re-dissolved and the process repeated. When a precipitate re-dissolves, the contaminant may not be in its original form and may form a different solute which may or may not be harmless.

SORPTION

Sorption is a combination of two processes, adsorption and absorption. Adsorption occurs when molecules or ions are attached to the surface of charged particles by weak Van der Waals or covalent bonds. Adsorption differs from absorption in that the latter involves penetration by the absorbed substance (Keenan and Wood, 1971; Matthess and Harvey, 1982). Sorption occurs on all surfaces where bonding conditions are present. Sorption increases with increasing surface area, which is usually a function of decreasing grain size. Colloidal particles range in diameter size from 10^{-3} to 10^{-6} mm. These particles tend to have a large charge relative to their surface area (Freeze and Cherry, 1979). Porous geologic materials that are composed of an appreciable amount of collodial-sized particles exhibit a higher capability to sorb constituents onto the particle surfaces.

The subsurface materials that exhibit sorptive properties include clay minerals, hydrous iron, manganese, aluminum oxides, organic substances (particularly humus), glauconites and the rock-forming minerals mica, feldspar, aluminous augite and hornblende (Matthess and Harvey, 1982; Freeze and Cherry, 1979; Davis and DeWiest, 1966). These minerals are commonly present in colloidal form and contain especially large surface areas available for sorption.

The surface charge on a mineral in the saturated or unsaturated zone creates an attractive force. This charge may be due to 1) imperfections or substitutions in the crystal lattice of the particle or 2) chemical reactions at the surface of the particle involving weak hydrogen bonding, due to the presence of water. The pH of the water and the crystal structure of the mineral have a direct affect on the charge of the particle surface; waters with a high pH and highly crystalline materials typically produce net negative charges on the particle surface thus favoring the sorption of positive constituents or cations (Matthess and Harvey, 1982). There is a direct relationship between the quantity of a substance sorbed on a particle surface and the quantity of the substance suspended in solution. In general, an increase in the concentration of the substance in solution will increase the quantity sorbed.

The presence of organic matter in porous materials appears to be an important factor in the sorption of non-ionic organic substances. Those organic substances that are nonpolar (not attracted to water) and relatively insoluble are frequently absorbed by soils and sediments containing clays and organic carbon. The sorption of nonpolar aromatic and chlorinated hydrocarbons has been shown to increase with decreasing particle size and subsequently increasing organic carbon content (Karickhoff et al., 1979). Sorption of polar organics primarily occurs through weak hydrogen bonds to mineral particles (Cherry et al., 1984; Brown et al., 1983). Studies by Haque et al. (1974) and Griffen et al. (1978) indicate that sorption of PCBs was enhanced in materials with greater surface area and higher organic content. The sorptive capabilities of clays and soils appear promising for attenuation of some contaminants, however further experimentation is necessary due to the complexity of chemical reactions that occur in the sorption process.

ION EXCHANGE

The process of ion exchange is similar to sorption, however, stronger ionic bonding occurs on the particle surfaces. Ion-exchange processes are virtually limited to colloidal size particles because these particles have large electrical charges with respect to their surface areas. Colloidal particles range in diameter size from 10^{-3} to 10^{-6} mm.

Ion exchange occurs when there is a surface charge imbalance. These surface charges are a result of 1) imperfections or ionic substitutions within the crystal or particle, or 2) chemical dissociation reactions at the particle surface. Upon exposure to water the charged molecules attract hydroxyl groups (OH-) to the surface. When these hydroxyl groups break down, the resulting charge imbalance attracts oppositely charged particles (Freeze and Cherry, 1979). Ionic substitutions within particle surfaces also cause a charge imbalance that attracts oppositely charged ions. These ions comprise an adsorbed layer that is interchangeable; thus the process is reversible. An example of ionic substitutions occurs within silicate minerals. Aluminum ions tend to substitute for the silica ions, forming an unbalanced charge on the mineral surface. The nature of the surface charge that develops is dependent on pH; positively charged surfaces develop at low pH and a negatively charged surface prevails with a high pH. Clay minerals are the primary geologic materials of colloidal size that exhibit surface charges as a result of ionic substitutions. Organic materials such as humus and plant roots in soils and recent sediments also exhibit high ion-exchange capacities (Davis and DeWeist, 1966; Matthess and Harvey, 1982).

The most common ion exchange involves the transfer of cations on charged surfaces. Cation exchange capacity is the capability of a charged surface layer to attract positive ions in the zone adjacent to that charged surface (Freeze and Cherry, 1979). The affinity for attraction of cations varies with the valence, or charge, of the ion and the ionic size. Other things being equal, the affinity for ion exchange is greater when the ion has a higher valence. For ions of the same valence, the affinity for exchange increases with atomic number and decreases with increasing hydrate radius (Matthess and Harvey, 1982).

Other colloidal particles that exhibit ion-exchange capacities include hydrated oxides of iron and manganese. Hydrated oxides of iron selectively sorb zinc, copper, lead, mercury, chromium, molybdenum, tungsten and vanadium through ion exchange. Similarly, hydrated oxides of manganese will bond to copper, nickel, cobalt, chromium, molybdenum, and tungsten (Matthess and Harvey, 1982). Clay minerals tend to preferentially bond zinc, copper, lead, mercury and radioactive elements such as rubidium, cesium, and strontium. Certain organic dyes are firmly bonded to clays by strong electrostatic bonds (Matthess and Harvey, 1982). For cationic organic substances, increasing valence will tend to increase the capacity for bonding to clay surfaces, and vice versa for anionic organic constituents (Brown et al., 1983).

Ion exchange can provide a means for attenuation of heavy metals and certain organic substances if the bonding is sufficiently strong to prevent reversal of the chemical reaction and release of the contaminant back into the ground-water system.

OXIDATION-REDUCTION

Oxidation and reduction (redox) are geochemically important processes because together with pH, they control the solubility, and thus the presence of many substances in water. These reactions involve the transfer of electrons between dissolved, gaseous and solid substances in the water. As a result of this electron transfer, there is a change in the oxidation state of the substance. A redox reaction consists of two parts or half reactions. In the oxidation reaction, the substance loses, or donates electrons; in the reduction reaction, the substance accepts, or gains electrons. Oxidation and reduction reactions are always coupled; no free electrons can exist in solution and electrons must be conserved (Snoeyink and Jenkins, 1980).

Deposits above the water table contain voids which are usually filled with atmospheric gases containing oxygen. Percolating water carries dissolved atmospheric oxygen to the water table where the processes of diffusion and dispersion can carry it to deeper water levels (Matthess and Harvey, 1982). The presence or absence of dissolved oxygen in the ground water is one factor which controls whether oxidizing or reducing conditions will predominate. Oxidation may be initiated in ground water by the presence or introduction of an oxidizing agent, such as potassium permanganate, or a change in valence state of ions such as Fe^{+3} and Mn^{+3}. In general, oxidation processes are increased in warm climates, and are more complete in humid and humid/arid climates than in arid climates.

Microorganisms are responsible for a large proportion of redox reactions which occur in ground water. The principal microorganisms involved in redox processes are bacteria which contain enzymes. Bacteria and their enzymes utilize redox processes to provide energy for cell synthesis and maintenance (Freeze and Cherry, 1979). Bacteria that require oxygen are known as aerobic bacteria, while anaerobic bacteria cannot tolerate dissolved oxygen in the water.

In many contaminated ground-water systems, dispersion exerts a strong influence on the redox state of the ground water. Dispersion causes a continuous mixing of waters that are different in chemical composition and redox potential. The mixing of these waters by dispersion affect the redox and pH conditions and may instigate other chemical reactions within the system.

The use of oxidation-reduction reactions for the attenuation of contaminants has proven effective for both inorganic and organic substances. The introduction of oxidizing agents into ground water is the most important mechanism of oxidation after microorganisms. Detoxification through oxidation of cyanides (Farb, 1978) and organic cyanides (Harsh, 1975) has been accomplished through the application of sodium hypochloride in conjunction with pH adjustments to produce substances that are insoluble. Dohnalek and Fitzpatrick (1983) documented removal of hydrogen sulfide from ground water in laboratory studies using oxidants. The FMC Corporation (1983) has conducted extensive experimentation using hydrogen peroxide to oxidize various sulfides and organic sulfides thereby rendering them insoluble. Certain organic compounds such as phenols, aldehydes, hydroquinine, as well as chlorine compounds and cyanides can also be oxidized by hydrogen peroxide (FMC, 1983). Matthess (1981) achieved treatment of arsenic-contaminated ground water by accelerating the natural precipitation process through the injection of the oxidant potassium permanganate. The soluble arsenic compounds were oxidized to the less soluble arsenate state and precipitated as iron and manganese arsenates and hydroxides, thus removing the arsenic from the ground water and eliminating the contamination problem. Injection of oxygenated water into an aquifer has also been shown to improve water quality by stimulating iron and manganese bacteria. The bacteria then provided the adsorption-oxidation mechanism that precipitated the iron and manganese hydroxides (Rott et al., 1981). Other chemicals susceptible to oxidation include phenols, aromatic amines and dienes (Cherry et al., 1984). The application of a strong reducing agent has also proven effective in changing the oxidation state of chromium causing the formation of an insoluble chromium product.

The mechanisms of oxidation and reduction provide a means for reducing the solubility and causing subsequent precipitation through several reactions. Those most effective reactions for reducing solubility include a change in oxidation state, the formation of new compounds, and the enhancement of naturally occurring bacterial processes.

BIODEGRADATION

Biodegradation results from the enzyme-catalyzed transformation of organic compounds by microbes, principally bacteria, fungi, actinomycetes, algae and yeasts. Biological treatment can eliminate hazardous organic wastes by transforming them into innocuous forms, degrading them by mineralization to carbon dioxide and water, or by anaerobically decomposing them to carbon dioxide and methane (Kobayashi and Rittmann, 1982). Bacteria and other microbes require nutrients to produce the necessary enzymes that use or attack the organic compounds. Most microbes require oxygen, water and nutrients such as carbon, nitrogen, phosphorus and trace metals. Aerobic bacteria require the presence of free oxygen; anaerobic bacteria require the absence of dissolved oxygen. The metabolic processes of both types of bacteria are energy efficient and tend to enhance certain critical reactions. Reactions such as reductive dehalogenation, nitroreduction and reduction of sulfoxides are catalyzed by anaerobic bacteria (Kobayashi and Rittman, 1982).

Biodegradation of a broad range of organic compounds particularly those that are man-made, have been demonstrated in laboratory studies. It is difficult to predict the exact transformations that may occur in the subsurface due to the complexity of chemical reactions present in natural systems of mixed microbes and organic compounds (Cherry et al., 1984; Kobayashi and Rittmann, 1982). Biodegradation is dependent on interactions in a natural environment such as redox potential, dissolved oxygen, pH, temperature, presence of other compounds, salinity, other competing organisms, and the concentrations of compounds and organisms. Organic compounds need to be fairly soluble in water in order to be utilized by microbes. Biodegradation can be limited if there are antagonistic interactions between two types of microbes, such as bacteria and fungi (Kobayashi and Rittmann, 1982). In addition, very low compound concentrations in a substrate may pose problems; certain organisms require minimal threshold values for survival and/or production of necessary enzymes.

Certain man-made organic compounds are refractory or resistant to biodegradation. This resistance is generally due to the presence of chemical substituents such as nitrogroups, chlorines and amines, that are attached to the parent compound. Generally, larger molecules are less degradable than smaller ones (Kobayashi and Rittmann, 1982). Other important refractory compounds are halogenated organics which are very resistant to biodegradation (Brown et al., 1983). These halogenated organics include pesticides, plasticizers, solvents and trihalomethanes. Chlorinated compounds such as DDT and other pesticides have been the most frequently studied compounds. The first step in degradation of halogenated organics involves dehalogenation by several biological mechanisms. Anaerobic reductive dehalogenation is an important mechanism in degradation of pesticides and certain halogenated aliphatic compounds.

Kobayashi and Rittmann (1982) and Tabak et al. (1980), indicate that most man-made organic compounds will undergo biodegradation to some extent. Actinomycetes and fungi are known to attack a wide variety of complex organic compounds. These microbes can grow under low nutrient conditions, wide temperature ranges and wide pH ranges. Actinomycetes break compounds down into groups that can be utilized by other organisms. Certain types of fungi are able to degrade complex hydrocarbons including the degradation of DDT. Fungi are believed to be capable of degrading PCB's more efficiently than bacteria (Gibson, 1978). Fungal metabolism is generally incomplete and requires other microbes for complete degradation. Bacteria have been found to degrade a wide variety of compounds under aerobic conditions. Bacteria are the major agents in the degradation of hydrocarbons and heterocyclic compounds (Kobayashi and Rittmann, 1982; Jhaveri and Mazzacca, 1983; Weldon, 1979; Tabak et al., 1980; Liu et al., 1981; Claus and Walker, 1964; Cherry et al., 1984).

Anaerobic bacteria degrade organic compounds to carbon dioxide and methane under oxygen-deficient conditions. Although little is known about these bacteria, four groups that utilize each of the metabolic products are responsible for degradation of the other groups. These bacteria are capable of dehalogenation, nitrosamine degradation, reduction of epoxide groups, reduction of nitro groups and the breakdown of aromatic structures (Kobayashi and Rittmann, 1982; Tabak et al., 1980). In a study conducted by Ehrlich et al. (1982) an aquifer contaminated by phenols and polynuclear aromatic hydrocarbons such as naphthelene showed significant reductions in these contaminants within 1000 m of the contamination source. Contaminant attenuation has been attributed to anaerobic degradation of the hydrocarbons by bacteria. Laboratory studies indicate that anaerobic bacteria are capable of degrading certain halogenated 1- and 2-carbon organic compounds such as trihalomethanes, chloroform and trichlorethylene (Bouwer et al., 1981).

HYDROLYSIS

The breakdown of substances by water and its ionic species H^+ and OH^- is known as hydrolysis. The breakdown of minerals by hydrolysis is an important reaction that occurs in the ground water, causing relatively insoluble minerals to form new minerals while releasing ions into solution. The hydrolysis process is dependent on pH, a measure of the concentration of H^+ and OH^- ions in solution, in addition to the oxidation-reduction potential (Matthess and Harvey, 1982). Hydrolysis is most effective at high temperatures, low pH and low redox potential. Hydrolysis is the basic reaction in the weathering processes which acts upon rocks and aids in the production of clays and soils.

Hydrolysis of an organic compound involves the introduction of a hydroxyl group (-OH) into the chemical structure, usually with the loss of a chemical group (X). The rate of hydrolysis of organic compounds is dependent on pH conditions and the presence of metal ions. A common hydrolysis reaction involves the replacement of halogens (X) by a hydroxyl group (Cherry et al., 1984). The occurrence of hydrolysis may aid in contamination attenuation. Certain organic compounds may be broken down by hydrolysis into simpler compounds that may then be easily assimilated through other processes. An example would be the hydrolysis of esters into a simple alcohol and acid that would comprise less harmful constituents in the ground water.

Hydrolysis is an important process in the attenuation of pesticides. It may be used to help predict the rate of decay of pesticides in the soil (Cohen et al., 1984; Cherry et al., 1984). Hydrolysis of atrazine and other pesticide derivatives has been shown to operate faster when humic material is present. Hydrolysis rates for breakdown of pesticides have been determined for certain organic groups (Cherry et al., 1984; Callahan et al., 1979; Cohen, 1984).

VOLATILIZATION

Volatilization is defined as the loss of a compound to the atmosphere. This process provides an attenuation mechanism for those compounds that are resistant to degradation and/or weakly absorbed, and to those that exhibit low solubilities and high vapor pressures (Callahan et al., 1979; Brown et al., 1983). Organic constituents with high vapor pressures are more easily volatilized from the soil. Compounds that are not soluble tend to be available for volatilization longer because they are not readily removed by water. Persistent organic constituents that are not easily removed by other processes may tend to volatize after a period of time. Organic compounds tend to volatize more easily if they are less strongly sorbed by the soil.

Factors that affect volatilization include vapor pressure, water solubility, soil moisture, adsorption, wind speed, turbulence, temperature, depth below land surface and time (Brown et al., 1983; Callahan et al., 1979). Studies indicate that the highest volatilization of organics occurs within minutes of application and decreases substantially within one hour (Wetherold et al., 1981).

Volatilization of organics is generally restricted to the purgable or volatile organic compounds. These compounds include hydrocarbons, compounds with simple functional groups such as alcohols, halides, and sulfur-containing compounds, and compounds containing unsaturated functional groups such as aldehydes, ketones and esters. Increasing air humidity, soil temperature and soil moisture have been shown to increase volatilization rates (Wetherold et al., 1981).

BUFFERING AND NEUTRALIZATION

Buffering and neutralization are chemical reactions which are similar. Neutralization is achieved by balancing the pH or activity of the hydrogen ion concentration so that a neutral solution is produced. Buffering refers to the ability of a substance to maintain a constant pH over a wide range of concentrations. The neutralization of an acid or base produces water and neutral salts. Lime is effective in neutralization of acidic wastes.

Many biological processes rely on maintaining neutral pH levels to enhance biodegradation of organic constituents (Brown et al., 1983). Neutral pH levels are maintained in soils by their natural buffering capacity. Aluminum ions in the surface of clay colloids maintain an equilibrium of hydroxide ions in the soil solution. The actual pH range of a soil may vary according to the predominant clay constituent present (Brown et al., 1983). Neutralization of contaminants through pH adjustment is generally achieved by the addition of an acid or base, precipitation and oxidation reduction.

A buffer solution is comprised of a weak acid or base plus a salt of that acid or base. A solution of this type will maintain a relatively constant pH even though a strong acid or base is added. A common example of this is the acetic acid-sodium acetate solution which will maintain a relatively constant pH when HCl is added, due to the H+ ions from the HCl combining with the acetate ions, as follows:

$$\begin{array}{ccc} Na_2C_3H_2O \longrightarrow Na^{+}+ \\ HCl \longrightarrow Cl^{-}+ \end{array} \boxed{\begin{array}{c} C_2H_3O_2^{-} \\ H+ \end{array}} \rightleftarrows H_2C_2H_3O_2$$

Therefore, no change occurs in the hydrogen ion concentration.

Carbonate systems provide very effective buffering effects in natural waters and waste waters (Snoeyink and Jenkins, 1980). The system is essentially based on a weak acid, carbonic, and sodium bicarbonate. As a consequence of the natural equilibria established between these parameters a relatively constant, near neutral pH is maintained for most ground water, making many important biological processes possible.

The precipitation of chromium from water is directly controlled by variable pH values by providing suitable electron donors to change the chromium to a less soluble oxidation state (Tolman et al., 1978; Fuller and Artiola, 1978). The use of variable pH levels enables the detoxification of cyanide through oxidation and subsequent precipitation of insoluble cyanide compounds (Farb, 1978).

DILUTION

The dilution of ground-water contaminants occurs through the addition of water by precipitation or other sources, introduced into the ground-water system. Dilution is an integral mechanism of dispersion occurring on a microscopic and macroscopic scale (Todd, 1980). These mixing mechanisms produce longitudinal and transverse dispersion of the contaminant such that the concentration decreases with the distance from the point of introduction. According to Todd (1980), dilution may be the most important mechanism for attenuation after the pollutant enters the ground-water system.

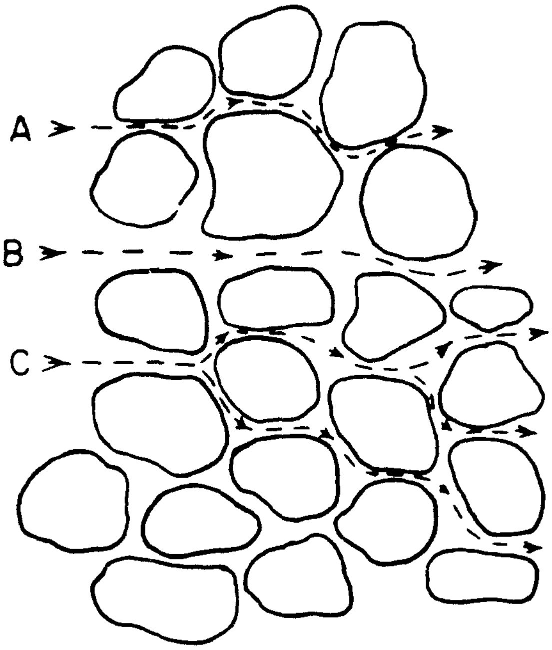
DISPERSION

A porous medium is composed of particles of varying sizes, shapes and orientations. As water flows through a porous medium, the velocity varies across pore space and around particles. As a result, when a contaminant is introduced into a ground-water system, it spreads, or disperses, so as to gradually occupy an increasing volume of that flow system. Thus dispersion constitutes a non-steady, irreversible mixing process by which the contaminant disperses within the surrounding ground water (Todd, 1980).

Dispersion has two components, longitudinal and transverse. Longitudinal dispersion occurs in the direction of flow and is caused by differences in macroscopic velocities as the water moves across pore spaces and around particles winding a tortuous path through the media in the direction of flow. Transverse dispersion occurs in two dimensions normal to ground-water flow and results from repeated division and deflection of the water flow by the particles (Todd, 1980; Bouwer, 1978). Figure A-1 illustrates transverse and longitudinal dispersion in a saturated porous medium.

Dispersion is a phenomenon that is caused by a combination of two processes, molecular diffusion and mechanical dispersion that occurs with laminar flow in a porous medium (Todd, 1980; Wilson et al., 1976). The result of these processes produces a contaminant plume with distinctly different characteristics dependent on the way the contaminant is introduced into the system. Figure A-2(a) illustrates the configuration of a plume that forms from the continuous input of a contaminant, whereas Figure A-2(b) represents input of a contaminant in pulses. The contaminant plume develops an expanding elliptical shape with declining concentration per unit mass of aquifer because of the process of dispersion (Freeze and Cherry, 1979).

The relative rates of dispersion and the subsequent configuration of the contaminant plume are dependent on the homogeneity of the aquifer. Most laboratory testing of dispersion has been restricted to homogeneous, sandy mediums. Heterogeneous aquifer media present a complex dispersion pattern related to the respective hydraulic conductivities of the individual stratigraphic units. High conductivity units dominate the flow of contaminants in the ground-water system as well as provide zones of migration where contaminants would move more quickly than through adjacent units of low conductivity (Freeze and Cherry, 1979). The predomination of heterogenous geologic units that serve as aquifers has necessitated the quantification of contaminant transport through mathematical models (Freeze and Cherry, 1979; Bouwer, 1978; Roberts, 1981; Anderson, 1984). These models have been extended to include molecular diffusion, the adsorption of solutes by the media and the decay of radioactive materials. The primary emphasis of these models is to provide an effective means of predicting the extent of contaminant dispersion, contaminant flow velocities, and concentrations at various points within the plume. Most modeling efforts are constrained by the lack of adequate control data.



Longitudinal dispersion occurs when a contaminant enters at A or B.

Longitudinal and transverse dispersion occurs when a contaminant enters at C.

Figure A-1. Schematic of pathlines showing longitudinal and transverse dispersion (Bouwer, 1978).

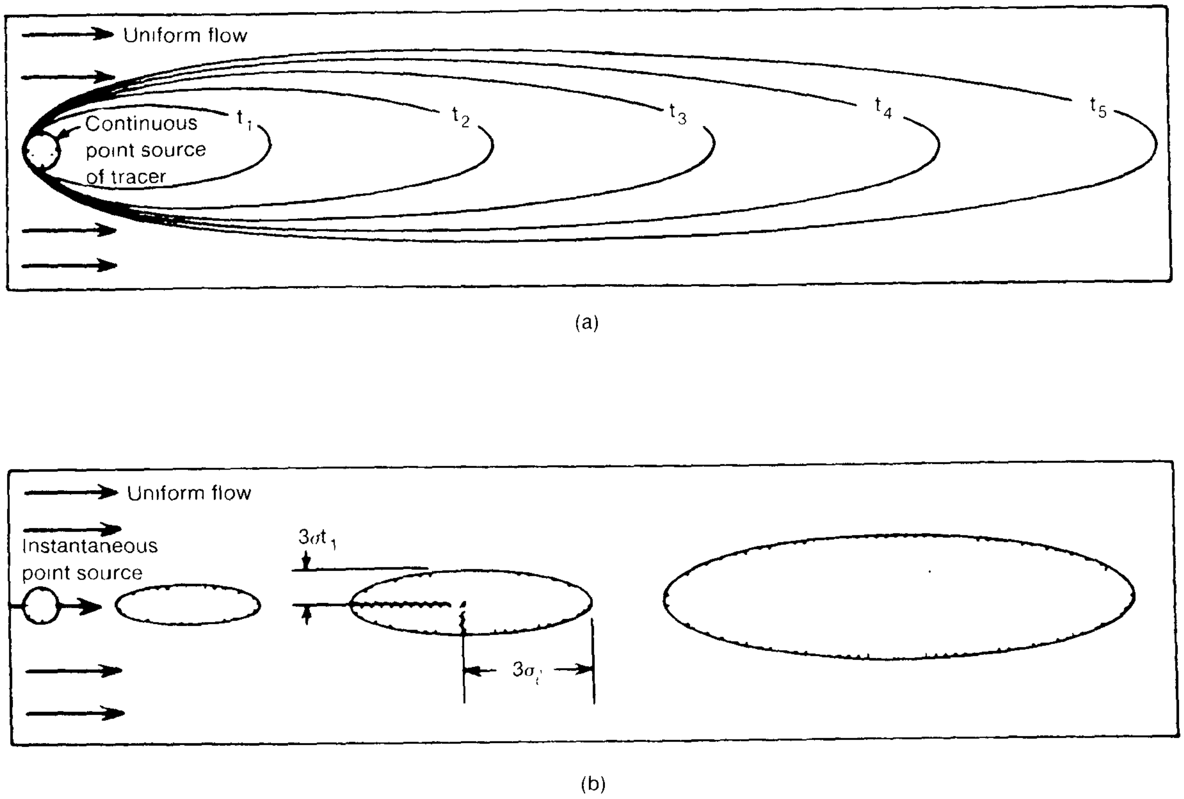


Figure A-2. Plume configuration based on contaminant input (Freeze and Cherry, 1979).

VISCOSITY

The viscosity of a fluid is the property of resistance to relative motion and shear deformation during flow. The more viscous the fluid, the greater the shear stress, and thus, the resistance to flow. Viscosity is affected by temperature; the higher the temperature, the lower the viscosity, the easier it will be for a fluid to move through the pores in a media. Viscosity of water has a direct affect on hydraulic conductivity that can be quantified as an inverse linear relationship (Bouwer, 1978). Reducing the viscosity by half will double the hydraulic conductivity.

Thus, the viscosity of a contaminant will partially control the rate of migration. More viscous contaminants will not move as easily through porous media. Consideration of contaminant viscosity if it differs significantly from water viscosity, in conjunction with other applicable chemical reactions, may be necessary for prediction of contaminant migration.

MECHANICAL FILTRATION

Mechanical filtration removes contaminants which are larger than the pore spaces of the host medium. This process is most effective in finer-grained materials such as clay or soil, but can occur in coarse-grained media depending on the particulate sizes being filtered. The effects of mechanical filtration increase with decreasing pore and/or channel size within the media. Retention of larger particles may effectively reduce the permeability of the media. Chemical reactions such as precipitation may form larger, insoluble particles that are retained by the media, thereby affecting porosity and permeability. The effectiveness of mechanical filtration for removal of contaminants is thus dependent on grain size and sorting of the media, hydraulic conditions within the media, and the particulate size of the contaminant being transported through the medium.

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APPENDIX B

CHARACTERISTICS OF SELECTED GROUND-WATER CONTAMINANTS

Contaminants have been divided into inorganic compounds and organic compounds. For purposes of this discussion, inorganic compounds are subdivided into metals and nonmetals, while organic compounds are separated into groups bearing similar molecular structures which influence those processes affecting the fate and transport of ground-water contaminants.

INORGANIC METALS

The mobility and attenuation of metals in any hydrogeologic setting is a function of the hydrochemical ground-water environment. Metals of primary importance include cadmium, chromium, copper, lead, mercury, manganese, silver, zinc and iron for which maximum Federal Drinking Water Standards have been established. With the exception of iron, metals typically occur naturally in the environment in concentrations below 1 mg/l. Concentrations are low due to the processes of adsorption, hydrolysis, precipitation and oxidation-reduction.

Metals tend to be hydrolized by water and exist as one or more ionic species. These metals combine readily with ligands to form ionic or neutral aqueous complexes. These ligands may be inorganic ions such as HCO_3^-, CO_3^{-2}, SO_4^{-2}, Cl^-, F^-, and NO_3^- (Freeze and Cherry et al., 1979). Any dissolved organic constituents that are present may also cause complexation or chelation. Increases in the concentrations of these anions increase the concentrations of the complexes that are formed. The occurrence of a complexed species is dependent on the pH and the equilibrium of a particular complex in the aqueous solution.

The oxidation-reduction potential of the ground water directly affects the oxidation state of the metal and may also affect the nonmetallic anions with which it forms complexes. Changes in the oxidation state of a metal may control the relative solubility or insolubility in water. The mechanism of sorption of trace metals is dependent on redox potential and pH.

Sorption of trace metals is an important process which may maintain metal concentrations far below that provided through solubility constraints. Trace-metal sorption occurs due to the presence of colloidal size clay particles, organic matter, and iron and manganese hydroxides. In most oxidizing environments, the iron and manganese oxides occur as surface coatings on grains thereby increasing their ability to sorb trace metals (Freeze and Cherry, 1979). This is particularly effective for Co, Ni, Cd and Zn in soils and freshwater sediments.

The hydrochemical environment of a ground-water system exhibits many effects on trace metals making the prediction of transport and migration difficult and complex. In general, the processes of sorption and precipitation cause the trace metals to migrate very slowly with respect to ground-water flow velocities. Thus, the occurrence of generally localized contamination by trace metals is common.

Cadmium (Cd)

Cadmium-contaminated wastes are generated as byproducts of cadmium-nickel battery production, pigments for plastics, enamels and paints, fumicides and in electroplating and metal coatings. The solubility and sorption of cadmium are controlled by pH. Under acidic or low pH conditions, cadmium solubility increases while sorption by colloids decreases (Brown et al., 1983). Precipitation of cadmium carbonates and cadmium phosphates may reduce cadmium concentrations at low pH values. Precipitation of cadmium sulfides occurs in reducing environments. The primary mechanism for cadmium attenuation is through sorption to organic matter in soils as organic-metallic complexes. The contaminant level as established in the Federal Primary Drinking Water Standards is 0.01 mg/l.

Chromium (Cr)

Chromium is present in waste streams as a consequence of its use as a corrosion inhibitor, production of refractory bricks to line metallurgical furnaces, plating operations, topical antiseptics and astrigents, and the tanning and dye industries (Brown et al., 1983). The oxidation-state of the chromium ion directly affects its toxicity; chromium is the most toxic and mobile at an oxidation state of +6. This is the most common form of chromium in industrial wastes, thus making chromium a concern. The soluble salts of chromium such as sulfate and nitrate, are more toxic than the insoluble salts of oxides and phosphates. The solubility of chromium will vary at different pH values in the presence of suitable electron donors, changing the oxidation state from +6 to +3 (Tolman et al., 1978; Fuller and Artiola, 1978). The +3 chromium is less toxic and generally immobile in ground water because it will readily precipitate with carbonates, hydroxides and sulfides to form insoluble compounds. The maximum contaminant level as established in the Federal Primary Drinking Water Standards is 0.05 mg/l.

Copper (Cu)

Industrial wastes from textile mills, cosmetics manufacturing and hardboard production contain significant amounts of copper. The sorption of copper onto colloids is a function of pH; sorption increases at higher pH values. Organic matter present in soils forms very stable complexes with copper (Brown et al., 1983). These include complexation with carboxyl and phenolic groups where sorption is high when iron and manganese oxide concentrations are low. Experiments indicate that copper is sorbed appreciably by quartz and even more strongly by clays. Copper is also beneficial because low concentrations are necessary for the metabolic processes of decomposition by bacteria. The maximum contaminant level as established in the Federal Secondary Drinking Water Standards is 1.0 mg/l.

Lead (Pb)

Lead is found in wastes from the manufacture of lead-acid storage batteries, gasoline additives, ammunition, pigments, paints, herbicides and insecticides. Lead may precipitate as sulfates, hydroxides and carbonates. The presence of free lead ions depends on the stability of the lead complex at varying pH values. At high pH levels, lead is less soluble and preferentially sorbed onto clay surfaces. Under reduced conditions, lead becomes mobile and may form insoluble complexes with organic compounds (Brown et al., 1983). The maximum contaminant level as established in the Federal Primary Drinking Water Standards is 0.05 mg/l.

Mercury (Hg)

Mercury is present in a wide variety of industrial wastes such as electrical apparatus manufacturing, production of chlorine and caustic soda, pharmaceuticals, paints, plastics, paper products and mercury batteries. Many pesticides have metals as part of their composition. Of these pesticides, over 40 percent use mercury as the major metal component (Brown et al., 1983). Mercury in the +2 oxidation state is rapidly and strongly complexed by covalent bonding to sulfur-containing organic compounds and inorganic soils. Colloidal particles of clay, iron and manganese oxides, fine sands and organic matter readily absorb mercury. Sorption by clay particles is most effective at high pH values. The solubility of various mercury ionic complexes can be affected by changes in pH and/or oxidation-reduction. Insoluble precipitates of mercury, sulfates, hydroxides and nitrates form at high pH conditions. Insoluble mercury sulfide occurs in reducing conditions, whereas, insoluble mercury chlorides favor oxidizing conditions.

Organic mercury compounds such as phenyl, alkyl and methoxyethyl mercury used as fungicides may be degraded by certain bacteria. However, other bacterial forms tend to produce toxic mercury compounds with organic matter (Brown et al., 1983). The most toxic form of mercury occurs as methyl mercury and poses a contamination problem for the aquatic food chain. The maximum contaminant level as established in the Federal Primary Drinking Water Standards is 0.002 mg/l.

Manganese (Mn)

The major source of manganese-contaminated waste waters are from the iron and steel industries and from the manufacture of paints, disinfectants and fertilizers. The manganese ion commonly occurs as Mn +2, which is soluble and mobile, and Mn +4, which is insoluable and thus non-mobile. Under reduced conditions, Mn +2 is strongly sorbed to clay minerals and organic matter, but becomes less soluble as pH increases. Under oxidizing conditions several stable manganese compounds will form (Brown et al., 1983). Manganese is considered a secondary constituent under Federal Drinking Water Standards; maximum contaminant levels are set at 0.05 mg/l.

Silver (Ag)

Silver is found in the waste streams of a variety of industrial processes including photographic, mirror and electroplating manufacturing (Brown et al., 1983). Silver may be adsorbed on clay minerals, hydrous oxides of iron or manganese and organic matter. Precipitation with common inorganic anions such as carbonate sulfates and chlorides or complexation with organic compounds can reduce silver concentrations in ground water. The solubility of silver is largely controlled by the pH and redox conditions present in the ground water system. The maximum contaminant level as established in the Federal Primary Drinking Water Standards is 0.05 mg/l.

Zinc (Zn)

Industrial wastes containing zinc are a byproduct of brass and bronze alloy production, galvanized metals for pipes, utensils, insecticides, glues, rubber, inks and glass (Page, 1974). Zinc can be attenuated through precipitation, absorption and ionic substitution (Brown et al., 1983). Zinc may be ionically substituted for aluminum, iron or magnesium in many clay minerals. Zinc is primarily sorbed onto organic colloids which are very soluble and mobile. Zinc may be sorbed onto the particle surfaces of alloys and is generally immobile. The solubility of zinc precipitates is dependent on the stability of the complex that forms under variable pH conditions. The only insoluble zinc precipitate is zinc sulfate. All other precipitates of zinc are soluble. Zinc is rendered insoluble in soils and water with a pH greater than 6.5. The maximum contaminant level as established in the Federal Secondary Drinking Water Standards is 5.0 mg/l.

Iron (Fe)

Iron, under oxidizing conditions in ground water, forms hydrous oxides which provide a major attenuation mechanism for the sorption of trace metals such as cobalt, nickel, copper and zinc in soils and freshwater sediments. When this oxide occurs as coatings on grains of a media, it can greatly increase the sorptive capacity of that medium. Iron compound stabilities are dependent on pH and oxidation-reduction potential. Iron in reduced form is soluble and remains in solution. However, either very small-scale variations in the pH/Eh relationship or in bacterial activity can result in precipitation of iron in the hydrous oxide form. The maximum contaminant level as established in the Federal Secondary Drinking Water Standards is 0.3 mg/l. Unlike most other limits, the level for iron was not set because of associated health risks, but rather for water quality problems associated with staining and color. Iron oxides precipitate and stain due to their relative insolubility.

INORGANIC NONMETALS

The chemical behavior of non-metallic substances in water has a significant effect on ground-water quality. Most non-metals tend to be fairly mobile in the ground-water system as ionic species. The type and amount of each species present is a function of temperature, pressure, pH, redox potential, dissolved concentrations, reactivity and microbial activity.

The following discussion focuses on the major nonmetallic chemicals occurring in ground water. For each chemical, information is presented on the source(s) of the chemical and its water chemistry characteristics. These nonmetallic chemicals can occur either naturally in ground water or as a result of human activities.

Nitrogen

The most common inorganic contaminant is dissolved nitrogen in the form of nitrate (NO_3-). Dissolved nitrogen also occurs in the form of ammonium (NH_4+), ammonia (NH_3-), nitrite (NO_2-), nitrogen (N_2), and nitrous oxide (N_2O). Common sources of nitrate in ground water are from the burial of nitrogen-rich wastes, application of fertilizers and disposal of sewage. When nitrogen-rich compounds are added to the environment, nitrogen is converted to different forms. The processes of nitrification [conversion or (NH_4+) to (NO_3-) by oxidation] and ammonification [conversion of organic N to (NH_4-)] generally occur above the water table where oxygen and organic matter are abundant (Freeze and Cherry, 1979).

Concentrations of (NO_3-) are not limited by solubility. Thus, this anionic form is very mobile and stable under oxidizing conditions. (NO_3-) is not easily retarded or transformed by chemical processes. The presence of reducing conditions may initiate denitrification, a process where (NO_3-) is converted to N_2 or N_2O. These resulting forms are of less concern from a ground-water pollution standpoint because they pose no health risk. A maximum contaminant level of 10 mg/l as N or 45 mg/l as (NO_3-) has been established for nitrates because of health concerns in infants when this level is exceeded.

Phosphorous

Phosphorous is not generally considered to be an intrinsically harmful constituent in ground water in normal concentrations, but its presence can cause significant environmental problems by decreasing available oxygen through accelerated algae and aquatic vegetative growth. The most common source of phosphorous contamination is by agricultural activity, decomposition of organic wastes and septic tank effluent. Dissolved phosphorous can occur in many forms depending on the pH of the water. Hydrolysis and mineralization can convert insoluble forms of phosphates to the soluble phosphate ion for use by plants and organisms (Brown et al., 1983). Degradation and mobilization of phosphorous by microbes accounts for a portion of its attenuation. Under certain conditions, phosphorous will precipitate as iron, aluminum or calcium phosphate or be sorbed by iron and aluminum oxides and hydroxides.

Boron

Boron is released during the decomposition of organic materials. Partial sorption of boron may occur on iron and aluminum hydroxyl compounds and clays. The sorption of boron to these materials is pH dependent; sorption will not occur at high pH levels. The amount of boron that will be sorbed is dependent on surface area and appears to be irreversible due to the formation of covalent bonds. No drinking water standards for human consumption of boron have been set.

Sulfur

Sulfur is moderately abundant in the earth's soils and is an important plant nutrient. Sulfur, in some form, is widespread in industrial waste from processes such as kraft mills, sugar refining, petroleum refining, and copper and coal extraction (Brown et al., 1983). Sulfur is commonly found in two forms; as sulfate (SO_4^{-2}) in oxidizing conditions, and as sulfide (HS^-) or (H_2S) under reducing conditions. Sulfides are toxic and produce an odor in water. The FMC Corporation (1983) has conducted extensive laboratory testing using hydrogen peroxide to oxidize sulfides to sulfur and water. Hydrogen peroxide has been shown to be effective in neutralizing other sulfur compounds that are common industrial waste effluents. These include polysulfides, sulfites, thiosulfates, polythionates, dithionites and dithionates. Sulfates are relatively mobile in the ground-water system as anions. Some clays have the capability to sorb sulfate onto their particle surfaces (Brown et al., 1983). Sulfates also tend to form inorganic ligands and complex with metal ions increasing their solubility. A maximum contaminant level for sulfates is established in the Federal Secondary Drinking Water Standards at 250 mg/l.

Fluoride

The mobility of fluoride depends on the types and quantities of cations present in the water that have formed salts with the fluoride ion. Sodium salts of fluoride (NaF) have high solubilities as opposed to calcium salts (CaF_2) which have low solubilities. Fluoride may be a natural constituent of ground water produced from the dissolution of fluoride-bearing rocks or from industrial wastes such as the production of phosphatic fertilizers, hydrogen fluoride and fluorinated hydrocarbons (Brown et al., 1983). Fluoride may also tend to complex with metallic ions. Soils with high cation exchange capacities are capable of retaining fluoride. The limit for concentration of fluoride has been established at 4.0 mg/l in the Federal Primary Drinking Water Standards based on possible adverse health effects and at 2.0 mg/l in Secondary Standards for aesthetic purposes.

Chloride

Chloride is very soluble and thus highly mobile in ground water. Chloride in ground water results from the dissolution of chloride-bearing rocks such as halite, and is a common product or byproduct (e.g. chlorinated hydrocarbon wastes) in most industrial wastes. Common causes of chloride contamination result from spillage or leakage of brines that are produced in oil and gas drilling operations, and from the widespread use and application of highway de-icing salts in many states. Chlorides introduced at the surface are readily transported into the ground water by recharge from precipitation. Excessive chloride concentrations in soils can also occur in areas of intensive irrigation due to leaching in the root zone and high rates of evapotranspiration. The maximum contaminant level as established in the Federal Secondary Drinking Water Standards is 250 mg/l.

Arsenic

Arsenic is contained in wastes from the production of herbicides, pesticides, pigments and wood preservatives (Freeze and Cherry, 1979; Brown et al., 1983). Arsenic in natural ground water occurs in four oxidation states which exist as many different species under variable conditions. In general, most forms of arsenic tend to become soluble under oxidizing conditions. Solubility is controlled by pH and redox potential.

The movement of arsenic in the environment is affected by sorption to soils and volatilization. Sorption and/or precipitation by soil colloids is an important attenuation mechanism. These colloids include iron and aluminum hydroxides or clays. Sorption increases with increasing pH, clay and hydroxide content. Levels of arsenic as low as 10 mg/l have been shown to be toxic (Brown et al., 1983). The maximum contaminant level as established in the Federal Primary Drinking Water Standards is 0.05 mg/l.

Selenium

Sources of selenium which can cause ground-water contamination include glass, electronics, steel, rubber and photographic industries. Selenium has properties which are similar to sulfur. Selenium has three oxidation states. These typically form selenites and selanates of sodium and calcium, and soluble selenium salts. Selenium anions form selanates with mercury, copper and cadmium which are very insoluble (Brown et al., 1983). Selenium in ground water is least soluble under acid conditions. Mechanisms for selenium attenuation include sorption onto hydrous iron oxides and precipitation to the insoluble ferric oxide selenite. The maximum contaminant level as established in the Primary Federal Drinking Water Standard is 0.01 mg/l.

ORGANIC COMPOUNDS

The contamination of ground-water resources by organic compounds has resulted in the initiation of studies on their occurrence and behavior in the ground-water system. Many organic compounds of environmental concern are at trace levels, parts per million, billion or trillion. However, even these minute levels may exhibit toxic effects on aquatic and mammalian life forms. The United States Environmental Protection Agency (EPA) has developed a list of what are considered to be the 129 priority pollutants and the relative frequency of these materials in industrial waste waters (Keith and Telliard, 1979) (Table B-1).

TABLE B-1. EPA LIST OF 129 PRIORITY POLLUTANTS AND THE RELATIVE FREQUENCY OF THESE MATERIALS IN INDUSTRIAL WASTEWATERS (KEITH AND TELLIARD, 1979)

Percent of samples[a]	Number of Industrial categories[b]		Percent of samples[a]	Number of Industrial categories[b]	
		31 are purgeable organics			
1.2	5	Acrolein	2.1	5	1,2-Dichloropropane
2.7	10	Acrylonitrile	1.0	5	1,3-Dichloropropane
29.1	25	Benzene	34.2	25	Methylene chloride
29.3	28	Toluene	1.9	6	Methyl chloride
16.7	24	Ethylbenzene	0.1	1	Methyl bromide
7.7	14	Carbon tetrachloride	1.9	12	Bromoform
5.0	10	Chlorobenzene	4.3	17	Dichlorobromomethane
6.5	16	1,2-Dichloroethane	6.8	11	Trichlorofluoromethane
10.2	25	1,1,1-Trichloroethane	0.3	4	Dichlorodifluoromethane
1.4	8	1,1-Dichloroethane	2.5	15	Chlorodibromomethane
7.7	17	1,1-Dichloroethylene	10.2	19	Tetrachloroethylene
1.9	12	1,1,2-Trichloroethane	10.5	21	Trichloroethylene
4.2	13	1,1,2,-Tetrachloroethane	0.2	2	Vinyl chloride
0.4	2	Chloroethane	7.7	18	1,2-trans-Dichloroethylene
1.5	1	2-Chloroethyl vinyl ether	0.1	2	bis(Chloromethyl) ether
40.2	28	Chloroform			
		46 are base/neutral extractable organic compounds			
6.0	9	1,2-Dichlorobenzene	5.7	11	Fluorene
		1,3-Dichlorobenzene	7.2	12	Fluoranthene
		1,4-Dichlorobenzene	5.1	9	Chrysene
0.5	5	Hexachloroethane	7.8	14	Pyrene
0.2	1	Hexachlorobutadiene	10.6	16	Phenanthrene
1.1	7	Hexachlorobenzene			Anthracene
1.0	6	1,2,4-Trichlorobenzene	2.3	6	Benzo(a)anthracene
0.4	3	bis(2-Chloroethoxy) methane	1.6	6	Benzo(b)fluoranthene
10.6	18	Naphthalene	1.8	6	Benzo(k)fluoranthene
0.9	9	2-Chloronaphthalene	3.2	8	Benzo(a)pyrene
1.5	13	Isophorone	0.8	4	Indeno(1,2,3-c,d)pyrene
1.8	9	Nitrobenzene	0.2	4	Dibenzo(a.h)anthracene
1.1	3	2,4-Dinitrotoluene	0.6	7	Benzo(g,h,i)perylene
1.5	9	2,6-Dinitrotoluene	0.1	2	4-Chlorophenyl phenyl ether
0.04	1	4-Bromophenyl phenyl ether	0	0	3,3'-Dichlorobenzidine
41.9	29	bis(2-Ethylhexyl) phthalate	0.2	4	Benzidine
6.4	12	Di-*n*-octyl phthalate	1.1	4	bis(2-Chloroethyl) ether
5.8	15	Dimethyl phthalate	0.8	7	1,2-Diphenylhydrazine
7.6	20	Diethyl phthalate	0.1	1	Hexachlorocyclopentadiene
18.9	23	Di-*n*-butyl phthalate	1.2	5	N-Nitrosodiphenylamine

(continued)

TABLE B-1. (continued)

Percent of samples[a]	Number of Industrial categories[b]		Percent of samples[a]	Number of Industrial categories[b]	
4 5	12	Acenaphthylene	0 1	1	N-Nitrosodimethylamine
4 2	14	Acenaphthene	0 1	2	N-Nitrosodi-*n*-propylamine
8 5	13	*Buty benzyl phthalate*	1 4	6	bis(2-Chloroisopropyl) ether
		11 are acid extractable organic compounds			
26 1	25	*Phenol*	1 9	8	*p*-Chloro-*m*-cresol
2 3	11	2-Nitrophenol	2 3	10	2-Chlorophenol
2 2	9	4-Nitrophenol	3 3	12	2,4-Dichlorophenol
1 6	6	2,4-Dinitrophenol	4 6	12	2,4,6-Trichlorophenol
1 1	6	4,6-Dinitro-o-cresol	5 2	15	2,4-Dimethylphenol
6 9	18	Pentachlorophenol			
		26 are pesticides/PCB's			
0 3	3	α-Endosulfan	0 3	3	Heptachlor
0 4	4	β-Endosulfan	0 1	1	Heptachlor epoxide
0 2	2	Endosulfan sulfate	0 2	4	Chlordane
0 6	4	α-BHC	0 2	2	Toxaphene
0 8	6	β-BHC	0 6	2	Aroclor 1016
0 2	4	δ-BHC	0 5	1	Aroclor 1221
0 5	3	γ-BHC	0 9	2	Aroclor 1232
0 5	5	Aldrin	0 8	3	Aroclor 1242
0 1	3	Dieldrin	0 6	2	Aroclor 1248
0 04	1	4,4′-DDE	0 6	3	Aroclor 1254
0 1	2	4,4′-DDD	0 5	1	Aroclor 1260
0 2	2	4 4′-DDT			2,3,7,8-Tetrachlorodibenzo-*p*-dioxin (TCDD)
0 2	3	Endrin			
0 2	2	Endrin aldehyde			
		13 are metals			
18 1	20	Antimony	16 5	20	Mercury
19 9	19	Arsenic	34 7	27	Nickel
14 1	18	Beryllium	18 9	21	Selenium
30 7	25	Cadmium	22 9	25	Silver
53 7	28	Chromium	19 2	19	Thallium
55 5	28	Copper	54 6	28	Zinc
43 8	27	Lead			
		Miscellaneous			
33 4	19	*Total cyanides*	Not available		Asbestos (fibrous)
			Not available		Total phenols

[a] The percent of samples represents the times this compound was found in all samples in which it was analyzed for divided by the total as of 31 August 1978 Numbers of samples ranged from 2 532 to 2 998 with the average being 2 617

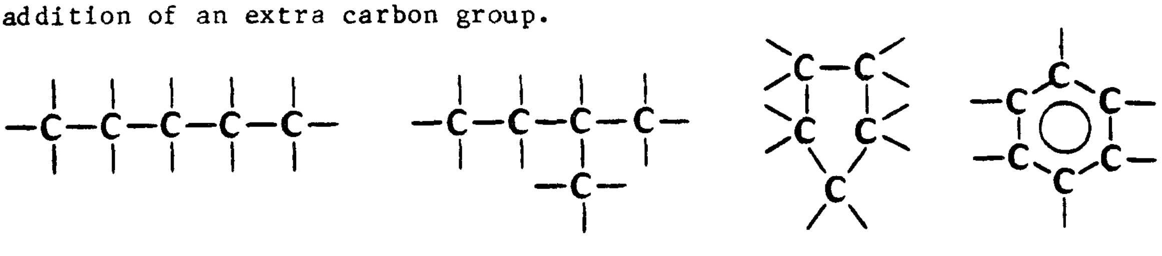
[b] A total of 32 industrial categories and subcategories were analyzed for organics and 28 for metals as of 31 August 1978

There are several chemical and biochemical reactions that are recognized as having a potential to significantly control contamination migration or attenuation in ground-water systems. These mechanisms include sorption, hydrolysis, oxidation-reduction and biodegradation. A discussion of these processes is contained in Appendix A, Processes and Properties Affecting Contaminant Fate and Transport.

The solubility of organic compounds may be divided into two broad groups: polar and nonpolar. Polar organics exhibit an affinity for water, and therefore do not bond or sorb to particle surfaces. Non-polar organics are not attracted to water and therefore tend to be easily sorbed. The solubility of an organic substance also affects its ability to be oxidized, hydrolyzed and biodegraded. These properties differ between the organic groups and those interactions are often strongly dependent on the hydrogeochemical environmental factors including the pH, redox potential and other constituent concentrations in the water.

The study of organic compounds, known as organic chemistry, deals with the compounds of carbon (Sawyer and McCarty, 1978). All organic compounds contain carbon in combination with one or more elements, most commonly, hydrogen, oxygen, nitrogen, phosphorous and sulfur. Organic compounds generally exhibit several properties that make them different from inorganic substances. Organic compounds are generally combustible, less soluble in water and have lower boiling and melting points. Reactions of organic compounds are generally molecular so they tend to be slower than most other chemical reactions. All organic compounds are either natural, synthetic or fermentative in origin. Organic wastes are often produced from the processing of natural and synthetic organic materials and fermentation at industrial facilities.

The basis of an organic compound is the element carbon. Carbon is diverse because it maintains four covalent bonds in addition to the ability of the carbon atoms to link together by covalent bonding in a wide variety of ways (Sawyer and McCarty, 1978). These bonds may occur as a continuous chain, a branched chain, a cyclic ring or as chains or rings containing other elements (Figure B-1). These structures serve as the basis for classification of organic compounds. For example, aliphatic compounds contain chains or branched chains of carbon atoms and aromatic compounds have carbon atoms linked in a six-member carbon ring which contains three double bonds that give them stability. Each of these compounds can be subdivided into groupings or homologous series where each member in the series differs from other members by the addition of an extra carbon group.



Straight chain Branched chain Ring Aromatic ring

Figure B-1. Covalent bonding arrangements of carbon atoms (Lippencott et al., 1978).

The naming of organic compounds is complex. The details of nomenclature may be found in a standard chemistry text or the CRC Handbook of Physics and Chemistry (Weast, 1983). The Office of Technology Assessment, (1984) provides a comprehensive list of organic compounds that are known to occur in ground water, their ranges of detected concentrations, examples of uses and quantitative estimates of carcinogenic potency and noncarcinogenic toxicity (Table B-2). This list has been subdivided according to characteristic organic classes: aromatic hydrocarbons, oxygenated hydrocarbons, hydrocarbons with specific elements (N,S,P,Cl,I,F,Br) and "others". The "others" group generally corresponds to the aliphatic hydrocarbons which includes many petroleum products. The following discussions use this classification for simplicity, but expands upon the groups found within these classes.

Aliphatic Compounds

A hydrocarbon is a basic organic compound of carbon and hydrogen that may be of two types: saturated and unsaturated. A saturated hydrocarbon has adjacent carbon atoms joined by single covalent bonds with all other bonds to hydrogen atoms. Unsaturated hydrocarbons have at least two carbon atoms joined by more than one covalent bond with all other bonds satisfied by hydrogen (Sawyer and McCarty, 1978; Lippencott et al., 1978).

Saturated compounds range from a compound with one carbon atom, to those with each successive compound containing an additional carbon atom. These compounds are known as the alkanes or the methane series and are relatively inactive. The principal source of alkanes is petroleum. Mixtures of these compounds comprise gasoline and diesel fuel. Some other alkanes include ethane and propane. Methane is the simplest hydrocarbon (CH_4) and is a major end product of anaerobic treatment processes as well as a constituent of natural gas.

In the alkane series, butane has two isomers. An isomer is a compound that has the same molecular formula, but different structural formulas (Lippencott et al., 1978). Many organic compounds exhibit this property. Compounds containing rings of saturated carbon atoms are known as cycloalkanes; they are more reactive due to the strained structure of the small ring. These are commonly known as the napthenes and have cyclo-prefixes.

The unsaturated hydrocarbons can lose hydrogen to bond with other elements or compounds. The alkene or ethylene series of compounds all have one double bond between two adjacent carbon atoms. The compounds are commonly called olefins and are formed in large quantities during the processing of petroleum products. The most important reaction of the alkenes is polymerization, where small molecules unite to form giant molecules or polymers. The most common reaction is the polymerization of ethylene to form polyethylenes. The alkadienes or alkapolyenes contain more than two carbon-carbon double bonds. Those hydrocarbons containing triple bonds between carbon atoms are known as the alkyne or acetylene series. These compounds represent starting substances for many synthetic fibers.

TABLE B-2. SUBSTANCES KNOWN TO OCCUR IN GROUND WATER, RANGES OF DETECTED CONCENTRATIONS, EXCEEDED STANDARDS, EXAMPLES OF USES, AND QUANTITATIVE ESTIMATES OF CARCINOGENIC POTENCY AND NONCARCINOGENIC TOXICITY (OTA,1984)

Contaminant	Concentration	Standard	Examples of uses	Carcinogenic potency	Noncarcinogenic toxicity
Aromatic hydrocarbons	(parts per billion)				
Acetanilide	-		Intermediate manufacturing, pharmaceuticals dyestuffs		
Alkyl benzene sulfonates	-	●	Detergents		
Aniline	-		Dyestuffs, intermediate, photographic chemicals pharmaceuticals, herbicides fungicides petroleum refining explosives		
Anthracene	18		Dyestuffs intermediate semiconductor research		
Benzene	0 6-20 230	*	Detergents, intermediate, solvents antiknock gasoline	Low	
Benzidine			Dyestuffs reagent stiffening agent in rubber compounding	High	
Benzyl alcohol	-		Solvent perfumes and flavors, photographic developer inks dyestuffs, intermediate		
Butoxymethylbenzene			NA		
Chrysene	10		Organic synthesis		
Creosote mixture			Wood preservatives disinfectants		
Dibenz[a h]anthracene			NA		
Di-butyl-p-benzoquinone			NA		
Dihydrotrimethylquinoline			Rubber antioxidant		
4 4-Dinitrosodiphenylamine	-		NA		
Ethylbenzene	0 9-4 000	*	Intermediate solvent		Low
Fluoranthene	31	●	NA		
Fluorene			Resinous products dyestuffs insecticides		
Fluorescein	-		Dyestuffs		
Isopropyl benzene	290		Solvent, chemical manufacturing		
4,4'-Methylene-bis-2-chloroaniline (MOCA)	-		Curing agent for polyurethanes and epoxy resins	Low	
Methylthiobenzothiazole	-				
Napthalene	6 7-82	●	Solvent, lubricant, explosives preservatives intermediate fungicide, moth repellant		Low
o-Nitroaniline			Dyestuffs intermediate, interior paint pigments chemical manufacturing		
Nitrobenzene			Solvent, polishes, chemical manufacturing		Moderate
4-Nitrophenol			Chemical manufacturing		
n-Nitrosodiphenylamine	--		Pesticides retarder of vulcanization of rubber		
Phenanthrene	18-471		Dyestuffs, explosives, synthesis of drugs, biochemical research		
n-Propylbenzene	–		Dyestuffs solvent		
Pyrene	48		Biochemical research		Low

(continued)

TABLE B-2. (continued)

Contaminant	Concentration	Standard	Examples of uses	Carcinogenic potency	Noncarcinogenic toxicity
Aromatic hydrocarbons (cont'd)	(parts per billion)				
Styrene (vinyl benzene)	-	•	Plastics, resins protective coatings intermediate		Low
Toluene	0 1-6 400	★	*Adhesive solvent in plastics, solvent aviation and high octane blending stock dilutent and thinner, chemicals explosives detergents*		
1,2,4-Trimethylbenzene			Manufacture of dyestuffs, pharmaceuticals, chemical *manufacturing*		
Xylenes (m o p)	0 07-300	•	Aviation gasoline protective coatings, solvent synthesis of organic chemicals		Low
Oxygenated hydrocarbons					
Acetic acid			Food additives plastics dyestuffs pharmaceuticals photographic chemicals insecticides		Low
Acetone	10-3 000		Dyestuffs, solvent, chemical manufacturing, cleaning and drying of precision equipment		Low
Benzophenone	–		Organic synthesis, odor fixative, flavoring, pharmaceuticals		Low
Butyl acetate	–		Solvent		
N-Butyl-benzylphthalate	10-38		Plastics, intermediate		
Di-n-butyl phthalate	470	•	Plasticizer, solvent, adhesives, insecticides, safety glass inks, paper coatings		Low
Diethyl ether			Chemical manufacturing, solvent analytical chemistry, anesthetic, perfumes		
Diethyl phthalate		•	Plastics, explosives, solvent, insecticides, perfumes		
D*iisopropyl ether*	20-34		*Solvent, rubber cements, paint and varnish removers*		
2,4-Dimethyl-3-hexanol			Intermediate, solvent, lubricant		
2,4-D*imethyl phenol*		•	*Pharmaceuticals, plastics disinfectants, solvent, dyestuffs,* insecticides, fungicides, additives to lubricants and gaso*lines*		
Di-n-octyl phthalate	23		Plasticizer for polyvinyl chloride and other vinyls		
1,4-Dioxane	2,100	★	Solvent, *lacquers, paints, varnishes, cleaning and detergent* preparations, fumigants, paint and varnish removers, wetting agent, cosmetics		
Ethyl acrylate	-		Polymers, acrylic paints, intermediate		
Formic acid	-		Dyeing and finishing, chemicals, manufacture of fumigants, insecticides, solvents, plastics, refrigerants		
Methanol (methyl alcohol)	–		Chemical manufacturing, solvents, automotive antifreeze, fuels		High
Methylcyclohexanone	—		Solvent, lacquers		
Methyl ethyl ketone	–		Solvent, paint removers, cements and adhesives, cleaning fluids, printing, acrylic coatings		

(continued)

TABLE B-2. (continued)

Contaminant	Concentration	Standard	Examples of uses	Carcinogenic potency	Noncarcinogenic toxicity
Oxygenated hydrocarbons (cont'd)	(parts per billion)				
Methylphenyl acetamide	-		NA		
Phenols (e g p-Tert-butylphenol)	10-234,000	●	Resins, solvent, pharmaceuticals, reagent dyestuffs and indicators, germicidal paints		
Phthalic acid	-		Dyestuffs, medicine perfumes reagent		
2-Propanol			Chemical manufacturing solvent, deicing agent, pharmaceuticals, perfumes, lacquers, dehydrating agent, preservatives		
2-Propyl-1-heptanol			Solvent		
Tetrahydrofuran		Solvent			
Varsol			Paint and varnish thinner		
Hydrocarbons with specific elements (e.g., with N,P,S,Cl,Br,I,F)					
Acetyl chloride			Dyestuffs, pharmaceuticals, organic preparations		
Alachlor (Lasso)	190-1 700	*	Herbicides		Moderate
Aldicarb (sulfoxide and sulfone Temik)	36-405	*	Insecticide, nematocide		High
Aldrin		●	Insecticides	High	
Atrazine		●	Herbicides, plant growth regulator, weed control agent		Moderate
Benzoyl chloride	-		Medicine, intermediate		
Bromacil	72-110	*	Herbicides		Moderate
Bromobenzene	1 9-5 8		Solvent motor oils, organic synthesis		Moderate
Bromochloromethane			Fire extinguishers, organic synthesis		Low
Bromodichloromethane	1 4-110	*	Solvent, fire extinguisher fluid mineral and salt separations		
Bromoform	2 4-110		Solvent, intermediate		Moderate
Carbofuran	4-160	*	Insecticide nematocide		Moderate
Carbon tetrachloride	0 3-18 700	*	Degreasers, refrigerants and propellants fumigants chemical manufacturing	Moderate	
Chlordane		●	Insecticides, oil emulsions		
Chlorobenzene	2 7-41	●	Solvent pesticides, chemical manufacturing		Moderate
Chloroform	1 4-1,890	*	Plastics, fumigants, insecticides, refrigerants and propellants		
Chlorohexane			NA		
Chloromethane (methyl chloride)	44		Refrigerants, medicine, propellants, herbicide, organic synthesis		Low
Chloromethyl sulfide		NA			

(continued)

TABLE B-2. (continued)

Contaminant	Concentration	Standard	Examples of uses	Carcino-genic potency	Noncar-cinogenic toxicity
Hydrocarbons with specific elements (e.g., with N,P,S,Cl,Br,I,F) (cont'd)	(parts per billion)				
2-Chloronaphthalene	83		Oil plasticizer, solvent for dyestuffs, varnish gums and resins waxes Wax moisture-, flame-, acid- and insect-proofing of fibrous materials, moisture- and flame-proofing of electrical cable, solvent (see oil)		
Chlorpyrifos			NA		
Chlorthal-methyl (DCPA, *or* Dacthal)			*Herbicide*		
o-Chlorotoluene	2 4		Solvent, intermediate		
p-Chlorotoluene	-		Solvent, intermediate		
Dibromochloromethane	2 1-55		Organic synthesis		
Dibromochloropropane (DBCP)	1 -137	★	Fumigant, nematocide		
Dibromodichloroethylene	-		NA		
Dibromoethane (ethylene dibromide, EDB)	35-300	★	Fumigant, nematocide, solvent, waterproofing preparations organic synthesis		
Dibromomethane	44 9		Organic synthesis, solvent		
Dichlofenthion (DCFT)			Pesticides		
o-Dichlorobenzene	2 7	●	Solvent fumigants, dyestuffs, insecticides degreasers polishes, industrial odor control		Moderate
p-Dichlorobenzene	0 6-0 7	★	Insecticides moth repellant, germicide space odorant intermediate, fumigants		Moderate
Dichlorobenzidine	-		Intermediate curing agent for resins	Moderate	
Dichlorocyclooctadiene			Pesticides		
Dichlorodiphenyldichloroethane (DDD, TDE)			Insecticides		Low
Dichlorodiphenyldichloroethylene (DDE)	0 01-0 8		Degradation product of DDT found as an impurity in DDT residues		
Dichlorodiphenyltrichloroethane (DDT)	0 05-0 22	●	Pesticides	High	
1,1-Dichloroethane	0 5-11 330		Solvent fumigants medicine		Low
1 2-Dichloroethane	250-847	★	Solvent, degreasers, soaps and scouring compounds organic synthesis, additive in antiknock gasoline, paint and finish removers	Low	
1 1-Dichloroethylene (vinylidiene chloride)	1 2-4 000	★	Saran (used in screens upholstery, fabrics, carpets, etc) adhesives synthetic fibers	Moderate	
1,2-Dichloroethylene (cis and trans)	0 2-323	★	Solvent, perfumes, lacquers, thermoplastics, dye extraction, organic synthesis, medicine		
Dichloroethyl ether	1,100		Solvent, organic synthesis, paints, varnishes, lacquers, finish removers, drycleaning, fumigants		

(continued)

TABLE B-2. (continued)

Contaminant	Concentration	Standard	Examples of uses	Carcinogenic potency	Noncarcinogenic toxicity
Hydrocarbons with specific elements (e g., with N,P,S,Cl,Br I,F) (cont d)	parts per billion				
Dichloroiodomethane	2 8-4 1		NA		
Dichloroisopropylether (bis-2-chloroisopropylether)			Solvent paint and varnish removers cleaning solutions		
Dichloromethane (methylene chloride)	4-8 400	★	Solvent plastics paint removers propellants blowing agent in foams		
Dichloropentadiene	0 36		NA		
2 4-Dichlorophenol		●	Organic synthesis		
2 4-Dichlorophenoxyacetic acid (2 4-D)	1-85 000	★	Herbicides		Moderate
1 2-Dichloropropane	46-60	★	Solvent, intermediate scouring compounds fumigant nematocide, additive for antiknock fluids		
Dieldrin		●	Insectides	High	
Diiodomethane	2 0		Organic synthesis		
Diisopropyl methyl phosphonate (DIMP)		●	NA		
Dimethyl disulfide			NA		
Dimethylformamide			Solvent organic synthesis		
2 4-Dinotrophenol (Dinoseb, DNBP)	124-400		Herbicides		Moderate
Dioxins (e g TCDD)		★	Impurity in the herbicide 2 4,5-T	High	
Dodecyl mercaptan (lauryl mercaptan)			Manufacture of synthetic rubber and plastics pharmaceuticals insecticides fungicides		
Endosulfan	0 8	★	Insecticides		High
Endrin	-	●	Insecticides		High
Ethyl chloride			Chemical manufacturing anesthetic solvent refrigerants, insecticides		
Bis-2-ethylhexylphthalate	12-170		Plastics	Low	
Di-2-ethylhexylphthalate		●	Plasticizers		
Fluorobenzene	67		Insecticide and larvicide intermediate		
Fluoroform	3 5		Refrigerants intermediate blowing agent for foams		
Heptachlor	-	●	Insecticides	Moderate	
Heptachlorepoxide		●	Degradation product of heptachlor also acts as an insecticide		
Hexachlorobicycloheptadiene	2 2		NA		
Hexachlorobutadiene	2 53		Solvent transformer and hydraulic fluid heat-transfer liquid		
α-Hexachlorocyclohexane (= Benzenehexachloride, or α-BHC)	6	★	Insecticides		
β-Hexachlorocyclohexane (β-BHC) β-BHC)	3 8	★	Insecticides		

(continued)

TABLE B-2. (continued)

Contaminant	Concentration	Standard	Examples of uses	Carcinogenic potency	Noncarcinogenic toxicity
Hydrocarbons with specific elements (e.g., with N,P,S,Cl,Br,I,F) (cont'd)	(parts per billion)				
γ-Hexachlorocyclohexane (γ-BHC, or Lindane)	0 5-43	★	Insecticides		Moderate
Hexachlorocyclopentadiene	—		Intermediate for resins, dyestuffs, pesticides, fungicides, pharmaceuticals		
Hexachloroethane	4 6		Solvent, pyrotechnics and smoke devices, explosives, organic synthesis	Low	
Hexachloronorbomadiene	—		NA		
Kepone	—	●	Pesticides		High
Malathion	—	●	Insecticides		
Methoxychlor	—	●	Insecticides		Moderate
Methyl bromide	7 4		Fumigants pesticides, organic synthesis		
Methyl parathion	4 6	★	Insecticides		
Parathion	—	●	Insecticides		High
Pentachlorophenol (PCP)	—	●	Insecticides, fungicides, bactericides, algicides, herbicides, wood preservative		Moderate
Phorate (Disulfoton)	—	●	Insecticides		
Polybrominated biphenyls (PBBs)			Flame retardant for plastics, paper, and textiles		Low
Polychlorinated biphenyls (PCBs)	8-40	★	Heat-exchange and insulating fluids in closed systems	Moderate	
Prometon	-		Herbicides		
RDX (Cyclonite)	3 400	★	Explosives		
Simazine	-	●	Herbicides	Moderate	
Tetrachlorobenzene	5,000	★	NA		
Tetrachloroethanes (1,1,1,2 & 1,1,2,2)	4	★	Degreasers, paint removers, varnishes, lacquers, photographic film organic synthesis, solvent insecticides fumigants, weed killer	Moderate	
Tetrachloroethylene (or perchloroethylene, PCE)	717-2 405	★	Degreasers, drycleaning, solvent, drying agent, chemical manufacturing, heat-transfer medium, vermifuge	Low	
Toxaphene	1-570	★	Insecticides	Moderate	
Triazine	2		Herbicides		
1,2,4-Trichlorobenzene	37		Solvent, dyestuffs, insecticides, lubricants, heat-transfer medium (e g , coolant)		
Trichloroethanes (1,1,1 and 1,1,2)	0 2-26,000	★	Pesticides, degreasers, solvent	Low	
1,1,2-Trichloroethylene (TCE)	210-37,000	★	Degreasers, paints, drycleaning, dyestuffs, textiles, solvent, refrigerant and heat exchange liquid, fumigant, intermediate, aerospace operations	Low	

(continued)

TABLE B-2. (continued)

Contaminant	Concentration	Standard	Examples of uses	Carcino-genic potency	Noncar-cinogenic toxicity
Hydrocarbons with specific elements (e.g., with N,P,S,Cl,Br,I,F) (cont'd)	(parts per billion)				
Trichlorofluoromethane (Freon 11)	26		Solvent refrigerants, fire extinguishers, intermediate		Moderate
2,4 6-Trichlorophenol	-		Fungicides, herbicides, defoliant		Low
2,4 5-Trichlorophenoxyacetic acid (2,4,5-T)	-	•	Herbicides, defoliant		Moderate
2 4,5-Trichlorophenoxypropionic acid (2,4,5-TP or Silvex)	-	•	Herbicides and plant growth regulator		High
Trichlorotrifluoroethane	35-135		Drycleaning, fire extinguishers, refrigerants, intermediate, drying agent		
Trinitrotoluene (TNT)	620-12,600	*	Explosives intermediate in dyestuffs and photographic chemicals		
Tris-(2,3-dibromopropyl) phosphate	-		Flame retardant		
Vinyl chloride	50-740	*	Organic synthesis polyvinyl chloride and copolymers adhesives	Low	
Other hydrocarbons					
Alkyl sulfonates			Detergents		
Cyclohexane	540		Organic synthesis, solvent, oil extraction		
1,3,5 7-Cyclooctatetraene	-		Organic research		
Dicyclopentadiene (DCPD)			Intermediate for insecticides, paints and varnishes flame retardants		
2,3-Dimethylhexane	-		NA		
Fuel oil	-		Fuel heating		
Gasoline	2,000-9,000	*	Fuel		
Jet fuels	–		Fuel		
Kerosene	243,000		Fuel, heating, solvent, insecticides		
Lignin	7,500[1]		Newsprint, ceramic binder, dyestuffs, drilling fuel additive, plastics		
Methylene blue activated substances (MBAs)	11	•	Dyestuffs, analytical chemistry		
Propane	—		Fuel, solvent, refrigerants, propellants, organic synthesis		
Tannin	7,500[1]		Chemical manufacturing, tanning, textiles, electroplating, inks, pharmaceuticals, photography, paper		
4,6,8-Trimethyl-1-nonene	—		NA		
Undecane	—		Petroleum research, organic synthesis		
Metals and cations	(parts per million)				
Aluminum	0.1-1,200	*	Alloys, foundry, paints, protective coatings, electrical industry, packaging, building and construction, machinery and equipment		High

(continued)

TABLE B-2. (continued)

Contaminant	Concentration	Standard	Examples of uses	Carcinogenic potency	Noncarcinogenic toxicity
Metals and cations (cont'd)	(parts per million)				
Antimony	—		Hardening alloys, solders, sheet and pipe, pyrotechnics		Moderate
Arsenic	0 01-2,100	★	Alloys, dyestuffs, medicine, solders, electronic devices, insecticides, rodenticides, herbicide, preservative	High	
Barium	2 8-3 8	★	Alloys, lubricant		High
Beryllium	less than 0 01	★	Structural material in space technology, inertial guidance systems, additive to rocket fuels, moderator and reflector of neutrons in nuclear reactors	Moderate	
Cadmium	0 01-180	★	Alloys, coatings, batteries, electrical equipment, fire protection systems, paints fungicides, photography	High	
Calcium	0 5-225		Alloys, fertilizers, reducing agent		
Chromium	0 06-2,740	★	Alloys, protective coatings, paints, nuclear and high-temperature research	High	
Cobalt	0 01-0 18	★	Alloys, ceramics, drugs, paints, glass, printing, catalyst, electroplating, lamp filaments		High
Copper	0 01-2 8	★	Alloys, paints, electrical wiring, machinery, construction materials, electroplating, piping, insecticides		Moderate
Iron	0 04-6,200	★	Alloys, machinery, magnets		
Lead	0 01-5 6	★	Alloys, batteries, gasoline additive sheet and pipe paints radiation shielding		High
Lithium	—	•	Alloys, pharmaceuticals, coolant, batteries, solders, propellants		Low
Magnesium	0 2-70		Alloys, batteries, pyrotechnics, precision instruments, optical mirrors		
Manganese	0 1-110	★	Alloys, purifying agent		High
Mercury	0 003-0 01	★	Alloys, electrical apparatus, instruments, fungicides, bactericides, mildew-proofing, paper, pharmaceuticals		High
Molybdenum	0 4-40	★	Alloys, pigments, lubricant		
Nickel	0 05-0 5	★	Alloys, ceramics, batteries, electroplating, catalyst	Moderate	High
Palladium	—		Alloys, catalyst, jewelry, protective coatings, electrical equipment		Low
Potassium	0 5-2 4		Alloys, catalyst		
Selenium	0 6-20	★	Alloys, electronics, ceramics, catalyst		High
Silver	9-330	★	Alloys, photography, chemical manufacturing, mirrors, electronic equipment, jewelry, equipment, catalyst, pharmaceuticals		High
Sodium	3 1-211	★	Chemical manufacturing, catalyst, coolant, non-glare lighting for highways, laboratory reagent		
Thallium	—		Alloys, glass, pesticides, photoelectric applications		High

(continued)

TABLE B-2. (continued)

Contaminant	Concentration	Standard	Examples of uses	Carcinogenic potency	Noncarcinogenic toxicity
Metals and cations (cont'd)	(parts per million)				
Titanium	—		Alloys, structural materials, abrasives, coatings		Low
Vanadium	243	★	Alloys, catalysts, target material for x-rays		High, moderate
Zinc	0.1-240	★	Alloys, electronics, automotive parts, fungicides, roofing, cable wrappings, nutrition		Moderate
Nonmetals and anions					
Ammonia	1-900	★	Fertilizers, chemical manufacturing, refrigerants, synthetic fibers, fuels, dyestuffs		
Boron	-	●	Alloys, fibers and filaments, semi-conductors, propellants		
Chlorides	1.0-49,500	★	Chemical manufacturing, water purification, shrink-proofing, flame-retardants, food processing		
Cyanides	1.05-14	★	Polymer production (heavy duty tires), coatings, metallurgy, pesticides		High
Fluorides	0.1-250	★	Toothpastes and other dentrifices, additive to drinking water		Moderate
Nitrates	1.4-433	★	Fertilizers, food preservatives		
Nitrites	—	●	Fertilizers, food preservatives		
Phosphates	0.4-33		Detergents, fertilizers, food additives		
Sulfates	0.2-32,318	★	Fertilizers, pesticides		
Sulfites	-		Pulp production and processing food preservatives		
Micro-organisms					
Bacteria (coliform)		●			
Viruses					
Radionuclides	(picocuries per milliliter)				
Cesium 137			Gamma radiation source for certain foods		
Chromium 51	-		Diagnosis of blood volume, blood cell life, cardiac output, etc		
Cobalt 60	6.4		Radiation therapy, irradiation, radiographic testing, research		
Iodine 131	—		Medical diagnosis, therapy, leak detection, tracers (e.g., to study efficiency of mixing pulp fibers, chemical reactions, and thermal stability of additives to food products), measuring film thicknesses		
Iron 59	–		Medicine, tracer		
Lead 210	–		NA		

(continued)

TABLE B-2. (continued)

Contaminant	Concentration	Standard	Examples of uses	Carcino-genic potency	Noncar-cinogenic toxicity
Radionuclides (cont'd)	(picocuries per milliliter)				
Phosphorous 32	—		Tracer, medical treatment, industrial measurements (e g , tire tread wear and thickness of films and ink)		
Plutonium 238, 243	—		Energy source, weaponry		
Radium 226	0.8-25	★	Medical treatment, radiography		
Radium 228	12 5		NA		
Radon 222	—	●	Medicine, leak detection, radiography, flow rate measurement		
Ruthenium 106	—		Catalyst		
Scandium 46	—		Tracer studies, leak detection, semi-conductors		
Strontium 90	0 817	●	Medicine, industrial applications (e g., measuring thicknesses, density control)		
Thorium 270	—		NA		
Tritium	150-353	●	Tracer, luminous instrument dials		
Uranium 238	10-500	★	Nuclear reactors		
Zinc 65	—		Industrial tracer (e.g , to study wear in alloys, galvanizing, body metabolism, function of oil additives in lubricating oils)		
Zirconium 95	—		NA		

[a] Based on Abrams, et al 1975 Bryant et al 1983 Harris et al n d O'Brien and Fisher, 1983 Tucker, 1981, University of Oklahoma 1983, Hawley 1977, Considine and Considine, 1983 Lewis and Tatken 1980 and Windholz, et al 1982

[b] *Concentrations represent single reported concentrations of ranges of reported groundwater or domestic well concentrations from references surveyed they generally do not include concentrations at hazardous waste sites* Dash (—) indicates contaminant detected but concentration not reported Note that units differ among categories, units are defined at the beginning of each contaminant category

[c] Solid bullet means that at least one type of standard exists for the substance Asterisk means that at least one standard is known to have been exceeded Note that these refer to standards for individual substances, standards for groups of substances or other measurements such as BOD are listed in app C

[d] Listed uses are primarily industrial applications Some substances occur naturally in groundwater and may not be a result of human activities

[e] *Absence of an entry does not necessarily mean that no adverse health effects are associated with that substance, rather, entries reflect data available to OTA In addition, if a value was found for carcinogenic potency of a substance* no search for non-carinogenic toxicity of that substance was made

[f] Carcinogenic potency is measured either according to unit risks developed by EPA Carcinogen Assessment Group or according to estimated unit risk based on assessment by EPA Office of Pesticides and Toxic Substances (as reported in Environ Corp 1983), carcinogens are listed only if peer-reviewed unit risk data are available Unit risk = risk per unit of exposure, where unit of exposure is defined as lifetime average daily intake Estimates of lifetime risk are obtained by multiplying unit risk by actual exposure Potency categories are defined as (Environ Corp 1983)

High potency unit risk greater than 5 $(mg/kg/day)^{-1}$
Medium potency - unit risk equal to 0 1-5 $(mg/kg/day)^{-1}$
Low potency unit risk less than 0 1 (mg/kg/day) ^{1}

[g] *Noncarcinogenic toxicity is measured by Minimum Effective Dose (MED, the minimum dose known to cause adverse impact, Environ Corp , 1983)*

High MED less than 10 mg/kg body weight/day
Moderate = MED 10-100 mg/kg body weight day
Low MED greater than 100 mg/kg body weight/day

[h] Value for combined anthracene and phenanthrene

[i] NA — *information on use not available in standard references that were consulted*

[j] Value for combined lignin and tannin

Oxygenated Hydrocarbons

Oxygenated hydrocarbons refer to any organic compound that contains an (OH) group, an oxygen group or responds as an acid in a solution. These may include both aromatic and aliphatic hydrocarbon groups.

Alcohols or hydroxy alkyl compounds are considered to be a step in the primary oxidation product of hydrocarbons. The alcohols are classified into three groups: primary, secondary and tertiary, depending on the location of the (OH) group. The common alcohols are methyl, ethyl, isopropyl and n-butyl. Methyl alcohol is used in the synthesis of organic compounds and in antifreeze. Ethyl alcohol is used in the production of beverages, synthesis of organic compounds and in medicines. Isopropyl alcohol is used extensively in organic synthesis as is n-butyl alcohol. Short chain alcohols are soluble in water and may be volatized and biodegraded (Brown et al., 1983). Polyhydroxyl alcohols contain two hydroxyl groups per molecule and are known as glycols. These are commonly used as radiator anti-freeze compounds and are very toxic. Glycerol is a trihydroxy alcohol used extensively in soaps, foods, cosmetics and medicines. Most alcohols are easily oxidized by oxidizing agents and many microorganisms.

Primary alcohols are oxidized to aldehydes, while secondary alcohols oxidize to ketones. Common aldehydes include formaldehyde and acetaldehyde. Formaldehyde is used extensively in organic synthesis, and is toxic to microorganisms, however, under dilute concentrations it can be used as food by microorganisms and oxidized to carbon dioxide and water. The chemical names of all aldehydes end in -al. Many of the aromatic aldehydes exhibit fragrant odors, such as coumarin and vanillan. The ketones are used as industrial solvents and in the synthesis of organic products. The most common ketone is acetone. Both aromatic and aliphatic ketones are easily oxidized by microorganisms.

Organic acids represent the highest oxidation state possible in an organic compound; further oxidation produces carbon dioxide and water (Sawyer and McCarty, 1978). All organic acids contain a carboxyl group. Thus, acids with one carboxyl group are known as monocarboxylic acids and so on. A wide variety of saturated and unsaturated acids occur in nature as constituents of waxes, fats and oils. These are known as fatty acids which are typically straight chain structures. The lower members of the saturated acid series are liquids, ranging in order from the sharp odors of formic and acetic acid to the unpleasant odors of butyric and valeric acids. Butyric acid gives rancid butter its disagreeable odor. Industrial wastes from the dairy industry must be treated to prevent formation of these acids. These acids range from being completely soluble in water to relatively insoluble. The unsaturated acids include acrylic, oleic and linoleic acids which are the general constituents of the glycerides of most fats and oils (Sawyer and McCarty, 1978; Lippencott et al., 1978). Organic acids are utilized by microorganisms through oxidation processes and are converted to carbon dioxide and water. Biodegradation of higher acids may be limited by their solubility in water. A wide variety of aromatic carboxylic acids are known such as benzoic acid, a preservative, salycilic acid, a constituent of aspirin, and phthalic acid, an important intermediate in the manufacture of organic compounds. These acids are also subject to biodegradation by microorganisms to carbon dioxide and water.

The degradation of aliphatic hydrocarbons by microorganisms depends on molecular weight, water solubility, number of double bonds, degree of branching, and whether the compound is an open chain or cyclic compound. Thus, the simplest compounds such as a straight chain hydrocarbon will be the most easily degraded as opposed to a more complex cyclic compound (Brown et al., 1983). The degradation rate decreases with either a decreasing number of double bonds or with the number and size of alkyl groups. Sediments containing aliphatic hydrocarbons are generally deficient in nitrogen and phosphorous. Addition of these fertilizers greatly enhances biodegradation rates (Brown et al., 1983). Volatilization of low molecular weight hydrocarbons is a mechanism that occurs with increasing temperature and soil moisture content.

Aromatic Compounds

The aromatic compounds contain stable ring structures, or cyclic groups, with very stable bonds which are hybrids of single and double bonds. Thus, aromatic compounds do not bond to substances by addition, but rather by substitution of a hydrogen atom for an element or compound. The simplest aromatic ring is made up of six-ringed carbon atoms bonded to six hydrogen atoms and is known as benzene or the benzene ring. Substitutions may occur at one or more hydrogen atom sites. The benzene series constitutes a single ring with alkyl substitutions; these include toluene and xylene and the respective isomers of xylene. These products are found in coal tar and crude petroleum and are used primarily as solvents.

The phenols are an important aromatic hydrocarbon. They consist of a basic ring hydrocarbon or benzene with an attached (OH) group. Phenols are generally known as carbolic acid which is widely used as a disinfectant, and in concentrated solutions is toxic to bacteria. Phenols occur as natural constituents of industrial wastes from coal and petroleum processing. Until recently, phenol was thought to be toxic to bacteria for biodegradation applications. However, more recent studies suggest that bacteria may be able to degrade low concentrations (Erlich et al., 1982; Tabak et al., 1980). Studies by the FMC Corporation (1983) indicate that hydrogen peroxide is capable of oxidizing phenols in the presence of a catalyst to produce carbon dioxide and water.

The next higher group of phenols are cresols. They are found in coal tar and exhibit even higher germicidal properties than phenols, but are less toxic. Cresols are commonly found in spray disinfectants such as lysol and in creosote, used in wood preservation. Phenols with more than one (OH) group are termed polyhydric. Three industrially important isomers of polyhydric phenols include the catechols, resorcinals and hydroquinone. These isomers are readily oxidized by microorganisms (Sawyer and McCarty, 1978). Other biodegradation mechanisms for benzenes and phenols occur through hydroxylation of the double bonds to produce dicarboxylic acid. These aromatic acids may be further biodegraded to simple compounds.

A polyring aromatic hydrocarbon consists of one or more cyclic rings that are bonded through shared carbon atoms. These carbon atoms do not have hydrogen atoms attached. The polyring aromatic compounds include naphthelene and anthracene used in the manufacture of dyes, and phenanthracene, an important constituent of alkaloids such as morphine and vitamin D. Halogenated and nitrogenous aromatics will be discussed in the next section.

Aromatic compounds are usually present in wastes generated by petroleum refineries, organic chemical plants, rubber industries and waste streams associated with combustion proceses (Brown et al., 1983). Most aromatic hydrocarbons are toxic and/or carcinogenic and fairly resistant to degradation. The decomposition rate of aromatic hydrocarbons is typically substance dependent; however, simple compounds typically degrade more easily. In addition, the more soluble compounds are more easily degraded by microorganisms (Tabak et al., 1980).

Hydrocarbons With Specific Elements

The final group of hydrocarbons may be either aliphatic or aromatic, but has one or more additional groups with specific elements as substituents, namely, nitrogen, sulfur and phosphorous and the halogens, chlorine, fluorine, iodine and bromine. The halogenated organics have received the most attention as ground-water contaminants. These compounds are refractory, or very resistant to degradation. This is thought to be due to the presence of a halogen; its location and type determine the relative persistence of the compound (Kobayashi and Rittmann, 1982). These compounds range from simple alkyl halides to polyhalogen compounds to complex halogenated hydrocarbons such as DDT. Common halogenated compounds include methyl chloride, ethyl chloride, ethylene dibromide, chloroform, carbon tetrachloride, tetrachloroethylene, chlorobenzene and freon (dichlorodifluoromethane). Methyl and ethyl chloride were once used as refrigerants; ethyl chloride is used in the manufacture of tetraethyl lead, an antiknock gasoline additive. Chloroform has been found in drinking water due to the reaction of chlorine with natural organic substances in water. Freon is an extensively used refrigerant due to its non-toxic and non-flammable properties (Sawyer and McCarty, 1978).

Chlorinated hydrocarbons were formerly used extensively as various types of pesticides, many of which are very resistant to degradation. These include dioxin, DDT, DDE, Aldrin, Dieldrin, Endrin, Lindane, Chlordane, Toxaphene, 2, 4-D and 2,4,5 TP Silvex which have been banned from usage or greatly restricted because of their toxicity and carcinogenic potentials (Solomons, 1978; Brown et al., 1983; Abrams et al., 1975). These products were used extensively for agricultural and defoliant purposes. Other pesticides have been studied to determine their potential for attenuation through hydrolysis, reductive dehalogenation and biodegradation.

Hydrolysis is a reaction in which a bond is broken by water. Often, an (OH) group replaces a halide ion or ester. Hydrolysis rates are dependent on pH, the presence of humic materials and individual compounds (Cherry et al., 1984; Cohen et al., 1984). Reductive dehalogenation involves the removal of the halogen through oxidation-reduction reactions in low redox state ground water (Cherry et al., 1984) and by certain microorganisms (Kobayashi and Rittmann, 1982). Biodegradation of halogenated hydrocarbons has been documented under both aerobic and anaerobic conditions (Kobayashi and Rittman, 1982; Cherry et al., 1984; Bouwer et al., 1981; Tabak et al., 1980; Brown et al., 1983). Hexachloroethene was shown to disappear with a 40 day half life in a sand aquifer. Supporting laboratory data indicated the compound was reduced to tetrachlorethylene through microbial biodegradation (Criddle et al., 1986).

Other types of pesticides include organic phosphorous and carbamate pesticides. Organic phosphorous pesticides include parathion, which is very toxic, and malathion which has low toxicity for mammals. Phosphorous pesticides tend to hydrolyze quickly at or above a neutral pH, thus losing their toxic properties. Carbamate pesticides typically have moderate to high water solubilities and are often volatile. These include IPC, a herbicide, captan, a fungicide and ferbam and sevin as insecticides. Aldicarb and carbofuron are toxic carbamate pesticides which have been found in ground water in many states.

As a rule, chlorinated aromatics are less degradable and less soluble than their aliphatic counterparts. This has proven true for the chlorinated benzenes including hexachlorobenzene (HCB) and its derivatives. These are found as by-products of industrial processes, and in chlorinated solvents and pesticides. The rates of degradation of these compounds are slow; they may persist in the soil and water for several years without significant degradation. Certain plants such as lettuce, carrots, grasses and potatoestend to absorb HCBs from the soil (Brown et al., 1983). Rates of degradation are variable depending on the degree of chlorination; in general, the less chlorinated, the more degradable (Tabak et al., 1980).

Another widely publicized group of halogenated organics are the polychlorinated biphenyls (PCBs). These are biphenyl molecules with the presence of one or more chlorine atoms at several locations on the phenyl structures. These mixtures have been commercially produced since 1929 with a total of 210 possible compounds. PCBs are classified according to chlorine content with most industrial mixtures containing 40 to 60 percent chlorine (Solomons, 1980).

PCBs had many uses including heat exchangers in transformers, in capacitors and thermostats, plasticizers in food bags and polystyrene cups, in printing inks and in waxes. Because the PCBs are highly persistent and fat soluble, they tend to collect in the tissues of many animals and humans. The EPA banned the manufacture, processing and distribution of PCBs in 1979 (Solomons, 1980).

Degradation of PCBs has been found to be affected by the nature of the chlorine substituents with respect to the substitution or relative position of the chlorine atom within the compound (Brown et al., 1983). Degradation tends to increase as the amount of chlorine substitution decreases; the relative position of the chlorine also affects rates of degradation. In general, the lower chlorinated compounds were found to be degradable in mixed microbial populations (Kobayashi and Rittmann, 1982).

Other hydrocarbons with specific elements have the nitrogen group as substituents. These include the amines, amides, anilines and nitriles. The amines are alkyl derivatives of ammonia and may be primary, secondary or tertiary depending on the number of hydrogen ammonia atoms that are replaced. The amines are found in industrial wastes from fish and beet-sugar industries, and little is known about their susceptibility to biodegradation. The amides are derived from organic acids and ammonia under special conditions. The nitriles are organic cyanides that are extensively used in the manufacture of synthetic fibers (Sawyer and McCarty, 1978). The most commonly used nitriles include acrylonitrile and acetonitrile. Attenuation of nitriles occur through oxidation reactions at specified pH values (Harsh, 1975). The primary form of amines are known as analines and are important compounds for organic synthesis and in dyes. The amines were shown to range in ease of biodegradability depending on the individual compound (Tabak et al., 1980; Kobayashi and Rittmann, 1982).

Mercaptans or thiols are aliphatic compounds that contain sulfur and have a structure similar to alcohols. Mercaptans are known to have disagreeable odors and are typically byproducts of kraft pulping and petroleum processing. The FMC Corporation (1983) has shown that thiols are readily oxidized under acid conditions to insoluble products.

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APPENDIX C

SOURCES OF GROUND-WATER CONTAMINATION

The quality of the ground water may be altered by a wide variety of human activities and naturally occurring phenomena. The innumerable waste materials and byproducts of man's activities provide potential for ground-water contamination through a variety of mechanisms.

Ground-water quality problems that are attributed to man's influence are commonly related to: (1) water-soluble products that are placed on the land surface and in streams or surface impoundments, (2) substances that are deposited in the ground above the water table, and (3) disposal, storage, or extraction of materials below the water table (Lehr et al., 1976). Sources of ground-water pollution are associated with a broad range of industrial, agricultural, commercial and domestic activities. Many of the problems that arise from wastes as a result of these activities are not well understood, due to their complexity. Technical solutions are available for many ground-water quality problems through planning, management, and/or prevention practices.

The application of a rating system designed to estimate potential for ground-water contamination is of concern with regard to individual contamination situations. Because ground-water contamination may occur from a variety of sources, it may be necessary to consider and possibly reevaluate the importance of a rating factor as the scale of the area being evaluated changes.

Soil attenuation characteristics such as sorptive capabilities, microorganisms, degradation capacities and textures are of major importance when considering the placement of wastes on the surface of the land (e.g. stockpiles, sludge, wastewater) and the subsequent potential for ground-water pollution. However, the effect of soil is relatively unimportant for situations where the soil has been removed, such as at a landfill, or where contaminants are buried beneath the soil surface (e.g. storage tanks). Thus, engineering and other practical considerations of an area can obviate the application of DRASTIC parameters.

Dry contamination sources that are implaced on the land surface, such as stockpiles, fertilizers and pesticides are dissolved and disseminated by rainfall resulting in the generation of ground-water pollution. Evaluation of the DRASTIC parameters suggests that the most important parameters with regard to this category of activities are: Depth to Water, which controls contact time of the pollutant with the unsaturated zone; Net Recharge, which limits the quantity of leachate generated; Soil Media, which affects both organic and inorganic attenuation mechanisms; and the Vadose Zone Media, which also directly affects attenuation properties. Parameters of lesser impact for this category of activities include: Aquifer Media and Hydraulic Conductivity of the Aquifer, since these are impacted less by surface-applied pollutants. Topography may be important for surface storage facilities, but most agricultural activities are confined to relatively flat terrain.

Wet contamination sources emplaced on the land surface include wastewater, irrigation water and spills. In this situation, the most important parameters are Depth to Water, Soil Media, Impact of the Vadose Zone Media and Topography which will affect the attenuation and infiltration rates of the liquid contaminants. Again, because the source is on the surface, Hydraulic Conductivity of the Aquifer and Aquifer Media are less important. Net Recharge has a less negative effect since the contaminant is already liquid. High net recharge may result in dilution.

This type of rationale can also be applied to either liquid or dry sources emplaced below the surface which may or may not intersect the water table. The potential for liquid sources below the water table to cause contamination, such as leaking underground storage tanks or drainage wells, is affected primarily by the Depth to Water, the Impact of the Vadose Zone Media, Hydraulic Conductivity of the Aquifer, and the Aquifer Media. These factors are directly related to attenuation and migration rates of the contaminant. Surface characteristics such as Topography, Net Recharge and Soil Media would subsequently be of lesser importance for potential pollution evaluations.

Lastly, for dry contaminant sources emplaced below the surface (e.g. landfills and quarries) it is necessary to consider Net Recharge in terms of volumes of leachate generated; the Hydraulic Conductivity of the Aquifer in relation to migration rates; and Aquifer Media for possible attenuation of contaminants, dispersion, dilution and routing. Again, surface characteristics are of lesser importance; Topography, Soil Media, and Impact of the Vadose Zone Media.

Thus, man's activities and the intensity of these activities present many potential contamination problems. The impact of these activities is discussed in Section 6, Impact - Risk Factors. Activities are not directly involved in the determination of the DRASTIC Index, but their impact is always of serious concern. These activities may be categorized according to their relative position with respect to the ground water; Table 11 represents a comprehensive list of activities that are potential sources of contamination and their respective modes of emplacement. Each of these sources will be discussed individually in relation to their effects and potential for ground-water contamination.

GROUND WATER QUALITY PROBLEMS THAT ORIGINATE ON THE LAND SURFACE

Land Disposal

One of the major causes of ground-water pollution is the disposal of solids or liquid waste materials directly onto the land surface in either individual deposits or spread over the land. Any soluble products present in the waste can be transported into the ground water either with the liquid portion of the wastes or as a consequence of precipitation. Land disposal practices include the application of sewage sludge, manure, garbage, industrial wastes, waste tailings and spoil piles. These activities are capable of producing a wide variety of contaminants, including organic chemicals, inorganic chemicals and reactive ions.

Stockpiles and Mine Tailings

The presence of material stockpiles, mine tailings and spoils poses a potential source of ground-water contamination. Contamination of ground and surface water occurs from the infiltration of precipitation, seepage of leachate into the subsurface and from runoff into streams and rivers. The Office of Technology Assessment (1984) estimates that approximately 20 percent of total mining materials production is stored in stockpiles. Commonly stockpiled materials that may affect ground-water quality include salt, coal, various metallic ores (e.g. copper, uranium, titanium, vanadium, silver, lead, zinc), phosphates and gypsum (Koch et al., 1982).

Because these stockpiles are commonly stored uncovered, precipitation falling onto the stockpiles may dissolve or react with soluble constituents to produce leachate that can percolate into the ground water or runoff to surface streams and water bodies. In particular, sulfide bearing minerals, including coal, lead, zinc, molybdenum, nickel and copper stored as ore stockpiles are capable of producing sulfuric acid from reactions with infiltrated water. The acidic leachate produced also may dissolve other constituents from the ores of these minerals. Coal which is used extensively by electric utilities, coke plants and industrial users is the most commonly stockpiled mineral. Koch et al. (1982) estimated coal stockpiles alone at 185 million tons in 1980. Table C-1 lists substances present in coal piles which have the potential to leach into the ground water.

TABLE C-1. MAJOR SUBSTANCES PRESENT IN COAL ORE STOCK-PILES AND SPOIL PILES (AFTER KOCH ET AL.,1982)

Major Constituents	Trace Amounts
Aluminum	Arsenic
Iron	Cadmium
Calcium	Mercury
Magnesium	Lead
Sodium	Zinc
Potassium	Uranium
Manganese	Copper
Sulfur	Cobalt
Phosphate	Antimony
	Barium
	Beryllium
	Boron
	Selenium

Mining

The disposal of mining wastes through spoil piles and tailings can also degrade the quality of ground water. Both types of waste are usually stored on the land surface and exposed to weathering and precipitation. Water moving through the waste piles will mobilize many hazardous constituents, depending on the nature of the materials and the chemical conditions within the pile.

Spoil piles are composed of the disturbed soils and overburden from surface mining, and the waste rock removed from underground mining (Miller, 1980). Some reclamation techniques use spoils to reclaim the area after mining, but in the past the mined areas were often left in their original state. The principal contaminants generated from mine wastes include acids, dissolved solids, metals and radioactive materials.

The generation of acid mine drainage and related contaminant products is associated with the mining of coal and other sulfide-bearing minerals. Upon exposure to the atmosphere, iron sulfides associated with coal and mineral ores oxidize and produce soluble hydrous iron sulfates. Water from precipitation and run-off react with the sulfates to produce sulfuric acid and ferrous sulfate, decrease the pH of the water and release substantial quantities of iron to the water (Miller, 1980; National Research Council, 1981). Acid formation may also be influenced by the presence of certain species of iron bacteria which catalyze and accelerate the oxidation rate above that typically found in natural systems (Koch et al., 1982; National Research Council, 1981; Atkins and Pooley, 1982). Accelerated acid formation and lower pH will enhance the dissolution of metals frequently associated with metallic ore deposits such as copper, zinc, cadmium, aluminum and manganese. Common minor elements may be released through dissolution, complexation and colloidal suspension contributing to total dissolved solids and turbidity (National Research Council, 1981). In addition to the trace constituents listed in Table C-1, other trace compounds associated with coal and sulfide mining include: nickel, zirconium, titanium, rubidium, lithium, chromium, gallium, germanium, lanthanum and tungsten (Miller, 1980; National Research Council, 1981).

Acid mine drainage from coal spoil piles alone represents a significant threat to ground-water quality in areas where coal reserves are mined (National Research Council, 1981). Degradation of ground-water quality from mine spoils has also been documented at lead-zinc mines (Sheibach et al., 1982; Miller, 1980; Hardie et al., 1974), and uranium mines (Kaufman et al., 1975; Williams and Osiensky, 1983).

The presence of limestones and dolomites in mining areas, particularly in the western states, serves to neutralize acid mine drainage which develops from spoil piles. Under basic conditions most heavy metals form insoluble salts, however, the water can still be highly mineralized due to an increase in sulfate salts of calcium, magnesium and sodium.

The total impact of mine spoils is dependent on the mineralogic characteristics, size and configuration of the spoils, the climate of the area, the hydrogeology of the mine site and the control technology implemented at the site to prevent the development and infiltration of leachate. Ground-water contamination from mine spoils leachate has been documented at several sites (Van Voast et al., 1974; McWhorter et al., 1974; Mele et al., 1982; Walker, 1973; Ricca and Schultz, 1979; Schubert, 1979).

Tailings piles and ponds result from the disposal of mining wastes generated from the on-site processing operations of cleaning and concentrating the ore. Tailings are transported as a slurry from the processing site via ditch or pipeline to the tailings pond along with process wastewater and mine drainage. The suspended solids in the slurry are allowed to settle to the floor of the ponds. The remaining wastewater is either recovered for reuse, lost to evaporation, discharged to surface streams or infiltrates to the ground water.

Tailings ponds may be located in natural depressions or in constructed excavations with perimeter dikes to contain the liquids. Tailings ponds are typically unlined, allowing for unrestricted seepage into the ground water (Miller, 1980). Some tailings may be used to construct the pond embankments if the materials are capable of preventing pond leakage and supporting the weight of the structure to minimize embankment failure (Williams, 1975). Fully sedimented tailings ponds are usually abandoned, and the remaining tailings piles are left uncovered. Precipitation that infiltrates these deposits may dissolve soluble constituents and carry these contaminants into the ground water. Ground-water contaminants associated with tailings piles and ponds include acids, metals, dissolved solids and radioactive materials.

The process of ore concentration or beneficiation typically utilizes the techniques of flotation and acid/alkaline extraction (Williams, 1975). Spent acid (sulfuric) or alkaline (sodium carbonate and biocarbonate) leach liquids are often discharged to the tailings ponds in addition to minerals associated with the metallic compound being recovered. The major dissolved species found in tailings ponds wastewater includes sulfate, iron, aluminum, sodium, chloride, manganese, calcium and magnesium; minor amounts of arsenic and selenium may also be present (Williams and Osiensky, 1983). Depending on the specific metal being recovered and the chemical nature of the waste stream, other metals may be found as dissolved or suspended species in the tailings ponds. Waste disposal from uranium-thorium mills may contain dissolved radionuclides of radium, thorium, uranium and lead. The typical pH of tailings ponds averages 1.8 for acid leach extraction and 10.2 for alkaline leach processes (Williams and Osiensky, 1983).

Incidences of ground-water contamination from seepage through tailings ponds and piles has been documented. Contamination from uranium mill tailings has been found in the Grants Mineral Belt, New Mexico (Kaufmann et al., 1975; McLin, 1982; Thompson et al., 1984; Longmire, 1984), as well as in Colorado, Wyoming, Utah and Washington (Williams and Osiensky, 1983;

Young et al., 1986). Hydrologic investigations at some sites have discovered contamination severe enough to prompt the implementation of ground-water "pumpback" systems by the Nuclear Regulatory Commission. Ground-water pumpback systems intercept the contaminant plume, withdraw the water and return it to a tailings or evaporation pond (Williams and Osiensky, 1983).

Additional examples of contamination can also be found in the literature. For example, early day lead-zinc mining operations coupled with present-day mining activities are now affecting ground-water quality at several sites in the Coeur d'Alene district in Idaho (Mink et al., 1971; Norbeck et al., 1974). Gold and silver tailings ponds in Nevada and South Dakota have contaminated the local ground water with cyanides, sulfates, chlorides, metals and dissolved solids (Thompson et al., 1984). Clay slime ponds from phosphate mines in Florida have increased concentrations of phosphorous, chloride, fluoride and total dissolved solids in the water table aquifer near mine disposal areas (Thompson, et al., 1984).

Salt

The improper storage of road salt for highway de-icing has caused contamination problems in many of the Midwest and Northeastern snowbelt states. Although pure salt is usually stored in watertight buildings, the source of contamination is often uncovered piles of mixed sand and salt at highway maintenance lots. An average size sand-salt pile contains 3000 cubic yards of sand and 150-250 tons of salt (Williams, 1984). The salt is usually commercial rock or marine salt with ferric ferrocyanide and sodium ferrocyanide added to reduce caking of the salt piles. Chromate and phosphate may also be added to reduce the corrosivity of the salt (Bouwer, 1978). Salt additives may also contribute to ground-water contamination; sodium ferrocyanide is water soluble and can generate cyanide when exposed to sunlight, while chromate can produce high concentrations of hexavalent chromium in run-off water (Field et al., 1974).

The dissolution of salt in sand-salt piles and subsequent infiltration into the ground water has caused elevated levels of chloride in more than 150 domestic wells in the state of Maine (Williams, 1984; Williams, 1986). Contaminant plumes generated by sand-salt storage piles have been successfully delineated through the use of resistivity soundings and terrain conductivity profiling (Williams et al., 1984). Chloride contamination of domestic wells from sand-salt piles has also been documented in Massachusetts, Michigan and Connecticut (Field et al., 1974). A five-year study in Monroe County, West Virginia showed an increase of chloride in wells located 1500 feet away from a stockpile (Wilmoth, 1972). When the salt piles were enlarged, an increase of chloride concentrations in the ground water sampled from the wells was noted. Conversely, removal of the salt piles caused chloride levels in the wells to decline within two months.

Disposal of Sewage and Sludge

The collection, treatment and disposal of large quantities of municipal and industrial wastewater constitutes a major problem in many communities. Towns with older combined sanitary and storm water collection systems are often confronted with a hydraulically overloaded treatment facility during periods of heavy runoff or meltwater. Deicing salts, litter and other street debris from storm water runoff may also adversely impact the operation of the treatment facility. Land application of stabilized wastewater and sewage sludge is often used as an alternative to more costly conventional treatment and disposal processes.

Wastewater

The adverse impact of sewage disposal on ground-water quality can originate during the collection and transport of sewage to the treatment facility. Sanitary and storm water sewer systems are designed to provide a watertight passage for the conveyance of waste to a treatment facility. If the sewer pipe is non-watertight, sewage may either leak out of the pipe or ground water may infiltrate into the pipe. Where ground-water levels are lower than the wastewater level in a cracked pipe, the wastewater can impact the ground-water quality by leakage into the ground. As an example, ground-water contamination by nitrates from leaky sewer systems has been documented on Long Island, New York (Kimmel, 1972). Conversely where ground-water levels are higher than the wastewater level in the pipe, leaking pipes allow ground water to enter the pipe. This additional volume of water must be treated at the treatment facility and may cause overloading of the system. Overloading the system may result in inadequate treatment of the effluent or bypassing of certain treatment phases before discharging to surface water.

In addition to leaking sewers, another inadvertent impact of sewage on ground-water quality may be infiltration from wastewater stabilization ponds. Wastewater stabilization ponds are primarily used for settlement of suspended solids and biological treatment of primary and secondary effluent. The function of the ponds will vary depending on the basic design, but commonly employs biological treatment under aerobic and/or anaerobic conditions (Miller, 1980). Leakage from unlined ponds may be significant and cause potential pollution problems. The presence of detergents and nitrates have been detected under waste stabilization ponds in sandy to silty soils (Preul, 1968).

Impacts on ground-water quality by sewage disposal may also occur as a result of the intentional land application of wastewater. The use of disposal practices may include discharging partially treated wastewater to the land surface for final treatment in disposal, the application of treated effluent for ground-water recharge and the irrigation and fertilization of agricultural land. Degradation of water quality occurs when the effluent infiltrates into the ground water without sufficient attenuation of desirable constituents.

Land spreading of wastes for the purposes of treatment, irrigation, and recharge is achieved by three basic application techniques: 1) spray irrigation, 2) overland flow and 3) infiltration-percolation basins. Irrigation of croplands using sewage effluent may be accomplished through the use of sprayers, ridge and furrow or flood techniques. The type of irrigation system utilized is dependent on soil permeability, topography, crop type and cost (Pound and Crites, 1973). Loading rates are calculated based on crop nutrient uptake, soils, climate and wastewater characteristics. Typical loading rates range from 1.5 to 4.0 inches per week. In general, effluent irrigation is capable of removing significant amounts of nitrogen, suspended solids and fecal coliform (Pound and Crites, 1973; Murphy, 1986). Soils with significant organic and clay content have been shown to attenuate heavy metals, phosphorous and certain types of viruses through adsorption and complexation (Pound and Crites, 1973; Keswick and Gerba, 1980). Sandy and silty loam soils at slow rate irrigation test sites have been shown to remove trace organic constituents in wastewater through adsorption, biodegradation and volatilization (Parker et al., 1984). However, ground-water contamination from nitrates, phosphorous, chlorides and fecal coliform during irrigation have also been documented (Barker, 1973; Sawhill, 1977; Reichenbaugh et al., 1979; Franks, 1981).

Overland flow techniques are suitable for soils with limited permeability such as silts and clays. Wastewater flows sheetlike over a vegetated surface and runoff must be collected. Overland flow systems have provided effective removal of BOD, suspended solids, nitrogen and partial removal of phosphorous through crop fixation, biological uptake and adsorption (Pounds and Crites, 1973).

Infiltration-percolation of treated effluent in spreading basins has become a popular mode of disposal for waste treatment and ground-water recharge. Successful use of infiltration-percolation systems requires soils with infiltration rates of 4 inches per day to 2 feet per day or more (Pound and Crites, 1973). Infiltration systems may be low rate (4 to 60 inches per week) or rapid rate (5 to 10 feet per week) systems. Rapid rate infiltration systems generally require pretreated or secondarily treated wastewater to maintain a high loading rate. Spreading basin surfaces may contain bare soils, gravel or vegetation. The intermittent inundation of spreading basins has proven successful for maintaining aerobic/anaerobic conditions for removal of nitrates, phosphorous, BOD, suspended solids and fecal coliform (Bouwer et al., 1972).

The attenuation and removal of wastewater constituents has been shown to occur by the processes of filtration, chemical transformation, adsorption, dilution and biodegradation (Bouwer et al., 1972; Borrelli et al., 1978; State of California, 1978; Idelovitch et al., 1979; Baxter and Clark, 1984). The removal of trace organics through biodegradation, sorption and volatilization at rapid rate infiltration sites has also been demonstrated (Bouwer et al., 1981; Hutchins and Ward, 1984; Parker et al., 1984).

Certain contaminants, however, are not totally attenuated in the subsurface. Ground-water contamination from rapid rate infiltration sites has caused increased elevations in dissolved solids and detergents (Hughes and Robson; 1973; Van der Leeden et al., 1975; Fujioka and Lau, 1984), nitrates, phosphorous (Baxter and Clark, 1984), trace organics (Tomson et al., 1981; Bedient et al., 1983), and bacteria and viruses (Keswick and Gerba, 1980; Moe et al., 1984). The discharge of primary sewage effluent has caused ground-water contamination at several treatment sites in England (Baxter, 1985). Table C-2 illustrates the effects of ground-water recharge by municipal effluent on a calcareous sandstone separated by silt and clay layers in the Dan Region, Israel (Idelovitch et al., 1979).

Municipal and industrial wastewater can be classified according to their physical, chemical and biological characteristics. Table C-3 lists municipal wastewater characteristics at various stages of treatment (Pound and Crites, 1973). Industrial wastewater contains many of the same constituents as municipal wastewater but varies by industry, product and the processing technique utilized (Pound and Crites, 1973). Wastes produced by chemical-related industries exhibit a wide variability in waste constituents and may contain any number of organic compounds.

Sludge

Sludge is the by-product or residue from the chemical, physical or biological treatment of industrial and municipal waste. Municipal sludge contains a mixture of sewage from metabolic wastes, industrial wastes, household wastewater, and in some cases, storm water run-off. The composition of municipal sludge typically contains partially decomposed organic compounds, inorganic salts, heavy metals, bacteria and viruses. Industrial sludge compositions may vary widely depending on industry type and waste treatment practice. The constituents of concern relative to ground-water contamination in typical municipal sludge include: nitrogen, phosphorous, heavy metals and trace metals, organic compounds and pathogens.

The most common disposal method for municipal and industrial sludge is land spreading of waste or placement in a sanitary landfill. Land spreading is the application of solid or liquid sludges to forested or agricultural lands. Sludge can also be utilized for land reclamation in strip mine areas.

The nitrogen content of municipal sludge varies from 1 to 7 percent according to the type of sewage treatment utilized. Approximately half of this amount occurs as organic nitrogen and the other half as ammonia which is directly available for uptake by plants (Knox, 1979; Miller, 1980). In addition, organic nitrogen is converted to ammonia by mineralization at a rate of 15 to 30 percent the first year and 3 percent per year thereafter. Nitrogen applied in excess of crop uptake is available for leaching into the ground water. The factors which affect nitrogen absorption into the environment and thus the rate of application of the sludge are: volatization, denitrification, climate, soil and crop type. Research indicates that proper farm management practices allow for repeated sludge applications with minimal nitrate impact on ground water (Higgins, 1984; Wengel and Griffin, 1979). Municipal sludge applications have also resulted in nitrate contamination problems in the ground water (Wengel and Griffin, 1979; Higgins, 1984).

TABLE C-2.COMPARISON OF EFFLUENT QUALITY PRIOR TO RECHARGE AND AFTER FLOW TO OBSERVATION WELLS (IDELOVITCH ET AL., 1979)

Parameter	Units	Recharge Effluent[a]	Effluent in Observation Wells 61 & 63
Basic Wastewater			
BOD	mg/l	8	<1
COD	mg/l	50*	6-20
DOC	mg/l	15	1.5-4.5
$KMnO_4$ Consumption	mg/l	13	1.5-5
Ammonia, as N	mg/l	3	<0.02
Total Nitrogen	mg/l	4[c]-10[d]*	2-8
Phosphorus	mg/l	1	0.005-0.060
Irrigation			
Chloride	mg/l	205[b]	175-240
Electrical conductivity	μmhos/cm	950	920-1070
Sodium	mg/l	152[b]	25-170
SAR	mg/l	6.5[b]	0.8-6.5
Boron	μg/l	460	40-430
Copper	μg/l	16	3-4
Fluoride	μg/l	300	<100
Selenium	μg/l	7	1
Drinking			
Detergents	mg/l	1.4	<0 01-0 6
Hardness, as $CaCO_3$	mg/l	103	120-440
Calcium	mg/l	36	40-150
Nitrate, as N	mg/l	0.11	0 6-7
Fluoride	μg/l	300	<100
Copper	μg/l	16	3-4
Selenium	μg/l	7	1
Cadmium	μg/l	4	3
Lead	μg/l	25	10-25
Phenol	μg/l	5	<1-4

[a] Weighted average — January 1977 to December 1978
[b] Weighted average — January 1977 to August 1978
[c] Approximate average — June to September, 1977 and 1978
[d] Approximate average — December to March, 1977 and 1978
*Based on results from Tahal Laboratory, Azur

TABLE C-3. MUNICIPAL WASTEWATER CHARACTERISTICS (POUND AND CRITES, 1973)

Constituent	mg/L (except as noted)		
	Untreated Sewage	Typical Secondary Treatment Effluent	Actual Quality Applied to Land
Physical			
Total solids	700	425	760-1,200
Total suspended solids	200	25	10-100
Chemical			
Total dissolved solids	500	400	750-1,100
pH, units	7.0±0.5	7.0±0.5	6.8-8.1
BOD	200	25	10-42
COD	500	70	30-80
Total nitrogen	40	20	10-60
Nitrate-nitrogen	0	—	0-10
Ammonia-nitrogen	25	—	1-40
Total phosphorus	10	10	7.9-25
Chlorides	50	45	40-200
Sulfate	—	—	107-383
Alkalinity (CaCO$_3$)	100	—	200-700
Boron	—	1.0	0-1.0
Sodium	—	50	190-250
Potassium	—	14	10-40
Calcium	—	24	20-120
Magnesium	—	17	10-50
Sodium adsorption ratio	—	2.7	4.5-7.9
Biological			
Coliform organisms, MPN/100 ml	10^6	—	2.2-10^6
Virus PFu/L	0-10^4	0-10^2	—

Phosphorous is found in municipal sludges at lower concentrations than nitrogen. Phosphorous is not a threat to ground-water quality because phosphorous that is not immediately utilized by plants is attenuated through fixation by soils.

The heavy and trace metals content of sludge varies with the types of wastes accepted at treatment facilities. Heavy metals present in domestic sewage are derived from: 1) metals excreted by humans (including chromium, cobalt, copper, iron, manganese, molybdenum, selenium and zinc), 2) metals from the dissolution of plumbing (lead, copper, and zinc) and 3) metals present in storm runoff (cadmium, lead and zinc). A variety of heavy metals and trace constituents may be added by industrial wastes.

The metals of most concern for land application purposes include lead, copper, zinc, nickel and cadmium. The total concentration of these metals will limit the length of time an area may receive sludge. The removal of heavy metals in soils is dependent on the organic content of the soils, soil texture and pH. Metals are removed primarily through adsorption by anion and cation exchange or chelation by organic compounds (Knox, 1979). Certain metals are utilized by plants during the growth cycle, while others in increasing concentrations become toxic to both plants and humans that consume the plant products. Leaching of metals may occur when the sorption capacity of the soil is exceeded or when other chemical factors affect metal solubilities.

Pathogenic organisms, primarily bacteria and viruses associated with domestic sewage, may be present in municipal sludge. The ability of pathogens to contaminate ground water depends on survival and transport of the organism through the soil system. The survival of pathogenic organisms in the subsurface is influenced by organism type, soil texture, moisture temperature and the presence of antagonistic organisms (Keswick and Gerba, 1980; Knox, 1979; Gerba, 1985). The migration of pathogenic organisms is dependent on the permeability and composition of the soil and vadose zone, pH, subsurface flow rate and presence of soluble organics and cations. Research indicates that bacteria and virus removal occurs primarily through the processes of filtration and adsorption (Keswick and Gerba, 1980; Gerba, 1985). Despite the presence of these processes, bacteria and viruses have been detected in both the vadose zone and ground water beneath sludge application sites (Miller, 1980; Keswick and Gerba, 1980; Gerba, 1985). Stabilization or pre-treatment of sludge prior to application may significantly reduce the potential for the migration of pathogens into the subsurface. In some cases, land application of sludge has proven effective in removing certain bacteria and viruses (Freeze and Cherry, 1979; Bouwer, 1978; Miller, 1980; Knox, 1979).

Several industries commonly employ land spreading for the disposal of sludges and wastes. For example, the canned fruit and vegetable industry produce wastes such as simple carbohydrates, starch and cellulosic substances that are readily biodegradable. The petroleum refining industry generates sludges that contain not only oily wastes, but also oil-free sludges resulting from water conditioning. Chemical sludges are produced from the refining process, and biotreatment sludges are generated during the pretreatment waste processes. Many of these wastes are biodegradable by soil microorganisms or are useful for soil conditioning (Knowlton and Rucker, 1979). However, heavy metals present in refinery sludges may effectively limit land application of these wastes. Fly ash and water treatment additives are common wastes from the coal fired, steam electric power industry. Fly ash is often used as soil conditioner, but land application may be limited by the boron and heavy metal content of the ash. Wastes produced from the pulp and paper industry include natural organic compounds such as sugars, tannins, resins and lignins as well as inorganic sulfur compounds. Pulp and paper sludges are commonly land spread because of their biodegradability.

Salt Spreading

The application of large quantities of anti-skid sand and de-icing salt to improve winter driving conditions has become a common practice in many of the snowbelt states. Excessive salt application to highways has increased levels of chlorides, sodium and other related constituents in ground water. In addition to direct dissolution of the salts on the road surface and roadside by precipitation, accumulated snow piles along roadsides can release constituents during melting periods to road surface runoff.

The de-icing salts consist principally of commercial rock salt and marine salt (Bouwer, 1978). The addition of calcium chloride for chemical de-icing has become more widespread, particularly in Europe, due to its superior ice control properties. Common salt or sodium chloride is ineffective for melting ice below -12°C; whereas, the addition of calcium chloride extends the melting range to -29°C (Jones, 1981). As an additive to common salt, calcium chloride improves the rate and extent of melt, prevents freezing of sand-salt mixtures and reduces salt loss from mechancial bouncing off the road during application.

Other types of additives are commonly blended with the sand-salt mixtures to increase useability. Ferric ferrocyanide and sodium ferrocyanide are often added to sand-salt piles to minimize caking during storage and application (Field et al., 1973). Sodium ferrocyanide is water soluble and can generate cyanide in excessive concentrations in the presence of sunlight. Chromate and phosphates are also added to de-icing salts as corrosion inhibitors. Consequently, increased levels of sodium chromate, hexavalent chromium and table chromium were detected in snowbelt samples during the winter of 1965-66 in the Minneapolis - St. Paul area (Field et al., 1973).

A recent study suggests that certain elements present in sampled snowmelt could be correlated to the source of the sand and salt applied (Oberts, 1986). Increased levels of lead, zinc, phosphorous and total dissolved solids were detected in sand-salt mixtures sampled in the Minneapolis metropolitan area. The source of dissolved solids and phosphorous appeared to be related to local quarries where the sand was acquired. Levels of lead and zinc were correlated with salt concentrations in the sand/salt mixtures. The source of salt for the area was from various suppliers in the southern United States.

Serious ground-water contamination problems have occurred in many areas of the northern United States from the application of de-icing salts. The state of New Hampshire in 1965 reported replacement of over 200 roadside wells due to increased concentrations of chloride and sodium from contamination by road salts (Field et al., 1973). Road salt contamination has occurred in more than 60 communities in Massachusetts, as well as in Maine, Connecticut, Michigan and Ontario (Field et al., 1973; 1974; Pollock and Toler, 1973; Miller et al., 1974; Jones, 1981). Seasonal fluctuations in chloride concentrations have been documented due to infiltration of runoff during spring melt periods (Miller et al., 1974).

Alternative practices to reduce the amounts of de-icing salts applied to highways are currently being implemented and evaluated. These include the development of effective management strategies combined with optimum mixture and application plans as related to the physical conditions of weather and the road surface. Improved highway drainage systems to prevent the infiltration of road runoff are currently being evaluated in Massachusetts (Pollock and Stevens, 1985). The development of experimental road surfaces, such as Verglimit (a chemical defroster added to the upper layer of asphalt), which reduce the bonding of ice to road surfaces, may also allow for a reduction in the use of de-icing salts (Jones, 1981).

Animal Feedlots

Leachate from large quanitites of animal wastes at feedlots or seepage from animal waste lagoons are point sources of contamination. The principal contaminant from animal waste is nitrogen in the form of organic nitrogen or ammonium. Nitrogen in these forms is readily oxidized in the vadose zone to produce nitrates. Other contaminants of concern include phosphates, bacteria and chlorides. The characteristics of the contaminants generated from animal feedlots will vary depending on feedlot management practices, feeding methods, feedlot surface (paved or unpaved) and slope (Miller, 1980).

The most significant volume of wastes are produced by cattle feeding operations, however, sheep, poultry and hog operations also represent potential contamination sources. Cattle feedlot operations are concentrated throughout the Corn Belt and Northern Plains regions; poultry raising is located primarily in the South, hogs in the Midwest and sheep in the West and Southwest (Miller, 1980). The traditional disposal method for manure is land application as a fertilizer and soil conditioner.

The potential for contamination from feedlots is dependent on several factors including the stocking rate, manure removal management and waste treatment facilties. Natural factors such as depth to water, soil texture and permeability and the net recharge to ground water will also influence the occurrence of contamination. Frequent removal of manure combined with low stocking rates allows for increased aeration of manure, and thus higher rates of nitrate production (Walter et al., 1979). Infrequent removal of manure can alter the underlying soil characteristics by decreasing soil permeabiity and infiltration capacity (Miller, 1971; Powers et al., 1975). The development of an impermeable manure pack in addition to soil clogging can restrict infiltration of leachate. Studies suggest that the presence of anaerobic conditions beneath the pack allow denitrification and may limit the quanities of nitrate present in the ground water beneath the feedlots (Borman, 1981; Walker et al., 1979).

The variations in research regarding nitrate leaching may be explained partially through differences in soil properties. In general, coarse-textured soils have a greater potential for nitrate movement after waste application. Finer-textured soils that exhibit restricted drainage have a lower potential for nitrate leaching due to reduced infiltration or anaerobic conditions which cause denitrification (Powers et al., 1975). Another factor which affects the potential for nitrate leaching is climatic conditions. The potential for nitrate movement also increases with higher rates of waste application.

Contamination of ground water by phosphorous and bacteria beneath feedlots has not yet been documented. Phosphates bound to organic molecules or as nitrophosphates have low water solubilities. Bacteria populations in soils that receive applied wastes increase initially, then decrease with time (Kansas State University, 1975). Ground-water contamination from the leaching of nitrates, however, has been shown to occur under animal feedlots and land application sites (Powers et al., 1975; Reddell et al., 1973; Walker et al., 1979; Stewart et al., 1967; Lorimor et al., 1972; Ritter and Chirnside, 1984). A ground- water quality monitoring study in southern Delaware identified increased nitrate concentrations in ground water within 825 feet of poultry farms in several areas (Ritter and Chirnside, 1984). Increased levels of chlorides and copper in the ground water were also detected in the samples. The occurrence of these contaminants was correlated with the poultry farming practice; animal and human wastes both contain chlorides while copper is used in the broiler feed. Highest concentrations of all constituents were located in areas of well drained soils.

Fertilizers and Pesticides

The increased use of agricultural chemicals during the past decade to obtain greater crop yields has contributed to increased levels of nitrates and pesticides in ground water in the United States and other agricultural countries (Madison and Brunett, 1984; Hallberg, 1986; Holden, 1986). An accurate characterization of the overall impact from agricultural nonpoint source pollution has been difficult to assess due to the complex interaction between crop management and tillage practices, chemical type and application, and soil and climatic conditions.

Fertilizers

The addition of organic and inorganic fertilizers to agricultural lands supplements the natural supplies of nutrients in the soils necessary to sustain crop growth. Organic fertilizers, such as solid and liquid manure and compost, contain the essential nutrients (nitrogen, potassium and phosphorous), as well as important growth-stimulators and microbes necessary for proper utilization of the nutrients by plants (Houzim et al., 1986). Organic fertilizers typically account for 40 percent of the humus component in agricultural soils. Increased humus content of soils improves soil water capacity, adsorptive capability and resistance to acidification. Soils deprived of organic fertilizers exhibit losses in biological activity and fertility over time. Thus, organic fertilizers are combined with inorganic fertilizers to provide optimum growth conditions. Inorganic fertilizers include nutrients such as nitrogen, potash and phosphate and lesser amounts of fluorine, cadmium, calcium, magnesium, cobalt and molybdenum (Houzim et al., 1986). Lime and gypsum are also added to farmland to reduce cumulative soil acidity.

The solubility, adsorptive capability, decomposition and mobility of fertilizers directly influence fertilizer impact on ground-water quality. Most nitrogen fertilizers do not readily adsorb into soils and are moderately to very soluble in water; thus, they are quickly leached to the ground water under a variety of conditions and constitute a major concern for contamination in agricultural areas (Hallberg, 1986). Granulated, coated and multi-component fertilizers dissolve more slowly than pulverized fertilizers. Phosphates and potash not assimilated by plants are readily sorbed onto clay particles or complexed with humus (Houzim et al., 1986; CAST, 1985; Letey and Pratt, 1984).

Nitrogen movement through the biosphere is controlled by a series of complex processes. In general, most crops utilize nitrogen in the inorganic form of nitrate or ammonium. Organic nitrogen in the soil is transformed into inorganic forms by microorganisms. Ammonium is the first transformation compound. In the presence of oxygen, the subsequent transformation to nitrate will occur. Nitrate not utilized by crops will either continue to leach through the soils under aerobic conditions, or be converted to nitrogen gas through denitrification under anaerobic conditions.

Ground-water contamination problems are thus manifested when nitrate concentrations in soils exceed crop uptake and significant nitrate losses occur beneath the root zone. Recent studies indicate that nitrogen recovery by agronomic crops seldom exceeds 50 percent of available nitrogen and more typically approximates 35 percent or less for grain crops (Hallberg, 1986). Extensive research over the past several years has clearly shown a direct relationship between excessive nitrogen fertilization and subsequent increases in nitrogen concentrations in ground water, particularly in shallow, fresh water aquifers (CAST, 1985; Pionke and Urban, 1985; Beck et al., 1985; Thompson et al., 1986; Libra et al., 1986; Ritter, 1984). Results of these studies indicate that three major factors affect the concentration of nitrate which reaches the ground water including: 1) the amount of nitrogen available, 2) the quantity of infiltrating water (dependent on the hydraulic conductivity of the materials), and 3) the presence of denitrification processes in the subsurface.

Increases in nitrogen concentrations have been related to agricultural land practices in many areas of the United States (Beck et al., 1985; CAST, 1985; Letey and Pratt, 1984; Alberts and Spomer, 1985; Thompson et al., 1986; Libra et al., 1986; Bruck, 1986; Detroy, 1986; Gburek et al., 1986; Ritter, 1984; Pionke and Urban, 1985). The implementation of best management practices to reduce the quanitites of nitrate available for leaching have been studied. Suggested practices for nitrate reduction include the determination of residual soil nitrates in the crop and rooting zone coupled with the application of nitrogen during periods of greatest crop intake (Olson, 1986; OTA, 1984). A study involving nine Iowa farmers showed how potential nutrient losses could be reduced by establishing realistic yield goals in conjunction with best management practices (Kaap, 1986). Other practices include improved irrigation water management to prevent excessive percolation (Hubbard et al., 1984) and the use of compounds which inhibit the oxidation of fertilizer ammonium to nitrate by microorganisms (Bremner et al., 1986). Agricultural practices such as cropping and tillage can also affect nitrate losses to the subsurface. The continuous culture of nonleguminous crops, such as corn and cotton, promotes the increased use of nitrogen fertilizers thus affecting nitrogen losses through leaching to ground water. Losses of nitrate can be minimized by alternating the planting of nonleguminous crops with soybeans, which utilize both organic and inorganic nitrogen and do not require additional nitrogen fertilization (CAST, 1985). Some studies suggest that the implementation of conservation or no-tillage practices serve to increase nitrate leaching (CAST, 1985; Thomas, 1983; Alberts and Spomer, 1985; Baker and Laflen, 1983). Conventional tillage enhances the release of nitrate from organic matter, but also promotes soil erosion. Conversely, while conservation tillage reduces soil erosion, the soil moisture is increased, and evaporation decreases (Blevins et al., 1983). Although less nitrate is released than soil organic matter, increased infiltration rates under conservation tillage fields provides the conditions for greater losses of nitrate to the ground water. In addition, conservation tillage minimizes the disturbance of soil structure thereby enhancing surface water infiltration through soil macropores (Thomas, 1983; Dick et al., 1986).

Pesticides

Pesticides are chemicals used for the control of insects, fungi or other undesirable organisms and weeds. At the beginning of the century, the use of mercury and arsenical compounds for pest control became widespread. Pesticide usage rapidly increased with the advent of new synthetic organic compounds. There are currently more than 32,000 different compounds with over 1800 active ingredients now used for agricultural applications (Houzim et al., 1986). Recent United States Environmental Protection Agency studies cite the presence of more than 50,000 different formulated products with only 1200 active ingredients (personal communication, Stuart Cohen, Biospherics, Inc., 1987). Agricultural activities account for 69 to 72 percent of pesticide use; government agencies and industries use 21 percent; home and garden uses constitute the remainder.

Despite the large quantities of pesticides applied yearly to agricultural lands, public attention had focused on other sources of toxic chemicals found in ground and surface water. Contamination from pesticides was largely unexpected; those pesticides in use were assumed to degrade or volatize rapidly, or to bind to soil particles (Holden, 1986). The discovery of DBCP (dibromochloropropane) and aldicarb in wells in California and New York respectively, in 1979, prompted extensive ground-water monitoring for pesticides which has led to the discovery of at least 17 pesticides in ground water in 23 states (Table C-4) (Cohen et al., 1986).

TABLE C-4. TYPICAL POSITIVE RESULTS OF PESTICIDE GROUND-WATER MONITORING IN THE U.S.† (COHEN ET AL., 1986)

Pesticide	Use*	State(s)	Typical Positive, ppb
Alachlor	H	MD, IA, NE, PA	0.1-10
Aldicarb (sulfoxide and sulfone)	I, N	AR, AZ, CA, FL, MA, ME, NC, NJ, NY, OR, RI, TX, VA, WA, WI	1-50
Atrazine	H	PA, IA, NE, WI, MD	0.3-3
Bromacil	H	FL	300
Carbofuran	I, N	NY, WI, MD	1-50
Cyanazine	H	IA, PA	0.1-1.0
DBCP	N	AZ, CA, HI, MD, SC	0.02-20
DCPA (and acid products)	H	NY	50-700
1,2-Dichloropropane	N	CA, MD, NY, WA	1-50
Dinoseb	H	NY	1-5
Dyfonate	I	IA	0.1
EDB	N	CA, FL, GA, SC, WA, AZ, MA, CT	0.05-20
Metolachlor	H	IA, PA	0.1-0.4
Metribuzin	H	IA	1.0-4.3
Oxamyl	I, N	NY, RI	5-65
Simazine	H	CA, PA, MD	0.2-3.0
1,2,3-Trichloropropane	N (impurity)	CA, HI	0.1-5.0

†Total of 17 different pesticides in a total of 23 different states.

* H = herbicide
I = insecticide
N = nematicide

Numerous studies now document the relationship between the use of agricultural chemicals and their occurrence in ground water, particularly in areas located over shallow unconfined aquifers with permeable soils throughout the country (Holden, 1986; Cohen et al., 1984; Cohen et al., 1986; Hallberg et al., 1986; Welling et al., 1986; Schmidt, 1986; Steichen et al., 1986; Pionke et al., 1986; Wehtje et al., 1984; Kelley et al., 1986; Harkin et al., 1986; Miller and Fischer, 1986; Tolman and Neil, 1986; Marin and Droste, 1986; Scarano, 1986). Pesticide contamination has also been found in other hydrogeologically vulnerable areas such as karst terrains (Leonard, 1986; Holden, 1986). In contrast, a recent sampling of irrigation wells over time in intensively agricultural areas of silt loam to clay soils in Arkansas revealed no positive presence of pesticides in the ground water (Lavy et al., 1985).

Attempts to accurately characterize pesticide fate and movement have been complicated by the wide variability in soil and vadose zone properties, climate, agronomic management and the physical and chemical nature of every pesticide. Seiber (1983) has grouped behavior and fate processes according to three major components including: 1) the environmental compartments (i.e. air, soil, water) in which the pesticide is found; 2) the transfer processes which affect pesticide movement, and 3) attenuation by transformation processes (i.e. chemical and biological degradation. Table C-5 lists the major factors which affect the fate and movement of various pesticides based on their chemical classification.

The properties of the soil media and the external effects of climate both influence the movement and transformation of pesticides in the soil. The adsorptive capabilities of soil colloids and organic matter has been recognized as an important factor in the attenuation of ionic and nonionic pesticides (Helling, 1986; Helling and Gish, 1985; Weber and Weed, 1974; Weber, 1972). Soil texture and the hydraulic conductivity of the soil also affect pesticide leaching. Studies confirm that a pesticide introduced into sandy coarse-textured soils will penetrate farther and faster than in finer-textured soils (Helling and Gish, 1985; Weber and Weed, 1974; Helling, 1986). The presence of soil structure, (in particular, the role of macropores), is being recognized as a possible rapid transport mechanism which reduces the opportunity for significant attenuation processes to take effect (Thomas and Phillips, 1979; Shaffer et al., 1979). Preferential flow through soil structure has been found to occur in all types of soils and accounts for solute transport several times greater than that recognized by traditional transport theories. Agronomic practices such as conservation or no-tillage, which advocates minimal soil disturbance has been shown to promote the development of extensive macropores in the soils. The presence of the macropores was related to increased infiltration rates in those fields under study (Dick et al., 1986; Gish et al., 1986).

Increasing soil moisture content is generally associated with increased adsorption and degradation. The moisture and temperature of the soil and soil pH, combined with climatic effects also influence pesticide behavior directly through adsorption, volatilization and photo decompositon, and indirectly through the chemical and microbial degradation processes (Weber and Weed, 1974).

The transfer and transformation processes which affect pesticides are dependent on the physiochemical nature of the pesticide and the interaction of these factors with the soil and climatic system. These processes have been reviewed by Sieber (1983), Cheng and Koskinen (1985) and Helling (1986). The significant properties which affect pesticide behavior include: ionizability, water solubility, volatility, presence of functional groups, molecular size and stability (Weber, 1972). The leaching of pesticides to ground water involves the consideration of both adsorption and degradation. In general, pesticides which are absorbed by the soil are not readily available for leaching; those pesticides not strongly absorbed are then susceptible to microbial and chemical degradation. For most pesticide groups, the adsorptive capacity is directly related to solubility; as pesticide solubility increases, adsorption to soil colloids and organic matter decreases (Houzim, et al., 1986). Cohen et al. (1984) suggest that pesticides with the following mobility and persistence properties have the greatest potential to leach to ground-water: 1) water solubilities greater than 30 parts per million, 2) soil binding constants (Kd values) less than 5, 3) root zone half lives greater than 2 to 3 weeks and 4) hydrolysis half lives of less than 6 months. Table C-5, Column 11 ranks the mobility of various pesticides according to various groups.

Pesticide fate is also influenced by agronomic practices such as tillage and irrigation. As previously discussed, tillage practices directly influence runoff and infiltration of pesticides. Extensive irrigation of fields also has been associated with increased pesticide leaching below the root zone (Helling, 1986). The use of improved irrigation practices such as drip irrigation, helps prevent excessive water percolation and subsequent pesticide movement into the subsurface.

Accidental Spills

A variety of hazardous and non-hazardous materials are transported throughout the country by truck, rail and aircraft and transferred at handling facilities such as airports and loading docks. Improper handling or accidents often results in spills of these solutions. Ground-water contamination resulting from these spills constitutes a significant problem which only recently has received attention by state, federal and industrial authorities. The National Academy of Sciences (NAS) estimates that approximately 16,000 spills occur annually, involving a variety of materials such as hydrocarbons (i.e. gasoline and jet fuel), paint products, flammable compounds, various acids and anhydrous ammonia (NAS, 1983). Of all accidental releases, petroleum products are the most frequently spilled or leaked (U.S. EPA, 1979b).

The potential impacts of an accidental spill on ground-water quality depends on: 1) the site specific hydrogeologic conditions, 2) the natural capacity for attenuation and/or degradation of the natural materials at the site, 3) the characteristics of the chemical(s) spilled, and 4) any remedial actions undertaken by authorities at the time of the spill.

TABLE C-5. FACTORS AFFECTING ADSORPTION OF SELECTED GROUPS OF PESTICIDES AND THEIR LEACHING INTO GROUND WATER (HOUZIM ET AL, 1986)

1	2	3	4	5	6	7	8	9	10	11
		Adsorption to		Bond to						
Chemical Group	Adsorption Mechanism	Organic Matter	Clay Minerals	Organic Matter	Clay Minerals	Soil pH Effect	Soil Water Content Effect	Solubility in Water at 20-25 C	Persistence in Soil (Half-life) in days	Mobility
I Ionic Pest										
1 Cationic Pest	e/d/g	+ d/	+ e/d	strong	very strong	small	positive small	high	4000 - 5000	1
2 Acidic Pest	f/g	+	-	weak	very weak	$>pK_a$	positive considerable	high at greater pH	10 - 140	4 5
3 Basic Pest	c/d/e/f/g/	+ c/d/e/f/	+ d/e/	weak	medium	$<pK_b$	positive medium	high at lower pH	25 - 400	2 3
4 Miscellaneous Ionic Pest	g/	+	-	weak	almost none	varies	positive considerable high		170 - 350	4 5
II Nonionic Pest										
5 Chlorinated Hydrocarbons	a/b/d/	+ a/d/	+	very strong	weak	none	positive small	low	460 - 1650	1
6 Organophosph	a/b/c/d/e	+ b/d/	+ c/	very strong	medium	<7 small	positive considerable	considerable	0 9 - 60	1
7 Substituted Anilines	a/b/d/	+ b/d/	+	strong	weak	none	negative considerable	low	45 - 180	1
8 Phenylureas	a/b/c/d/f/	+ b/d/	+ c/f/	medium	weak	<7 small	pos , consid	low to medium	120 - 400	2 3
9 Phenylcarbonates and Carbonates	a/b/c/d/	+ b/d/	- c/	medium	weak	<7 small	positive considerable	considerable	10 - 70	2 3
10 Amides	a/b/d/	+ b/d/	-	weak	very weak	none	pos , medium	medium	30 - 70	3
11 Thiocarbonates Carbothioates Acetamides	a/b/d/	+ b/d/	+	strong	medium	none	positive considerable	medium	30 - 220	2
12 Phenylamides	a/b/d/	+ b/d/	-	strong	weak	none	pos , medium	medium	300 - 400	2
13 Benzonitriles	a/b/d/	+ b/d/	+	strong	medium	none	pos , medium	medium	60 - 180	2

Column 2
a/ Van der Waals attractions
b/ Hydrophobic bonding
c/ Hydrogen bonding
d/ Charge transfer
e/ Ion exchange
f/ Ligand exchange
g/ Ion-dipole and dipole-dipole

Column 3, 4
+ adsorption exists
- adsorption low or none

Column 7
pH effect understood in the sense of adsorption increase

Column 8
Soil water content understood in the sense of adsorption increase

Column 11
1 = immobile pesticides
2 = poorly mobile pesticides
3 = mobile pesticides
4 = highly mobile pesticides
5 = extremely mobile pesticides

Documentation on spill incidents which includes information about the cause, chemical name, volume spilled and suspected or documented pre-existing contamination problems is usually insufficient. In many cases, little emphasis is placed on ground-water protection during spill clean-up activities until contaminants are detected in nearby domestic or municipal water supply wells.

Reported spill volumes range from a few gallons to several million gallons. Current methods to quickly and adequately clean up spills have improved over the past few years but are still limited to quick response to contain and recover the substance. For example, spill areas are frequently flushed with water to quickly remove spilled liquid. This is particularly true in tanker truck accidents where removal of the spilled liquids from road surfaces helps prevent further hazards to life and property. However, these contaminants then infiltrate through adjacent soils and may possibly contaminate ground-water supplies.

A successful program for spill remediation involves several steps for containment and recovery of the contaminant. This was illustrated during an actual spill of 130,000 gallons of organic chemicals which entered a shallow unconfined aquifer (Ohneck and Gardner, 1982). Initial action at the site involved immediate containment and collection of the surface liquids. Chemicals were then properly identified for disposal. Air monitoring systems were established to identify the presence of toxic fumes. Information was collected on the hydrogeology of the site and test borings were performed to identify the extent of the contamination. Monitoring wells were installed to determine site specific hydrogeologic characterisitcs and for later use in ground-water sampling. An effective in-situ reclamation program combined with a ground-water recovery and treatment program resulted in complete clean-up of the spill site. Other successful cases of accidental spill clean ups of organic chemicals have been documented by Harsh (1975) and Sterret, et al. (1985).

Particulate Matter from Airborne Sources

Fallout of particulate matter from the atmosphere is a relatively minor, but potential source of ground-water contamination. Particulate materials fall to the surface of the earth and are transferred as soluble or insoluble products by water to the subsurface. The primary source of atmospheric pollution is automobile emissions and various industrial processes. The major contaminants from these emissions include sulfur and nitrogen compounds, asbestos and heavy metals (Owe et al., 1982). The distribution of particulates in the atmosphere and on the surface depends on their size when released, weather patterns and climate. The attenuation of these pollutants depends on the site-specific hydrogeochemical characterisitics, location of pollutant fallout and chemical nature of the pollutant.

The infiltration of airborne contaminants is typically higher in heavily industrialized areas (Lehr, et al., 1976). Concentrations of lead, cadmium and mercury which exceeded EPA maximum allowable concentrations in drinking water have been detected in the precipitation of mountain regions of New England. Precipitation recharging the aquifers in these areas could lead to potential contamination of these aquifers (Miller, 1980). Airborne chromium from an electroplating firm in Michigan has been suspected as a source of ground-water contamination of nearby wells. Chromium-laden dust discharged through ventilators on the roof and settled to the ground. The dust was carried by precipitation into the subsurface where it directly impacted the ground-water quality (Deutsch, 1963).

The major environmental concern today related to airborne contaminants is the effect of acid rain on the surface and subsurface water quality. Acid rain is divided into two categories, wet deposition or dry deposition. Wet deposition refers to atmospheric pollutants that are deposited with rain and snow in the form of acids (mainly sulfuric and nitric). Dry deposition includes those solid or gaseous pollutants deposited on the surface of the earth (Hubert and Canter, 1980). The occurrence of acid rain near heavily industrialized and urbanized areas has impacted vegetation and surface-water quality. Infiltration of acid precipitation and the solubilization of dry particulates which may be transported to the ground water can impact ground-water quality. The potential effects of sulfur/sulfur dioxide compounds, nitrogen/nitrogen dioxide compounds, hydrogen ions and heavy metals in acid rain as they enter the ground water will decrease the pH of the water and raise the concentrations of these compounds above safe consumption levels (Hubert and Canter, 1980). These substances may also undergo secondary and tertiary reactions in the subsurface to form other potentially toxic compounds.

GROUND WATER QUALITY PROBLEMS THAT ORIGINATE IN THE GROUND ABOVE THE WATER TABLE

Septic Systems, Cesspools and Privies

On-site sewage disposal systems are used to treat and dispose the domestic wastewater from approximately one-third of the homes in the United States. Each year, an estimated one trillion gallons of effluent is discharged into the environment by approximately 22 million on-site sewage disposal systems (U.S. EPA, 1986c). Of these individual on-site disposal units, conventional septic tank-soil absorption systems constitute 85 percent of the systems in use, while alternative systems (i.e. aerobic treatment systems, filter beds, mounds, etc.) and unregulated systems (i.e. cesspools) comprise the rest (Scalf et al., 1977).

The basic on-site sewage disposal system consists of a septic tank with an accompanying soil absorption and treatment field. The septic tank separates the floating and settable solids from the liquid portion of the wastewater. Solids settling to the bottom of the tank (i.e. sludge) undergo partial anaerobic decomposition in the tank. Sludge builds up in the tank and must be periodically removed to prevent these solids from discharging out of the tank along with the liquid effluent. Septic tanks typically are designed and sized to retain the anticipated daily volume of wastewater from the home for 24 to 48 hours. This is accomplished by using a single compartment tank, double portioned tank or multiple single compartments tanks in series. These latter tank designs are favored for their improved solids removal capabilities (Canter and Knox, 1985). Septic tanks may be constructed from a variety of materials, including reinforced concrete, steel, plastic or fiberglass. The effluent from the septic tank discharges into a soil absorption and treatment field. The soil absorption and treatment field is designed to distribute the septic tank effluent into the soil for final treatment and disposal. Soil absorption and treatment fields are commonly designed as gravel-lined trenches or beds containing perforated distribution tile or pipe (Canter and Knox, 1985). Seepage pits, above-ground mounds or other innovative designs may also be used in lieu of conventional soil absorption fields.

On-site sewage disposal systems provide safe and effective disposal of domestic waste when the system is correctly designed, installed, operated, maintained and located in appropriate environment conditions. However, sewage effluent may be a significant potential source of ground-water contamination where regulations do not adequately address these elements or where proper regulations are inadequately enforced. The potential for ground-water contamination by on-site systems may also exist where the density of these systems exceeds the capacity of the soil to adequately treat the sewage effluent before it reaches the ground water. This is especially a concern with certain soluble salts, such as chlorides, nitrates and sulfates, which are not readily removed by the soil treatment and absorption system. Canter and Knox (1985) estimate that septic system densities exceeding 40 systems per square mile may constitute a significant potential ground-water contamination problem.

General site criteria must be examined prior to designing and locating the on-site system. Suitability of the soil for treating and disposing of wastewater is often evaluated by digging soil test pits and/or conducting percolation tests. Soil test pits are used to evaluate soil properties, such as texture and structure, the occurrence of seasonally high water tables or perched water tables, depth to bedrock and depth to apparent ground-water. Percolation tests may also be conducted as a rough, empirical method of evaluating the capability of the soil to absorb sewage effluent. In general, a minimum depth of four feet of permeable, unsaturated soil should be present between the bottom of the absorption trench or bed and the top of the seasonal water table and/or bedrock (Scalf et al., 1977). Proper isolation distances between septic tanks and water wells must be maintained to prevent contamination of domestic water wells by the sewage effluent.

The potential for ground-water contamination by septic tanks depends on the quality of the effluent discharging from the system and the capacity for the soils and unsaturated zone materials to effectively attenuate and degrade these substances. Wastewater constituents which are a primary concern to ground-water quality include biological contaminants (i.e. bacteria and viruses), phosphates, nitrates, heavy metals, and synthetic organic and inorganic compounds. The transport and fate of these contaminants depends on the efficiency of the physical, chemical and biological attenuation mechanisms in the unsaturated zone including filtration, adsorption and microbial degradation.

Biological contamination of ground water from septic systems is widely recognized. Bacterial movement in unsaturated soils is generally limited by the physical filtering capability of the soils and adsorption onto soil particles. The filtration and adsorptive capacity of the soil depends on various soil factors including: soil pH, moisture content, temperature, oxidation-reduction potential, the size and shape of interstitial voids of the soil and the permability and related velocity of flow through the soil (Canter and Knox, 1985; Bauder, 1984). Unsaturated flow conditions beneath the absorption trench or bed provide increased contact and detention time between the bacteria and the soil (Hackett, 1984). Bacteria survival times depend on several soil conditions, including pH, temperature and moisture content. Survival times of up to 2 to 3 months in soil have been documented (Gerba et al., 1975). These extended survival times of bacteria are important when considering that bacteria adsorbed to the soil particles beneath the adsorption trench can remain viable and penetrate deeper into the soil should suitable flow conditions develop (Hackett, 1984).

With regard to other potential wastewater pollutants, phosphorus is typically attenuated by chemical precipitation and adsorption. Ammonium is removed primarily through adsorption, cation exchange or volatilization. Nitrogen and ammonium converted to nitrates move readily through the soil system unless other processes such as denitrification or uptake by plants occur. Heavy metals discharged in septic effluent may be attenuated by the soils through adsorption, ion exchange, chemical precipitation and complexation with organic substances (Canter and Knox, 1985). Synthetic organic compounds from various household wastes may be attenuated through the physical and chemical processes of adsorption, hydrolysis, complexation, volatilization, and most importantly by microbial degradation. One of the most frequently detected contaminants in ground water, trichloroethylene (an industrial solvent and degreaser), is also used as a septic tank cleaner.

In order to provide effective removal of wastewater contaminants, proper septic system design and soil conditions must exist. Contamination of both regional and localized ground water due to septic system discharges has been documented (Canter and Knox, 1985; Flipse et al., 1984; Scalf et al., 1977). Contamination problems commonly occur from improper construction and maintenance causing a significant percentage of systems to fail prior to their expected design life (Scalf et al., 1977). The direct discharge of untreated sewage wastes into gravel beds, fractured bedrock or solution channels which is still practiced in some areas of the United States may also cause ground-water contamination. Other contamination problems occur when the soil adsorption systems are located beneath the biologically active zone, effectively excluding the process of biological degradation. High densities of septic tanks in areas where permeable soils exist have caused regional contamination of aquifers in Nassau and Suffolk Counties, New York, and in Dade County, Florida (Flipse et al., 1984). The installation of public sewers in high density septic system areas will alleviate some ground-water contamination problems but at a considerable cost. Other alternatives to improve septic systems and help prevent degradation of ground-water quality include the use of specialized systems such as percolation and evapotranspiration mounds in areas with thin or unsuitable soils or in areas of fractured or impermeable strata.

Surface Impoundments and Lagoons

Surface impoundments are used by farms, industries and municipalities for the treatment, retention, and/or disposal of non-hazardous and hazardous liquid wastes. Holding ponds, surface impoundments and lagoons present a significant potential for ground-water contamination because of their relative numbers and size. A recent Surface Impoundment Assessment (SIA), conducted by the U.S. Environmental Protection Agency, located over 180,000 impoundments at approximately 80,000 sites (U.S. EPA, 1983). Table C-6 lists six major categories which show the nationwide distribution of sites and impoundments, both active and abandoned. Agricultural impoundments are associated with farming, crop production and animal husbandry. Uses of impoundments on farms range from manure and dairy waste lagoons to fish hatcheries. Municipal impoundments are utilized at water and sewage treatment plants and at sanitary landfills. Industrial impoundments are primarily used for the storage, processing, treatment or disposal of industrial wastes. Oil and gas impoundments contain brines associated with oil and gas extraction. Impoundments at mining sites are used for ore refinement processes and mine wastewater treatment.

TABLE C-6. CATEGORIZATION AND TOTALS OF IMPOUNDMENT SITES FROM THE SURFACE IMPOUNDMENT ASSESSMENT (U.S. EPA, 1983)

	Active Sites	Active Impoundments	Abandoned Sites	Abandoned Impoundments
Agricultural	14,677	19,167	173	270
Municipal	19,116	36,179	630	1,006
Industrial	10,819	25,749	941	2,163
Mining	7,100	24,451	264	587
Oil and Gas	24,527	64,951	463	537
Other	1,500	5,745	53	168
TOTAL	77,739	176,242	2,524	4,731

Total Located Sites 80,263
Total Located Impoundments 180,973

Impoundments or lagoons may range in depth from two feet to more than 30 feet and range in size from a fraction of an acre to thousands of acres (OTA, 1984). Agricultural, municipal and oil and gas impoundments typically are less than five acres in size. The size of industrial impoundments may vary, however, from less than a tenth of an acre to over 100 acres. The mining, pulp and paper, and electrical utility industries operate some of the largest impoundments (U.S. EPA, 1978b).

Waste impoundments may be either natural or man-made depressions, and may or may not be lined. The overflow from many impoundments is discharged either periodically or continuously to surface water bodies, such as streams, rivers, lakes and oceans. Some impoundments are designed to permit seepage of fluids into the subsurface. Seepage impoundments typically are unlined and located in permeable materials. Other impoundments are designed to reduce liquid volumes through evaporation. Many evaporation impoundments, however, lose liquid volumes through seepage as opposed to evaporation. Impoundments used for waste storage and/or treatment are commonly lined either with clay, admixed liners (such as hydraulic asphalt concrete and soil cements), flexible polymeric membranes, sprayed-on linings, soil sealants and chemical adsorptive liners to prevent seepage into the subsurface (U.S. EPA, 1980). Certain types of waste fluids may effect liner integrity; therefore, the material chosen for a liner must be compatible with the waste fluids which will come in contact with the liner.

Ground-water contamination from surface impoundments commonly occurs from seepage of wastes into the subsurface. Seepage typically occurs when impoundments are unlined and the underlying materials are sufficiently permeable to accept and transport the liquid wastes. Impoundments with supposedly "impermeable" clay liners, however, have also been shown to leak significant quantities of wastes for a variety of reasons. At some sites, waste chemicals have affected the integrity of clay liners through chemical reactions resulting in a more permeable clay liner which allows the seepage of wastes into the subsurface (U.S. EPA, 1980; U.S. EPA, 1983). Other causes of liner failure have been attributed to improper construction and installation of the liner. Ground-water contamination from wastes in lined impoundments has also resulted from unanticipated overflows or loss of the liquid wastes from the impoundments as a result of failure of a dike. In other instances, ground-water contamination has occurred where impoundments were located in karstic areas. Catastrophic collapse of surface materials, involving solution channels or sinkhole enlargements has resulted in the loss of wastes from impoundments into the subsurface. Ground-water contamination has also occurred where liquids in the impoundment were in direct contact with the water table.

Incidents of ground-water contamination from surface impoundments have been reported in nearly every state and in most cases have affected shallow, unconfined aquifers. The contamination typically is in the form of a discrete plume that is elongated in the direction of ground-water flow. The pattern and flow of the plume depends on the ground-water gradient, vertical and horizontal permeabilities, amount of recharge, physical and chemical properties of the contaminant and the affects of nearby pumping wells. Attenuation and degradation of contaminants can occur due to various physical, chemical and microbial processes related to vadose and saturated zone conditions.

Data collected during the Surface Impoundment Assessment indicate that nearly 50 percent of all sites are located over saturated zones that are either very thin or very permeable, and that over 50 percent of the impoundments at these sites contain industrial wastes (U.S. EPA, 1983). Approximately 70 percent of all sites are located over very thick, permeable aquifers, with nearly 80 percent of the impoundments at these sites containing industrial wastes. The assessment also revealed that 98 percent of the sites located over thick, permeable aquifers are also located within one mile of potential drinking water supplies. This data indicates the great potential for ground-water contamination by waste liquids contained within impoundments.

In an effort to minimize future impacts to ground-water quality, recent amendments to RCRA require increased levels of leak protection at impoundments receiving hazardous wastes. Existing impoundments and newly installed impoundments must have a double liner and leachate collection system as well as a ground-water monitoring system to detect releases into the ground water.

Landfills

Landfills accept various types of solid wastes, both hazardous and non-hazardous. Solid wastes not classified as hazardous under RCRA regulations generally are disposed of in municipal and sanitary landfills and dumps. Subtitle D under the Resource Conservation and Recovery Act regulates these types of solid waste management facilities. According to 1979 data, there are approximately 18,500 municipal landfills and 75,700 industrial landfills subject to Subtitle D regulations (Lehman, 1986). It is estimated that 15 to 20 percent of these facilities receive household hazardous waste or industrial or commercial hazardous wastes from small-quanitity generators. Municipal and sanitary landfills regulated under Subtitle D typically receive solid waste products from residences, small industries and commercial activities that are usually non-hazardous. Potential contamination problems from these facilities occur when contaminants leach from the landfills into the ground water. Of the total known landfills (94,200) only about 5600 facilities were licensed landfills in 1979, while the rest were open dumps (Petersen, 1983).

Typical landfill construction and operation involves the spreading of wastes in thin layers, compacting the wastes to the smallest volume, and then applying and compacting cover material to minimize scavenger, aesthetic, vector and air pollution problems. A sanitary landfill is an engineered facility that is constructed and operated to minimize environmental hazards. Careful design, construction and operation of the landfill, combined with proper maintenance during facility closure, can minimize potential impacts to ground-water quality from the landfill wastes.

Landfills are constructed by three common methods; the area, ramp and trench methods (O'Leary and Tansel, 1986a). In the area method, the landfill is placed in a natural depression or man-made excavation. The waste is placed on the ground surface or landfill liner and compacted. Successive layers of compacted wastes are built to a height of 10 or 15 feet. An intermediate cover of soil or synthetic material is usually emplaced on the top and exposed sides of the compacted waste at the end of each day. A completely covered compacted waste unit is called a "cell"; a series of cells the same height constitutes a "lift." A completed landfill may consist of several vertical lifts that extend 50 to 100 feet above the original landfill surface. Appropriate soil and/or synthetic materials are used to cover the finished landfill. The ramp method commonly is utilized in sloping areas; wastes are spread and compacted on a slope and cover materials are compacted on the waste. The trench method may be used on level or sloping land; the land is excavated in trenches, and wastes are emplaced in the trenches and covered. Trenches are parallel and separated by a three to four-foot dirt wall. The degree of waste compaction will affect the final capacity of the landfill and the waste to soil ratio.

The design and development of a landfill involves the consideration of five phases: 1) site selection, 2) detailed plan design, 3) construction and operation, 4) landfill closure and 5) monitoring and long term care. (Brunner and Keller, 1972). During each phase, the landfilling techniques, waste stabilization processes and environmental impacts must be considered. Methods of operation should assure minimal impacts from litter, pests, scavengers, fire, odors, methane gas and leachate.

After the solid wastes are placed in the landfill, physical, chemical and biological processes begin to act upon the waste. Initial physical changes involve settlement and compaction. Water contained within the waste combines with infiltrated water which may dissolve soluble substances to form leachate. Chemical and microbial reactions occurring within the landfill initially involve aerobic decomposition that produces volatile acids and low pH conditions, which can solubulize constituents in the waste. Later stages of decomposition involve anaerobic processes which produce methane gas in addition to leachate (O'Leary and Tansel, 1986a). Moisture content, temperature, soil cover permeability, rainfall, the resistance of the wastes to degradation and the type of waste processing prior to landfilling, are all factors which affect the rate and extent of decomposition within a landfill. Various models have been developed to predict leachate generation based on these factors. One of these models, the Hydrologic Evaluation of Landfill Performance Model (HELP) (U.S. EPA, 1984), was developed to predict leachate generation under a variety of climatic and cover conditions. Leachate composition will vary widely depending on the nature of the refuse, the leaching rate and the age of the fill (O'Leary and Tansel, 1986b; Stegman, 1982). Table C-7 lists the chemical characteristics of leachate from municipal solid waste, as well as the typical concentration values and the reported range of concentration values for these chemicals.

TABLE C-7. SUMMARY OF MUNICIPAL SOLID WASTE LEACHATE CHEMICAL CHARACTERISTICS (KMET AND MCGINLEY, 1982)

	Typical Values	Range Reported Literature Range (mg/l)	Parameters (mg/l)
T. Alkalinity	50	500-10,000	0-20, 850
Arsenic	34	ND-0.4	ND-40
5 Day BOD	876	400-40,000	9-54, 610
Boron	2		0 42-70
Cadmium	53	ND-0.10	ND-1 16
Calcium	7		5-7,200
Chloride	98	100-2,500	5-4,350
T. Chromium	42	ND-1 0	ND-22.5
Hex Chromium	3		ND-0 06
COD	108	500-50,000	0-89, 520
Conductivity[1]	352	1,000-20,000	2,810-16,800
Copper	41	ND-0 5	ND-9 9
Cyanide	27	ND-0.40	ND-0 08
Fluoride	1		0.1-1.3
Hardness	92	500-10,000	0-22,800
Iron	88	ND-500	0.2-42,000
Lead	46	ND-1 2	ND-6 6
Magnesium	7		12-15,600
Manganese	19	ND-10	0 06-678
Mercury	24	ND-0.005	ND-0.16
Ammonia-N	28	0-350	0-1,250
TKN	32	25-1,500	
Nitrate + Nitrate	36	0-10	0-10 29
Nickel	40	ND-3 3	ND-1 7
Phenol	20	2-20	0 17-6 6
T. Phosphorus	92	0-10	0-130
pH[2]	432	5.7-7 6	1 5-9.5
TSS	812	100-1,000	6-3,670
Zinc	38	ND-75	0-1,000

[1] μmho/cm

[2] Standard Units

Depending on the subsurface conditions, leachate that reaches the base of a landfill may seep into and contaminate the ground water. Natural attenuation and degradation may occur through mechanical filtration, precipitation, adsorption, dilution and dispersion, volatilization and microbial degradation. The efficiency of these mechanisms depends on the physical and chemical conditions within the landfill and the unsaturated zone. The degree of attenuation may fluctuate in response to changes in climatic conditions and landfill/leachate decomposition phases.

The impacts on ground-water quality by wastes from landfills have been documented (U.S. EPA, 1978a; OTA, 1984; Miller, 1980). The proper installation of impermeable clay, admixed and flexible polymeric membrane liners, combined with leachate collection systems, can minimize leachate seepage from landfills. The various types of liners and their performance is discussed by Dinchak (1983), Forseth and Kmet (1983) and U.S. EPA (1980). Recent studies have examined the effect of various types of leachate composition which may affect the integrity of clay and admixed liners (U.S. EPA, 1980; Weullner et al., 1985; Shimek and Hermann, 1985; Whittle et al., 1984).

Current regulations under Subtitle D set forth criteria to use as minimum technical standards for solid waste disposal facilities. These criteria include protection of surface and ground water and the prohibition of open dumping of refuse. Recent ammendments to Subtitle D will influence these criteria in areas of enforcement and increased protection of the environment (U.S. EPA, 1986a). These new criteria will particularly affect those facilities which currently accept hazardous wastes from small-quanitity generators. The new criteria will include provisions for site selection, ground-water monitoring and corrective actions, as appropriate.

Waste Disposal in Excavations

The excavation and removal of materials such as clay, limestone, slate, sand and gravel commonly results in open pits and quarries that may be actively mined or abandoned. Oftentimes these pits and quarries are used as sites for the unregulated dumping of non-hazardous and hazardous waste. A variety of materials have been emplaced in these excavations including domestic wastes, refuse, junk automobiles, construction wastes, fly ash from utilities, oil field brines and various industrial organic wastes. Wastes are usually left uncovered and thus are subject to scavengers, vermin, odors and fire hazards. Open dumps in excavations are frequently burning dumps, either by intentional burning to reduce volume, or by spontaneous ignition of the wastes. Because these sites exist as unregulated dumps in areas potentially sensitive to ground-water contamination, they may significantly impact ground-water quality.

Gravel pits and quarries which are commonly excavated at a depth below the ground surface often intersect shallow aquifers. Some excavations contain ground water due to seasonal fluctuations in water table elevations. Wastes emplaced in these excavations would be subjected to periodic wetting, which may dissolve consitutents in the waste and produce leachate that can migrate directly into the ground water. Precipitation percolating through these wastes may also produce leachate that can seep into the ground water from what seems to be an apparently "dry" excavation.

The unregulated disposal of wastes into excavations and quarries often results in the contamination of ground water. The disposal of liquid industrial wastes into a gravel pit in England resulted in the contamination of an unconsolidated sand and gravel aquifer (Goldthorp and Hopkin, 1972). A quarry in Indiana was used for the disposal of old electrical parts, resulting in the contamination of the entire area with PCB's (Stimpson et al., 1984).

Leakage From Underground Storage Tanks

Underground tanks, which are used to store billions of gallons of liquids for domestic, commercial and industrial purposes, are emerging as a major source of ground-water contamination (OTA, 1984; Cheremisinoff et al., 1986a). Leakage from underground storage tanks, due to corrosion of the tank and other causes, release substances into the subsurface. Major users of underground storage tanks include farms, retail gasoline stations, military and fleet users and airports. Liquids stored in underground storage tanks include gasoline and motor fuels, process chemicals, hazardous and toxic chemicals and dilute wastes. The majority of underground storage tanks in use today contain regulated substances, such as petroleum products, and thus are a major focus of concern with regard to impacts on ground-water quality. Many underground storage tanks which contain petroleum products were installed in the 1950's during the highway transportation boom. These underground tanks are currently reaching and/or exceeding their design life expectancy. This factor alone could result in a significant increase in the number of leaking tanks within the next few years.

Problems with the tank operation and maintenance of underground storage tanks can be minimized if proper tank materials are used and proper tank installation procedures are followed (API, 1979). Tank materials should be compatible with the liquids which will be stored in the tank. The tank materials should also be capable of withstanding physical stresses and chemical attack from soil and water conditions present at the site. Tank installation procedures should be in accordance with appropriate engineering specifications and the manufacturer's instructions to better ensure the integrity of the buried tank. Proper supervision and inspection coupled with tank testing after installation is recommended.

Underground storage tanks commonly are constructed from bare steel, coated steel and fiberglass reinforced plastic. Corrosion is the major factor contributing to leaks in steel tanks; ruptures, physical breakage and loose fittings also contribute to tank leakage (New York State, 1985). Corrosion is an electrochemical process which results from interactions between the tank and the surrounding environment (both external and internal). The corrosion is either galvanic or electrolytic in origin. Both types of corrosion may cause either widespread or localized corrosion, depending on the tank material, the use of dissimilar metals for piping and fittings and the electrochemical nature of the surrounding materials. A variety of factors influence the occurrence and extent of tank corrosion, including the corrosivity of the surrounding materials, the presence of oxidizing agents, temperature, surface films, bacterial action, soil resistivity and moisture, adjacent metallic structures and stray electrical currents. In general, the corrosion process is accelerated in the presence of moist soil conditions, increased soil resistivity and ground water containing high dissolved solids. Because corrosion is the most frequently cited reason for tank leakage that has resulted in ground-water contamination, a variety of methods have been developed to protect the buried tank against corrosion. The most widely used and recommended method is cathodic protection, which reverses the electrochemical action of corrosion, thereby protecting the tank (API, 1983). Cathodic protection includes both galvanized cathodic protection, which utilizes a sacrificial anode, and impressed current cathodic protection, which employs an induced electrical current (Cheremisinoff et al., 1986b; New York State, 1985). Other corrosion protection methods involve the use of soluble corrosion inhibitors, coatings, linings and electrical isolation. Corrosion-resistant materials such as fiberglass reinforced plastic (FPR) provide an alternative choice for tank construction materials, however, fiberglass tanks require careful installation to maintain tank integrity and must be compatible with the liquids to be stored. The use of double-walled fiberglass-coated steel tanks with interstitial leak detectors is another way to minimize tank leakage, but this type of installation significantly increases the overall cost of the tank.

Other efforts to reduce tank leakage and minimize adverse environmental impacts employ the regular monitoring of tank integrity through tank tightness testing, and early leak detection by internal and external monitoring devices. One or more of these methods are often used in conjunction with inventory reconciliation to detect early signs of tank leakage. Inventory control requires careful record-keeping of the amount of product received in comparison to the quantity of product dispensed. Regular inspections of the product handling system and recognition of conditions which indicate a leak are also important parts of inventory control. Loss rates which can be detected through inventory reconciliation are usually estimated at no less than 5 percent of total throughput volume.

A number of testing methods are used to detect leaks and determine tank and piping tightness at a single point in time. These tests usually consist of filling the tank with a fluid or air until a certain pressure is reached, and observing for pressure or fluid losses over a period of time. Current standards for precision tank testing require the detection of at least 0.05 gallons per hour leak rate while taking into account the effects of temperature and pressure (National Fire Protection Association, 1983).

Internal tank monitoring devices are located inside the tank and provide a continuous measurement of the liquid level within the tank. These tank monitoring devices include mechanical sensors which measure the liquid level through an observation tube or float, or electronic systems which utilize either capacitance or sonar to detect minute changes in liquid levels (Cheremisinoff et al., 1986a). External tank monitoring systems are located outside of the tank in either the tank pit excavation or hydraulically downgradient of the tank. These monitoring devices are used to detect the presence of vapors or product either on the water table or within the tank pit resulting from a tank leak. External tank monitoring devices may operate in either a continuous or intermittent mode. Continuous liquid phase detectors require a monitoring well screened at the surface of the water table or in the excavation pit, and utilize a sensor which responds to the presence of hydrocarbons. Intermittent liquid phase monitoring employs the use of hydrocarbon-sensitive pastes or periodic ground-water sampling to detect free product. Both continuous and intermittent gas phase detectors use sensors which respond to the presence of hydrocarbon vapors (Ecklund and Crow, 1986). Problems associated with both types of detectors are false alarms and/or sensor failure. Sensor sensitivity must also be considered when designing and installing external monitoring systems for underground tanks.

Hydrocarbons

The U.S. Environmental Protection Agency currently estimates that at least 35 percent of all underground storage tanks are now leaking (U.S. EPA, 1986e). Accidental releases from underground storage tanks have been documented in every state with subsequent impacts to the surrounding soil, ground water, surface water and air (U.S. EPA, 1986d). The impact of accidental leaks on ground water depend on the processes which govern hydrocarbon fate and transport in the subsurface. Hydrocarbons occur in either a vapor, dissolved, or bulk liquid state. After subsurface leakage, the hydrocarbons will move vertically through the vadose zone. A portion of this liquid will volatilize depending on product solubility and vapor pressure. Vapor diffusion in the soil is controlled largely by soil porosity and permeability as well as temperature (Young, 1986). Vapors may migrate and collect in low lying areas such as basements and sumps causing potential health and fire hazard problems. The remainder of the liquid may either be subject to retention and attenuation in the vadose zone, or if a sufficient amount of product has been released, migrate into the ground water. Because most hydrocarbons are immiscible fluids, the product will accumulate on the water table. Depending on the solubility of the product, certain constituents will dissolve and migrate with the ground water and interact with the aquifer materials (Hinchee and Reisinger, 1985). The transport of bulk and dissolved hydrocarbons depends on the density, viscosity and solubility of the product, as well as the permeability, moisture content and attenuation processes (such as adsorption and natural biodegradation) which occur in the subsurface.

Successful remediation techniques have been used to remove both dissolved and bulk hydrocarbons from the vadose zone and ground water (API, 1980). Contaminant recovery systems typically employ the use of multiple recovery wells in which devices are used to recover the free product floating on the water table. Ground water containing dissolved product is also pumped from these wells for subsequent treatment and for enhancement of natural flushing of the vadose and saturated zone (Smith, 1985; Peterec and Modesitt, 1985; Yaniga and Demko, 1983; Brocius et al., 1986; O'Connor et al., 1984; Burke and Buzea, 1984). The presence of residual hydrocarbons trapped by capillary forces in the pore spaces of the vadose zone and aquifer media, however, are difficult to remove under normal subsurface conditions. Fluctuating water levels conditions directly affect the occurrence of residual hydrocarbons and may affect hydrocarbon recovery schemes and the apparent product measured in wells (Wilson and Conrad, 1984; Yaniga, 1984; Dalton et al., 1984). Reductions in residual hydrocarbon concentrations have been achieved through the implementation of in-situ bioreclamation techniques (Brenoel and Brown, 1985; Yaniga and Mulruy, 1984; Yaniga et al., 1985). Bioreclamation utilizes native hydrocarbon-utilizing bacteria, which, with the addition of oxygen and the proper nutrients, biologically degrade the hydrocarbons into innocuous substances. Enhanced biodegradation can therefore effectively lower hydrocarbon concentrations in the soil and ground water. Successful biodegradation of gasoline hydrocarbons by anaerobic bacteria has also been documented in the laboratory using authentic aquifer material (Wilson and Rees, 1985).

Leakage from Underground Pipelines

Pipelines are used to convey and transport waste and non-waste products. The primary waste transported by pipelines is municipal sewage. Sewers commonly occur in densely populated areas and convey municipal sewage over relatively short distances to wastewater treatment facilities. Non-waste products transported by pipelines include petroleum products, natural gas, ammonia, coal and sulfur (Miller, 1980). Non-waste pipelines are located throughout the nation, forming a major means of interstate transport of products which are regulated by the Department of Transportation. Leakage due to rupture or failure of these pipelines causes a loss of various products to the subsurface which can significantly affect ground-water quality. All spills and leaks from most interstate pipelines must be reported to the Department of Transportation. Intrastate sewage and commercial collection and distribution systems, however, are not required to report leaks and spills. Installation requirements for intrastate pipline also may not be as stringent as the requirements for interstate pipelines.

The major causes of leaks in pipelines are ruptures, external and internal corrosion, defective welds and incorrect operating procedures. The most common cause of pipeline leakage is corrosion; other causes of leakage include flood surges and rupture or heaving by tree roots and earthquakes (OTA, 1984; New York State, 1985). Petroleum products are the most frequently reported substances which have leaked from underground pipelines (OTA, 1984).

Loss of wastewater from sewer systems occurs when wastewater exfiltrates from the sewer lines due to rupture or leakage of the pipe. Miller (1980) estimated leakage from sewers at approximately 5 percent of the total annual volume of the transported sewage. This volume represents a potential loss of approximately 280 billion gallons of wastewater annually to the subsurface. Increases in nitrate concentrations in the ground water under portions of Long Island have been attributed to extensive sewer line leakage over time (Flipse et al., 1984).

Leakage from petroleum pipelines in conjunction with leaking underground storage tanks also represents a major source of ground-water contamination. Leakage from petroleum pipelines often occurs due to pipe corrosion, swing joints which have failed and improper connections between fittings and the tank. Underground pipe leaks can be minimized by proper pipe design, installation, testing and timely replacement or monitoring (New York State, 1985; API, 1979). Important criteria to be considered in pipeline design includes the type of service of the pipeline, the characteristics of the transported material, the volume to be transported, potential surges in flow and the corrosivity of the surrounding materials. Pipelines used for underground transport are commonly composed of carbon or stainless steel, plastic, fiberglass reinforced plastic, galvanized steel and coated or lined steel.

Artificial Recharge

Artificial ground-water recharge is a technique used to replenish ground water at an enhanced rate. Artificial recharge is accomplished by either augmenting the natural infiltration of surface water via man-made systems or changing natural hydraulic conditions to induce recharge water to enter a desired formation. Man-made systems include the use of spreading basins, playa lakes, recharge pits and shafts, ditches and recharge wells. Indirect methods which involve alteration of natural hydraulic conditions include induced streambed infiltration and connector wells (O'Hare et al., 1986; Pettyjohn, 1981; United Nations, 1975; Oaksford, 1985). Water used for artificial recharge systems is often derived from surface water reservoirs, streams, flood and storm-water drainage, cooling water, reclaimed wastewater and sewage effluent. Impacts to ground-water quality from artificial recharge are directly related to the quality of the applied water and the natural contaminant attenuation and filtering process which occur in the subsurface. Because artificial recharge is currently practiced in every state, as well as internationally, potential impacts to ground-water quality may be significant.

Artificial ground-water recharge has been used throughout the world for many purposes including ground water management, reduction of land subsidence, renovation of wastewater and sewage effluent, improvement of ground-water quality, storage of flood flows and reduction of salt water intrusion in coastal areas (Pettyjohn, 1981). The majority of artificial recharge systems in the United States are relatively small and are used to minimize water-level declines in aquifers and replenish ground-water supplies. Larger recharge systems operate mainly to lessen or halt saltwater intrusion into freshwater formations and to renovate sewage and wastewater effluent. International uses of artifical recharge focus primarily on aquifer recharge, improvment of ground-water quality and control of saltwater intrusion.

The design and site selection for an artificial recharge system is largely controlled by the hydrogeologic conditions that exist at a site. Proper site selection should consider the availability of an aquifer suitable for recharge, the thickness and permeability of the materials overlying the aquifer as well as the thickness and permeability of the aquifer itself. These factors must be considered in relation to the source and quality of the recharge water, the quality of the aquifer water and the flow conditions at the site (Pettyjohn, 1981, O'Hare et al., 1986). The chemical and physical quality of the recharge water must be compatible with the quality of the aquifer water to prevent the occurrence of chemical reactions that may reduce aquifer permeability. Most importantly, the chemical quality of the recharge water must be monitored to prevent contamination of the receiving aquifer. Recharge water should have low suspended solids to minimize both clogging of recharge systems and reductions in aquifer permeability. Suspended sediments in recharge water are the major cause of reductions in the infiltration capacity of spreading basins, playa lakes, recharge pits and wells (O'Hare et al., 1986; United Nations, 1975). The materials overlying the aquifer to be recharged must also be sufficiently permeable to permit the applied recharge water to infiltrate down to the aquifer. The aquifer must also be permeable enough to accept and transmit the recharge water throughout the aquifer.

The type of artificial recharge system used at a site will depend upon the site hydrogeologic conditions and the purpose of the recharge system. Spreading basins are constructed in low lying, level areas which have permeable soils at the surface. These basins may be either continuously or intermittently indundated with recharge water. The quantity of water recharged to the aquifer depends on the infiltration capacity of the basin materials and the capacity for horizontal water movement in the subsurface. Spreading basins frequently experience reductions in infiltration capacity due to clogging of the overlying soils by suspended sediments in the recharge water. Playa lakes may also be used for artificial ground-water recharge after first breaking up, removing and/or regrading the normally restrictive soils in the lake bottom. Because playa lakes are natural collection points for surface runoff, they can be successfully used as recharge basins (Schneider and Jones, 1983; O'Hare et al., 1986). Ground-water recharge pits and shafts commonly are constructed in areas where relatively impermeable materials at the surface normally limit infiltration into more permeable underlying materials. The pits typically are excavations which bypass the impermeable layers at the surface and are finished into coarser materials at depth. Reductions in infiltration rates through recharge pits and shafts may occur over time due to clogging of the absorption surface by fine-grained materials in the recharge water. Recharge wells are also used to directly recharge water into deeper water bearing zones, particularly where thick impermeable layers exist between the surface and the aquifer. Reductions in recharge well infiltration capacities can occur due to sediment clogging, air entrainment, microbial growth, chemical precipitation, particle flocculation and temperature differences between recharge and native ground water (O'Hare et al., 1986).

Indirect methods of recharge are accomplished through induced infiltration of water from surface reservoirs and streams. Wells or galleries constructed adjacent to surface-water bodies are pumped to induce hydraulic gradients from the surface water body to the well. The quantity of recharge to the well depends on the permeability of the stream or lake bottom deposits and the materials between the wells and the surface water. The chemical quality of the surface water supply can affect the usefulness of such an infiltration scheme; contaminants found in surface water can be introduced into the ground water. Another source of indirect recharge includes the use of connector wells which are screened in both an overlying shallow aquifer and a deeper aquifer. Depending on localized pumpage and piezometric heads, ground water is allowed to flow from shallow aquifers into the deeper aquifers for recharge. Connector wells have been used successfully in Florida to recharge portions of the Floridan aquifer from the surficial sand aquifer (Bush, 1979).

Ground-water quality impacts have occurred from artificial recharge programs where poor-quality surface water, renovated wastewater and sewage effluent were used for recharge water (Bouwer et al., 1972; Bouwer, 1985; Nightingale and Bianchi, 1977; Wood and Bassett, 1975; Roberts et al., 1980; Piet and Zoetemann, 1985; Idelovitch and Michail, 1985). These sources of recharge water have resulted in increased concentrations of nitrates, bacteria, viruses, metals, detergents and synthetic organic compounds in the ground water.

Conversely, various studies conducted at artificial recharge facilities have illustrated the capability for removal of contaminants from recharge water during infiltration to the aquifer (Idelovitch and Michail, 1985) (Table C-2). When infiltration basins in Arizona were inundated in accordance with a proper schedule, reductions in suspended solids, fecal coliform, nitrogen, phosphorous and organic compounds were observed in the infiltrating recharge water beneath the basins (Bouwer et al., 1972; Bouwer, 1985). Significant biodegradation of trace organics in recharge water was supported by field data at a recharge project in California (Rittman et al., 1980; Roberts, 1985). Processes which affect the fate and attenuation of organic compounds in the subsurface are governed largely by the processes of adsorption, biodegradation and volatilization (McCarty et al., 1980, Crites, 1985). Inorganic contaminant removal processes include ion exchange, adsorption, precipitation, chelation and complexation (Chang and Page, 1980). Bacterial and viral pathogens have been shown to be removed from infiltrating water during ground-water recharge (Gerba and Goyal, 1985; Gerba, 1985; Gerba and Lance, 1980). Field and laboratory studies suggest that pathogen removal depends on organism survival times in soil and organism retention rates on soil particles. Organism retention rates on soil are controlled by soil filtration and adsorptive capabiltiies, soil moisture, pH, temperature and the type of the microorganism.

Sumps and Dry Wells

Sumps and dry wells are structures which facilitate the drainage and disposal of liquids into permeable vadose zone sediments. A dry well or sump is a small to medium diameter hole or pit that is dug or augered into the ground. The well or pit commonly is filled with pea gravel, coarse sand or other aggregates. Some sumps and dry wells may contain a slotted pipe or screen, backfilled by coarse materials, which allow water to drain into the surrounding sediments (Hannon, 1980). Various types of filter cloths and/or filter sand emplaced in the wells are used to trap silt and sediment in the drainage water. Dry wells and sumps commonly are used for the disposal of storm water runoff in urban areas, irrigation water and flood water, and in some areas, septic tank effluent (Hannon, 1980; Seitz et al., 1977). These types of disposal wells are located in nearly every state and are used to drain waste and excess water into a wide variety of subsurface materials. For example, disposal wells commonly are used in permeable basalts within the state of Idaho, in unconsolidated sediments within the state of California and in permeable sands and limestones within the state of Florida.

Drainage from dry wells and sumps is a potential source of ground-water contamination because the quality of the water draining into these wells frequently is unknown and usually is not regulated. Several studies in Idaho, Arizona and Florida have attempted to document the effects of drainage from dry wells on ground-water quality (Wilson et al., 1984, Seitz et al., 1977 and McBee and Wanielista, 1986). The potential affects of this drainage on ground-water quality are determined by the drainage water quality, the amount of dilution that occurs (related to the total volume of drainage water), the permeability of the vadose zone materials and naturally occurring attenuation processes. Waste and excess water entering dry wells and sumps commonly creates a temporary perched water table beneath the dry well or sump. This perched water zone may spread horizontally, beneath the disposal site, thereby dispersing the contaminant-laden water. Mounding of the water table can also occur beneath these disposal sites where large volumes of liquids are continuously discharged into highly permeable materials (Wilson et al., 1984). Filtration, dilution and chemical attenuation processes may effectively remove some contaminants in the vadose zone.

Actual contamination from dry wells and sumps is not well documented. Certain studies suggest possible impacts on ground-water quality in water sampled from water supply wells near a dry well (Seitz et al., 1977; Hannon, 1980; McBee and Wanielista, 1986). Storm surface runoff originating from urban area drainage may contain a variety of contaminants which are either dissolved or suspended by the storm water, including metals, organic compounds, bacteria, organic matter and sediment. Irrigation water may contain high concentrations of nitrogen, phosphorous, bacteria and pesticides. Sewage effluent disposed of in dry wells in Idaho contained very high concentrations of nitrogen, phosphorous, chloride and bacteria (Seitz et al., 1977).

Graveyards

Leachate from graveyards may cause ground-water contamination, especially where wooden or non-leakproof caskets are used. The potential for ground-water contamination by leachate from graveyards primarily depends on the permeability and contaminant attenuation characteristics of the vadose zone media and the depth to water beneath the cemetery (Lehr, et al., 1976). Areas that have permeable soils, high amounts of precipitation and seasonally high water tables may be more susceptible to this potential ground-water contamination problem (Bouwer, 1978). Leachate from graveyards may also pose a potential ground-water contamination problem in areas underlain at shallow depth by fractured bedrock or karst limestone. Rapid transport of water through these types of formations may not provide adequate treatment of leachate. Few actual cases of ground-water contamination from graveyard leachate have been documented. Where cases have occurred, the ground-water contamination has been localized (Bouwer, 1978).

GROUND WATER QUALITY PROBLEMS THAT ORIGINATE IN THE GROUND BELOW THE WATER TABLE

Waste Disposal in Wet Excavations

The mining of natural materials such as clay, limestone, slate, sand, gravel and coal often produces quarries, shafts and pits that frequently are abandoned after mining activities cease. These excavations commonly intersect shallow aquifers and thus contain water that is in direct hydraulic connection with the aquifer. Indiscriminant and unregulated disposal of various wastes into these excavations can result in a direct ground-water contamination. In addition, the disposal of waste into quarries, shafts and pits may also affect localized ground-water flow conditions because of the variable permeability of the emplaced wastes. Ground-water flow directions have been altered as a result of the disposal of waste in a quarry in Rhode Island (Kelly, 1976).

The unregulated disposal of wastes in excavations has occurred in many areas and has impacted ground-water quality. Ceroici (1985) detailed a case history where the disposal of waste in a water-filled, open-pit coal mine generated a ground-water leachate plume that migrated off-site. Natural attenuation processes, however, may limit the extent of ground-water contamination at some sites. For example, Peffer (1982) reported that the disposal of fly ash in a limestone quarry initially increased sulfate concentrations in the ground water. Sulfate concentrations in the ground water decreased over time, however, due to natural attenuation of the sulfate and compaction of the fly ash. In addition, the initially low pH value of the fly ash, which contributed to the high sulfate concentrations in the ground water, later was neutralized by the limestone.

Drainage Wells and Canals

Drainage wells and canals are often constructed in low-lying and coastal areas where impermeable surficial materials restrict the downward drainage of surface water. Drainage wells consist of pits or holes which are excavated or drilled into an aquifer. The shafts or holes are filled with coarse, permeable materials or slotted pipe with a permeable backfill. Water flows by gravity down the well into deeper sediments. Drainage wells are often constructed as "overflow wells" in marshes or swampy areas and in lakes or ponds to control water levels. Excessive storm runoff and flood waters may also be channeled into drainage wells for disposal. Canals consist of man-made channels which may be either lined or unlined. Canals are used to collect surface runoff and control water flow and drainage in an area. Canals are often used in coastal areas to control floodwater and to maintain hydraulic heads which prevent saltwater intrusion into freshwater formations (Sonntag, 1980). Drainage of poor-quality surface water into wells and canals may cause potential ground-water contamination. The quality of the drainage water is often unregulated and frequently unknown. Recent studies which assessed the impacts of drainage wells on ground-water quality in Florida found little degradation of ground-water quality (Kimrey, 1978; Kimrey and Fayard, 1984; McBee and Wanielista, 1986). However, increases in bacteria, color and suspended solids were noted in water supply wells located near drainage wells. Although storm water runoff and sewage effluent have been disposed of in the Floridan aquifer for years, there is evidence of little to no water-quality impact. Lack of impact on ground-water quality by drainage from these wells has been attributed to natural contaminant attenuation and significant dilution of the drainage water within the aquifer. Drainage wells in some areas of Florida have been shown to provide significant recharge to the Floridan aquifer (Kimrey, 1984; McBee and Wonielista, 1986). Drainage wells are used in many states although potential impacts on ground-water quality are not well documented.

Increased urbanization in many coastal areas has resulted in the degradation of water quality in many canals. Canals frequently are used as receptacles for the disposal of urban runoff and sewage effluent. Leakage from unlined or partially lined canals can transmit contaminants into the ground water, especially in areas where the canals are underlain by permeable unconsolidated deposits, extensively fractured bedrock and karst limestone. Increased concentrations of inorganic ions, nitrogen, bacteria and pesticides in canal water in southern Florida have raised conerns over the potential impact of this water on local ground-water quality (Sonntag, 1980).

Abandoned and Exploration Wells

The leakage of contaminants and poor quality water through abandoned oil and gas wells, exploration and test holes and water wells has become a significant ground-water contamination problem in many areas. Wells or holes that have been abandoned or improperly plugged provide a conduit for the migration of contaminants and poor quality water into fresh water aquifers. The migration of fluids between formations may occur if the casing is pulled or allowed to deteriorate. Improperly plugged wells may leak around the casing or grout seal. Exploration or test holes used for mineral exploration or as shot holes for seismic surveys pose a special problem because they are not cased, or maintained or plugged in any way. Abandoned wells frequently become receptacles for the disposal of garbage and various solid and liquid wastes which can lead to undeterminable contamination problems.

Although the primary cause of contamination from abandoned wells stems from the leakage of poor quality water into other permeable zones, leakage may occur under several different situations. The potential for ground-water contamination from an abandoned well depends on the original use of the well, the local geology, the hydraulic characteristics of the ground-water flow system and the type of well construction (Gass et al., 1977). Improper abandonment of oil and gas wells is a major source of ground-water contamination due in part to the large number of wells that have been drilled over the last one hundred years. Oil and gas wells commonly penetrate fresh-water zones and are completed in deeper resource-bearing strata. Brines are typically associated with the occurrence of oil and gas in the subsurface. Where casing is deteriorated or absent and hydraulic gradients are upward, brines may migrate through the conduit and enter shallower, fresh-water aquifers. Where brine formations overlie fresh-water aquifers and hydraulic gradients are downward, brines may migrate through a deteriorated casing or open borehole and contaminate the underlying fresh water-bearing zone. If abandoned wells are open at the surface and gradients are downward, poor quality surface water may drain directly into fresh water aquifers. Conversely, in areas where ground-water gradients are upward, poor quality water may discharge at the surface through the open conduit. Abandoned wells open at the surface can cause particular problems when the wells are located in areas which are prone to flooding or inundation by surface water. Surface water reservoirs frequently cover areas where domestic wells were previously located. These wells were probably never plugged before the reservoir was filled. The submerged unplugged wells can provide a conduit for poor quality surface water to migrate into the underlying aquifer (Warnken, 1984).

Specialized contamination problems may occur when abandoned or improperly plugged wells penetrate a formation actively used for the underground injection of wastes. As these wastes are injected under pressure into the receiving formation, abandoned wells provide ready conduits for the upward migration of the injected fluids (Fryberger and Tinlin, 1984). Current Federal Underground Injection Control Regulations require the identification and location of all abandoned wells within an area of review around a proposed injection location to minimize potential contamination hazards.

The potential for contamination by abandoned wells may be recognized when the total number of abandoned wells that are probably present across the country are considered. Comparison of the total number of oil and gas wells drilled to the total number of active producing wells provides an estimate of approximately 2 million abandoned oil and gas wells alone (Aller, 1984; Canter, 1984). These numbers do not even account for possible abandonment of many other types of wells and test holes.

Gass et al., (1977) cites numerous case histories of ground-water contamination due to improperly plugged or abandoned wells. Contamination problems associated with abandoned wells have been identified in nearly every state (Gass et al., 1977; Blomquist, 1984; Canter, 1984). Adequate plugging and abandonment regulations are necessary to minimize and eliminate future contamination problems from these wells. A state well abandonment regulation survey indicates that most states do have regulations that deal with the hazards of abandoned wells, but they vary widely in their requirements, and are compounded by inadequate enforcement (Gass et al., 1977). Minimum recommended standards for proper well abandonment have been developed by the National Water Well Association and the American Water Works Association.

Attempts to minimize contamination from abandoned wells are often complicated by the inability to pinpoint the well location or to acknowledge the existence of the well. In the past, significant efforts to locate abandoned wells were only pursued when the well was a prime suspect of contamination. Requirements to locate abandoned wells and an increased recognition of the pollution potential of abandoned wells has prompted the re-evaluation and development of various methods to locate these wells. Conventional well location searches have employed a combination of record searching, talking with residents, or using metal detectors and magnetometers (Aller, 1984; van Ee et al., 1984). Other potentially useful methods for abandoned well location also include the use of historical aerial photographs, electrical resitivity, electromagnetic conductivity, ground penetrating radar, remotely sensed imagery, water-level measurement in surrounding wells and injection (Aller, 1984; van Ee et al., 1984). These methods may be used alone or in combination depending on the condition and surface expression of the abandoned well and the resources available for the search.

Water Supply Wells

Water wells can be a potential source of contamination when they are improperly constructed, not maintained or when they are abandoned and left unplugged. The conditions which commonly permit ground-water contamination to occur from water wells include: 1) the well casing is open or not watertight at the top allowing the direct entrance of contaminants, 2) the well is located where surface water can directly drain into the well, and 3) surface water is entering the well after having passed through only a few feet of soil. In addition, when the water well connects two aquifers of differing water quality, poor quality water from one aquifer may mingle with water from the second aquifer and degrade the water quality.

Contamination from improperly constructed wells may result from several causes including: nonwatertight joints between lengths of casing, failure to use grout or the proper grout material in the annular space between the borehole wall and well casing, improper placement of grout, constructing the well in a floodplain or low lying area where surface water collects, installing the well in an underground pit with poor drainage, using poorly fitting buried well seals; and nonwatertight pitless adapter connections. Water supply wells that are not properly maintained may be subject to corrosion or other deterioration of casing and piping materials. Saline waters in subsurface formations can accelerate corrosion of steel well casing in coastal areas, resulting in openings in the casing which permit saline water to enter the well and contaminate the fresh water aquifer (Miller, 1980). Other contamination problems can occur when well casings and surface seals are destroyed during the demolition of houses or buildings.

Ground water from large diameter dug wells is particularly susceptible to contamination from surface runoff due to improper well construction. Dug wells are usually two or more feet in diameter, shallow in depth (i.e. less than 50 feet) and lined with a variety of open-jointed materials such as wood, brick, rock or clay tile. These wells commonly do not have proper caps and/or surface seals to prevent the entry of surface water into the well. Dug wells commonly are older wells which were constructed prior to established well construction codes. The installation of public water supplies in many areas often leads to the abandonment of these large diameter wells without proper plugging practices.

Ground-water contamination problems from improperly constructed and abandoned water wells is considered a significant problem in many south-central states, particularly in areas of cavernous limestones (Miller, 1980). Abandoned wells that produce saline water are also a major contamination problem in the state of Florida. Improper well construction was cited as the principal cause of elevated concentrations of nitrates, bacteria and pesticides in domestic and stock wells in southeast Nebraska (Exner and Spalding, 1985). The high concentrations of contaminants in ground water from the sampled wells were directly correlated with improper well construction practices and improper well location.

Regulations and codes addressing proper well construction and abandonment vary widely from state to state. Minimum code specifications should address proper well location, design, construction, installation, development, maintenance and abandonment. The implementation of a licensing or certification program for well drillers can also assist in improving well construction practices.

Waste Disposal Wells

Wells are used for a variety of disposal and resource recovery purposes, including the injection of hazardous and non-hazardous wastes, oil and gas storage and production, solution mining and irrigation and stormwater drainage. Wells used for any purpose of emplacing fluids into the subsurface are regulated under the Underground Injection Control Program (UIC). The primary focus of this act is to regulate underground injection of fluids which endanger drinking water sources. To ensure these safeguards, the UIC legislation provides minimum requirements for well permitting, construction and operation, mechanical integrity testing and reporting, as well as establishes uniform requirements for state programs. The estimated presence of as many as 500,000 injection wells nationwide which are used for purposes ranging from artificial recharge to hazardous waste disposal, illustrates the potential for impacts on ground-water quality from these wells (U.S. EPA, 1979a).

To effectively implement the full scope of the UIC program, injection wells are categorized into five classes based on injection activity:

. Class I	wells used to inject both hazardous and non-hazardous industrial, nuclear, and municipal wastes beneath the deepest stratum containing an underground drinking water source.
. Class II	wells used to dispose of fluids (such as brines) associated with oil and gas production, enhanced oil and gas recovery, and hydrocarbon storage.
. Class III	wells used in special process operations such as solution mining, in-situ gasification of oil shale and coal, and recovery of geothermal energy.
. Class IV	wells used to inject hazardous wastes into or above a drinking water source (all such wells are currently banned).
. Class V	wells used for non-hazardous injection including air conditioning return flows, recharge wells, drainage and dry wells, septic system wells, and saltwater barrier wells.

The potential for ground-water pollution by Class I, II and III wells has received significant attention because of the type of possible contaminants introduced through these wells; however, the large numbers of Class V injection wells in use today may actually constitute the greatest threat to ground-water quality. The classes of wells and the impact of contamination introduced through these wells are discussed under the related sections on artificial recharge, dry wells and drainage wells.

Drinking water supplies can be protected and water-quality impacts from injection wells can be minimized by: 1) proper well siting, 2) proper well construction and 3) proper well maintenance, testing and operation. Where ground-water contamination does occur, the problem can be traced to deficiencies in any one or a combination of these factors.

The siting of injection wells must take into account the geology and hydrogeology of a prospective site and be made in accordance with the UIC regulations. The UIC regulations require that subsurface disposal must utilize a formation containing a total dissolved solids content of 10,000 mg/l or greater. Both regional and local site evaluations must be performed to assure waste confinement and compatibility in the injection zone. Regional site assessments should include considerations of the general geology, structure, stratigraphy, hydrogeology, seismicity and mineral resources (Warner and Lehr, 1981). Areas suitable for injection should have overlying and underlying confining strata and extensive, thick sedimentary sequences which provide adequate injection intervals. The geology should be simple and the geologic formation should have an absence of faulting and folding which could provide waste migration pathways. Areas where injection wells are to be located must be free of seismic activity because earthquakes may damage an injection facility and injection may cause earthquakes to occur. For these reasons, most injection activities are located in geologic basins or coastal plain areas (Whiteside and Raef, 1986). Site investigations should indicate the presence of an injection interval sufficiently thick and homogeneous, with adequate porosity and permeability to accept wastes at proposed injection rates without the risk of fracturing the overlying strata from increased injection pressures. The overlying and underlying confining strata should be sufficiently thick and free of fractures and faulting to prevent undesirable waste migration. Additional factors which may positively affect siting of an injection well include normal formation temperatures and pressures, wastewater and formation water compatibility and slow lateral migration rates in the injection zone (Warner and Lehr, 1981).

UIC regulations require the delineation of an area of review surrounding the well. Within the area of review, the factors must be evaluated which affect the potential for upward migration pathways due to increased pressures resulting from the injection process. Of primary concern within the area of review is the presence of abandoned or improperly plugged wells which intersect the injection zone and which may provide conduits for waste migration into shallower aquifers. The presence of these wells is of particular significance in areas of prolific oil and gas production where the number of abandoned production wells may be extremely large. Factors which affect the area of review include the radial extent of ground-water movement from the well bore and the rate of pressure build-up in the reservoir over time (Davis, 1986). Improper siting of injection wells can result in the contamination of aquifers through migration of fluids out of the pressurized zone through faults or fractures in the confining beds or by displacement of fluids through lateral migration from the injection zone into hydraulically connected underground sources of drinking water (U.S. EPA, 1979a).

Injection well design and construction must ensure well integrity while providing efficient and controlled injection conditions. The well components must be capable of withstanding stresses caused during both the drilling operations and the injection process. Reservoir pressures, potential workover operations and the effects of reservoir and injected fluids must all be considered. Three concentric casings are commonly used for well construction. First, conductor pipe is installed to seal off shallow-water zones during the drilling and cementing of the surface borehole. Second, surface casing is typically installed through the conductor pipe to a depth below useable drinking water supplies and cemented in place to the surface. Third, the protection casing, which provides secondary protection of drinking water supplies, is set to the total depth of well. Protection casing must be able to withstand the rigors of cementing, workover operations and exposure to injection fluids (Whiteside and Raef, 1986). The bottom hole completion of the well may be open hole for direct injection into the formation, or may be designed with screens and gravel packs, or perforated casing. Injection tubing is then installed to carry the wastes to the bottom of the hole. Tubing materials should be chosen for compatibility with the injected wastes and must be capable of withstanding injection pressures. The annular space may be sealed with a packer or the use of static or fluid flush liquid seals (Sherman and Craig, 1986). The injection tubing and the annulus serve as the primary protection against contamination due to leakage. Annular pressures and/or fluids are continuously monitored to detect early leaks or problems with the system (Miller et al., 1986; Warner and Lehr, 1981). Corrosion of well construction materials is a common injection well problem that causes loss of well integrity and may be minimized by the use of corrosion resistant cements, casing and injection tubing (Creech, 1986; George and Thomas, 1986).

The preservation of the mechanical integrity of the well depends on proper well maintenance, monitoring and operation. Many wastes must be pretreated prior to injection to remove suspended solids and oils, modify wastewater chemistry for injection compatibility, reduce corrosiveness and inhibit the growth of microorganisms (Warner and Lehr, 1981). UIC regulations require the continuous monitoring and recording of injection pressure, flow rate, volume and annulus pressure. All well components should be inspected regularly for wear and corrosion. Mechanical integrity testing of wells is also required to demonstrate no significant leaks or losses in the casing, tubing or packer and that there is no significant vertical fluid migration adjacent to the borehole into an underground drinking water supply. The principal methods of integrity testing include continuous monitoring of injection and casing-tubing annulus pressures and pressure testing with liquid or gas (Klemt et al., 1986; Nielsen and Aller, 1984). Various geophysical logs and surveys may also be used to confirm well integrity and/or detect casing leaks including temperature and noise logging, pipe analysis surveys, electromagnetic thickness surveys, caliper logging, borehole television, flowmeter surveys, radioactive tracer surveys and cement bond logging (Nielson and Aller, 1984).

The fate and transport of injected wastes depends on both the physical and chemical characteristics of the wastewater and the injection zone environment. The types of wastes which are injected will vary widely in composition from various organic compounds and acids to oil and gas production brines. Consideration of physical and chemical waste characteristics such as density, viscosity, pH, stability or reactivity and total waste volume is necessary to accurately predict waste migration in the subsurface. Reactions that occur in the injection zone and that affect waste characteristics such as neutralization (i.e. carbonate, sand and clay dissolution), hydrolysis, coprecipitation, ion exchange and microbial degradation must also be considered in fate and transport assessments (Scrivner et al., 1986). Analytical and numerical models may be applied to injection sites to assess the total effects of waste injection such as fate and transport of wastes, plume movement, pressure buildup in the injection zone and the evaluation of upward permeation through confining layers (Miller et al., 1986; Prickett et al., 1986).

Performance surveys of hazardous waste injection wells indicate that less than 2 percent have caused environmental damage (Davis and Hineline, 1986). According to a study by Paque (1986), loss of well integrity and subsequent leakage of the injected fluid was most commonly caused by corrosion, upward waste migration from excessive injection pressures and flow through abandoned wells. Environmental impacts at the sites which were investigated included leakage into an underground source of drinking water (five sites), leakage at the surface (four sites) and injection into an unpermitted zone not containing a drinking water source (1 site). Walter (1986) documented contamination of a shallow aquifer in Louisiana resulting from casing leaks in an injection well. Additional contamination problems resulting from loss of casing integrity have been reported in several states (Gordon and Bloom, 1986). Plugging of the injection zone resulting from waste incompatibility, inadequate pretreatment or biological activity may also cause loss of well integrity (Davis and Hineline, 1986). Contamination resulting from upward migration of wastes through abandoned wells has been documented in Ontario and Pennsylvania (Gordon and Bloom, 1986; Kent et al., 1986).

Mines

Excavation and operation of both surface and underground mines can alter hydrogeologic flow conditions and cause degradation of ground-water and surface water quality. The effects of mining typically are manifested during both the active mining phase and after abandonment. At the time of a 1975 EPA report, the number of operating mines was estimated at over 15,000, while the number of inactive or abandoned mines was estimated to be nearly 200,000 (U.S. EPA, 1975). These numbers serve to illustrate the potential impact which mining activities can have on ground-water quality.

Metallic and non-metallic minerals are mined as ores or natural assemblages of rocks and minerals. Minerals or rock materials of no value in mining are called gangue or spoils and may be used to fill in the mine after the mining activities have ceased (Martin and Mills, 1976). Surface mining techniques commonly employ the removal of overburden materials (up to 300 feet) by open-cut operations, including open pits, strip mines and quarries. Underground mining techniques employ the construction of tunnels and shafts to access deeply buried minerals. Open stopes, supported stopes, caving methods, flat seam and solution-mining techniques are all used for accessing deeply buried minerals (Martin and Mills, 1976). Both surface and underground mining activities can create water quality and/or quantity problems which result from either the chemical characteristics of the mineral assemblage being mined or the physical disturbance to the hydrogeologic environment.

Adverse hydrogeologic and water-quality effects can occur during all mining phases. During the active mine phase, dewatering operations can lower ground water levels in the surrounding aquifer causing nearby wells to go dry. Potentiometric surfaces of aquifers overlying the dewatering operation may also be affected and shifts in the position of ground-water divides may also occur. As a result of dewatering operations at a mine site, the mine area acts as a large diameter well or sink producing a "cone of depression" that can extend beyond the mine area. The extent of the cone of depression is a function of several factors including the physical position of the mine in relation to the ground-water flow system, the hydraulic conductivity of the aquifer media, and storage capacity of the aquifer (National Research Council, 1981). Underground shafts can also intercept ground water that would normally flow above or below a mineral seam (Sgambat et al., 1980). Hydrostatic pressures in aquifers near the mining area often return to pre-mining conditions after the cessation of mining activities. However, the disturbance of overburden from surface mining and the presence of open mine shafts and shafts containing rubble from underground mining can locally affect ground-water flow conditions. Mining processes and collapse of abandoned mine shafts can cause fracturing and rock bursting which can increase permeabilities and infiltration in the mine area. Land subsidence caused by the caving and collapse of underground formations may also result from mining activities.

Most ground-water contamination related to mining results from the oxidation of base metal sulfide compounds and the associated release of trace metal constituents. These problems are especialy prevalent in coal mining areas and result in the production of acid mine drainage. Acid mine drainage and the concomitant dissolution of minerals is caused by the circulation and drainage of ground water through mine shafts and spoils. Sulfide minerals associated with coal deposits are oxidized as they come in contact with oxygen and water. This reaction produces acid and high concentrations of sulfate and ferrous iron. Acidic waters moving through earthen materials can accelerate the breakdown of clay, silicate minerals and carbonates, thus increasing the total dissolved solids in the water (Sgambat et al., 1980). The solubility of iron, aluminum and manganese is increased in acidic environments, resulting in high concentrations of these elements in the ground water. Acidic waters can also increase the concentrations of metals such as lead, copper, nickel, zinc, cadmium and chromium. The amount of acidic water produced from mining activities and the effects of this acid is influenced by available alkalinity, the presence of water and the presence of iron or sulfur reducing bacteria (Sgambat et al., 1980; Atkins and Pooley, 1982). Carbonate formations such as limestones or dolomites can provide alkalinity which buffers the low pH of acid mine drainage. The carbonate rock, however, contributes total dissolved solids to the ground water as a result of buffering the acid mine drainage. This buffering effect commonly occurs in western coal areas and is responsible for the high total dissolved solids and sulfates in the ground water.

Impacts from mining on ground-water quality have been recognized in many states, particularly in those states where coal, lead-zinc and uranium is extensively mined. Ground-water contamination by acid mine drainage and alterations to hydrogeologic conditions from coal mining have been extensively documented (McCurry and Rauch, 1986; Wirries and McDonnel, 1983; Ahmad, 1974; Emrich and Merritt, 1969; Van Voast, 1974; Stroud et al., 1985; Slack, 1983; Traylor, 1984; Seifert, 1984). Lead-zinc mining has resulted in elevated concentrations of lead, zinc, cadmium, iron and sulfates in ground water in portions of Oklahoma, Wisconsin and Idaho (Mink et al., 1971; Sheibach et al., 1982; Toran and Bradbury, 1985; Riley et al., 1984). In situ leach mining of uranium has contributed radionuclides to ground water in shallow aquifers above and below the ore zone (Thompson et al., 1978). Water-quality degradation related to other mining processes typically occurs during processing or storage of the ore.

Impacts to ground-water quality are usually noticed several years after mining is initiated and/or after mine abandonment. Recent studies suggest that ground-water contamination impacts from mining are most severe four to six years after mining is begun (McCurry and Rauch, 1986). The time delay is attributed to iron sulfide reaction rates and solute transport travel times within aquifers. Impacts on ground-water quality from surface mining typically are more pronounced due to the mining methods used and the duration of mining. Impacts to ground-water quality typically are more severe in shallow ground water systems, however, problems with ground-water contamination from underground mines may persist longer than contamination from surface mines due to constant exposure of ground water to pyrite in deep mine shafts (McCurry and Rauch, 1986).

Salt Water Intrusion

Pumping ground water in excess of natural recharge in coastal areas or areas underlain by saline aquifers often results in the contamination of freshwater aquifers by saltwater intrusion. When freshwater is underlain by saline water, the pumping of wells near the freshwater-saltwater interface can cause saltwater to move in the direction of the pumping gradient and enter the well. The "upconing" of saltwater occurs in response to the drawdown of the freshwater level around the pumping well and the resulting hydrostatic pressure reduction at the freshwater-saltwater interface (Bouwer, 1978). Intrusion of saltwater into freshwater aquifers impacts ground-water quality by increasing the salinity of the freshwater. This increase in salinity in the freshwater often results in the dissolved solids concentration in the water exceeding acceptable drinking water standards.

Saltwater intrusion has been documented in 43 states and has caused contamination of drinking water supplies (Newport, 1977). Movement of saline water into freshwater aquifers typically occurs in response to hydrodynamic changes in the aquifer system often caused by man. The mechanisms of saltwater intrusion include the reversal or reduction of hydraulic gradients (particularly in coastal areas) due to excessive pumping, destruction of natural barriers, upstream encroachment in coastal rivers and migration of brines associated with oil and gas production.

Saltwater intrusion due to reversal or reduction of hydraulic gradients (due to excessive pumping) is a common problem in coastal areas. Under normal nonpumping conditions, freshwater discharge to the ocean exerts positive pressure which prevents inland migration of saline waters. A cone of depression forms in response to excessive freshwater pumping, thereby reversing hydraulic gradients and inducing saline water flow towards the pumping wells. The interface between the saltwater and freshwater has a parabolic form, with the denser saltwater forming a wedge under the freshwater. Under equilibrium conditions, the interface is stationary with freshwater discharging toward the coast. The length of the saline water edge varies inversely with the magnitude of the freshwater head. In coastal areas, the depth to the interface is equal to 40 times the height of the freshwater head above sea level (Bouwer, 1978).

Diffusion and hydrodynamic dispersion between the saltwater and freshwater create a brackish transition zone that may fluctuate in response to ground-water pumping, recharge and tides. Mathematical models have been developed which attempt to simulate the freshwater-saline water interface and the effects of pumping and recharge on the aquifer flow system (Bouwer, 1978; U.S. EPA, 1973b). Saline water intrusion may also occur in inland areas where freshwater aquifers are underlain by saline water. Excessive pumping draws saline water toward pumping wells due to hydrostatic pressure reductions in the freshwater aquifer (U.S. EPA, 1973b; Newport, 1977). Lateral saltwater intrusion, caused by excessive pumping, has occurred in 27 states and is a particular problem in Florida (Wilson, 1982), the Gulf Coast States (Counts and Donsky, 1963; McCollum and Counts, 1964; Walter and Kidd, 1979), New York (Lusczynski and Swarzenski, 1966), the Northeast (Newport, 1977) and the state of Washington (Wallace, 1984).

The destruction of natural barriers such as the removal of low permeability materials through dredging and deepening of coastal waterways and canals has also resulted in saltwater intrusion. This problem is often associated with saltwater encroachment in estuaries, rivers and canals in coastal areas. Reductions in surface-water flow can allow sea water, under tidal influences, to flow inland by means of rivers, channels and canals. Saltwater in these channels may then infiltrate into shallow, freshwater aquifers. This problem is especially prevalent along the east coast and Florida (U.S. EPA, 1973b; Leach and Grantham, 1966). Saltwater intrusion into the Nile Delta has formed a salt water wedge that is estimated to extend nearly 130 km inland (Kashef, 1983).

Methods to control saline water intrusion in coastal and inland areas have been successfully implemented. Lateral migration of sea water in coastal areas has been retarded by reducing and controlling ground-water pumping patterns to maintain desired hydraulic gradients. Wells may be relocated further inland or wells may be spaced further apart to minimize intensive pumping (U.S. EPA, 1973b; Newport, 1977). Artificial recharge, through surface water spreading or the formation of a hydraulic barrier through injection wells, has also been successfully implemented. Wells which are designed to pump saltwater can also be used to form an extraction barrier or trough in the saline-water wedge to maintain desired hydraulic gradients. This type of protective pumping has been successful in areas of the southeast (Gregg, 1971). Tide gate and lock control in coastal waterways can also prevent inland migration of sea water in canals and coastal waterways. The regulated release of impounded surface water to coastal rivers during low flow conditions can prevent inland migration of sea water, especially during high tide conditions (U.S. EPA, 1973b). Vertical intrusion of saline water into inland aquifers can also be controlled by minimizing areas of intensive ground-water pumping. Reduced ground-water pumping or the spatial separation of pumping wells are techniques which can be used to minimize vertical intrusion of saltwater into freshwater aquifers.

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APPENDIX D

CUMBERLAND COUNTY, MAINE

Cumberland County, Maine, lies within the Northeast and Superior Uplands hydrogeologic region. Sand and gravel aquifers are the major ground-water resource for the county and are capable of supplying significant yields to domestic and municipal wells. These aquifers consist of glacial ice-contact and outwash deposits, which occur primarily in the valleys of major rivers and along their tributaries. These deposits are typically very permeable with shallow water depths. Where sand and gravel deposits are not present, the igneous/metamorphic aquifers are used for water supplies. These aquifers are typically in hydraulic connection with overlying glacial till; however, well yields are low. The DRASTIC Index numbers reflect evaluation of water table aquifers only. Computed DRASTIC Index values range from 84 to 184.

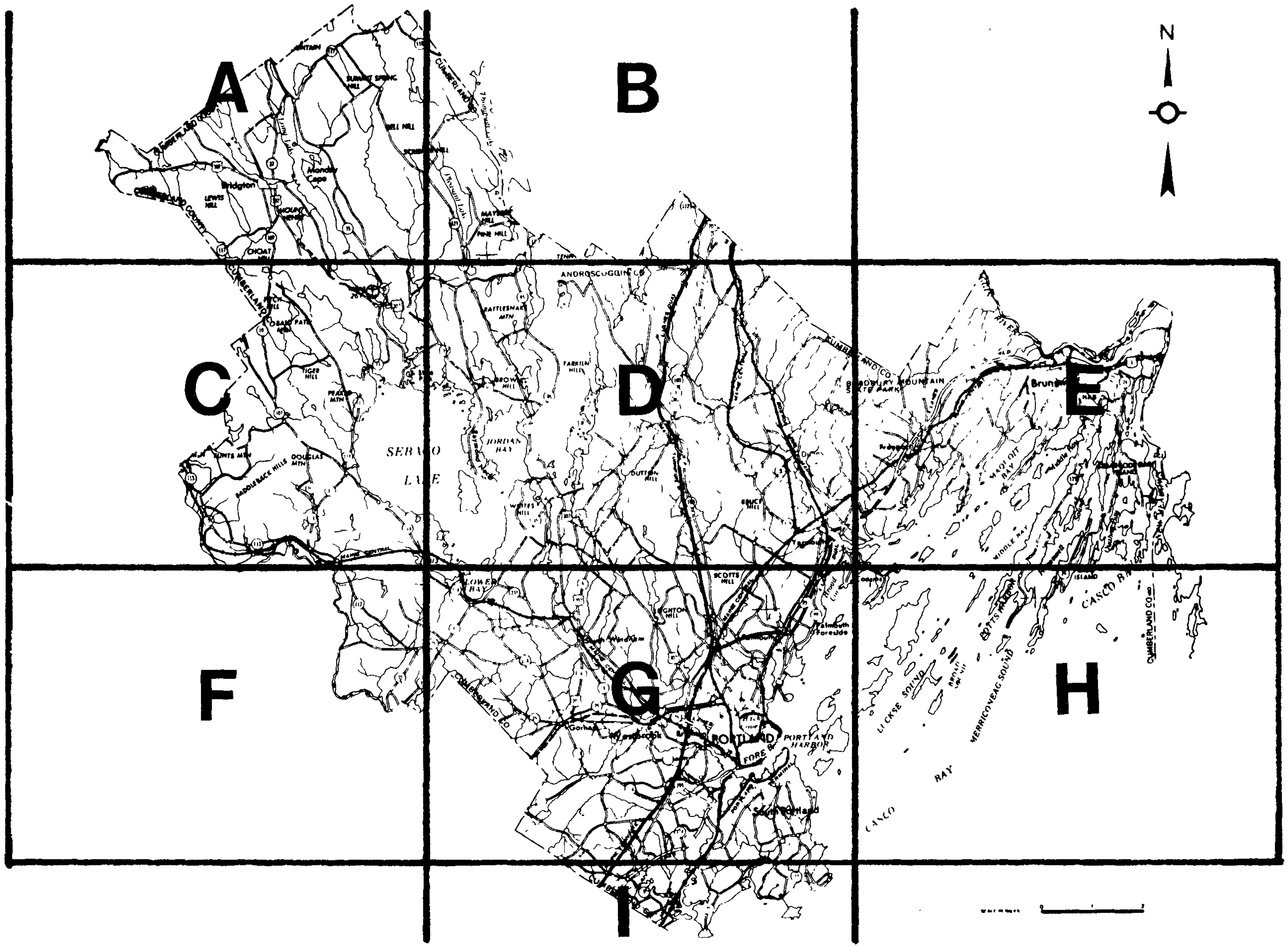
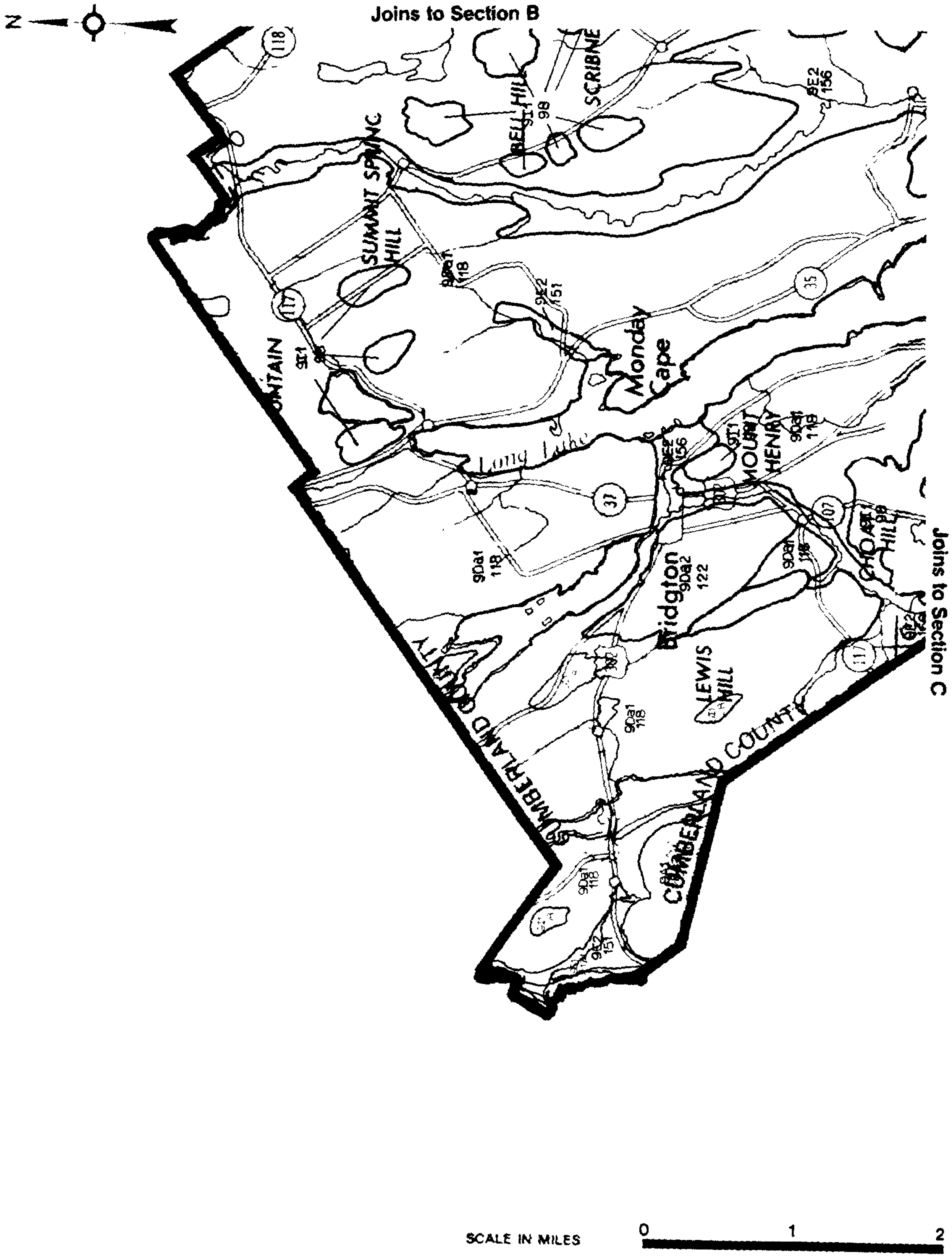
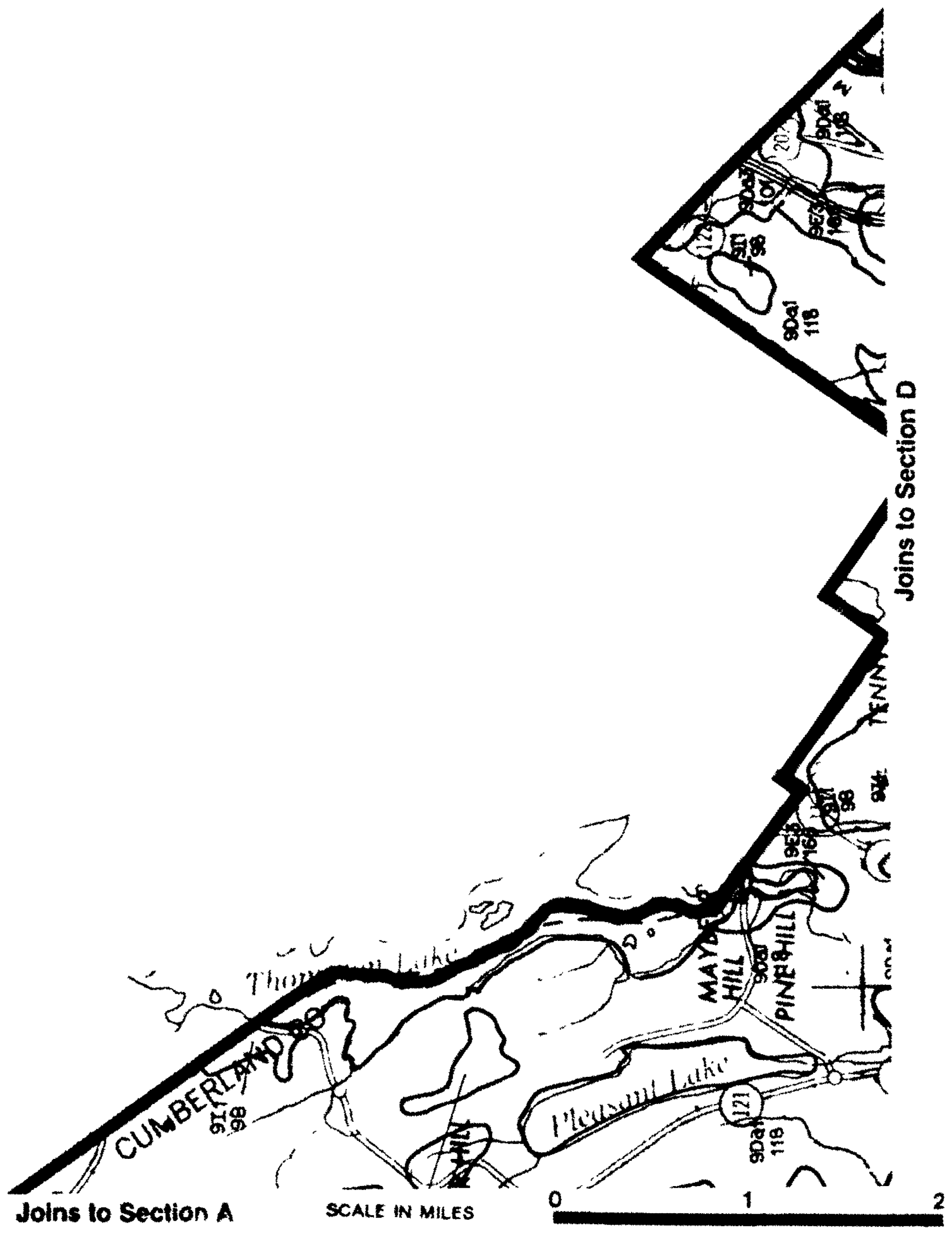


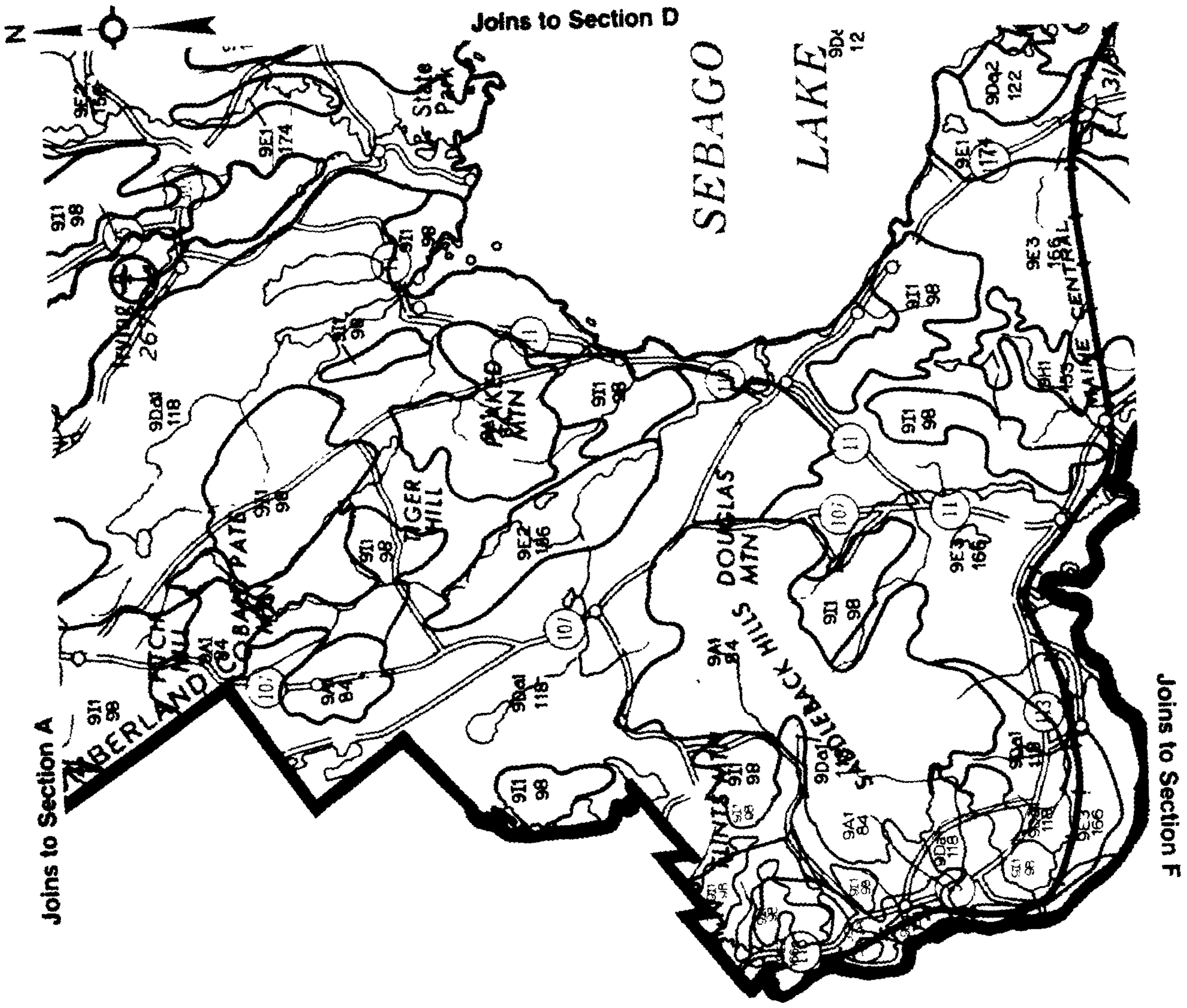
Figure D-1. Index to map sheets, detailed pollution potential map, Cumberland County, Maine.



Index Sheet A

Index Sheet B





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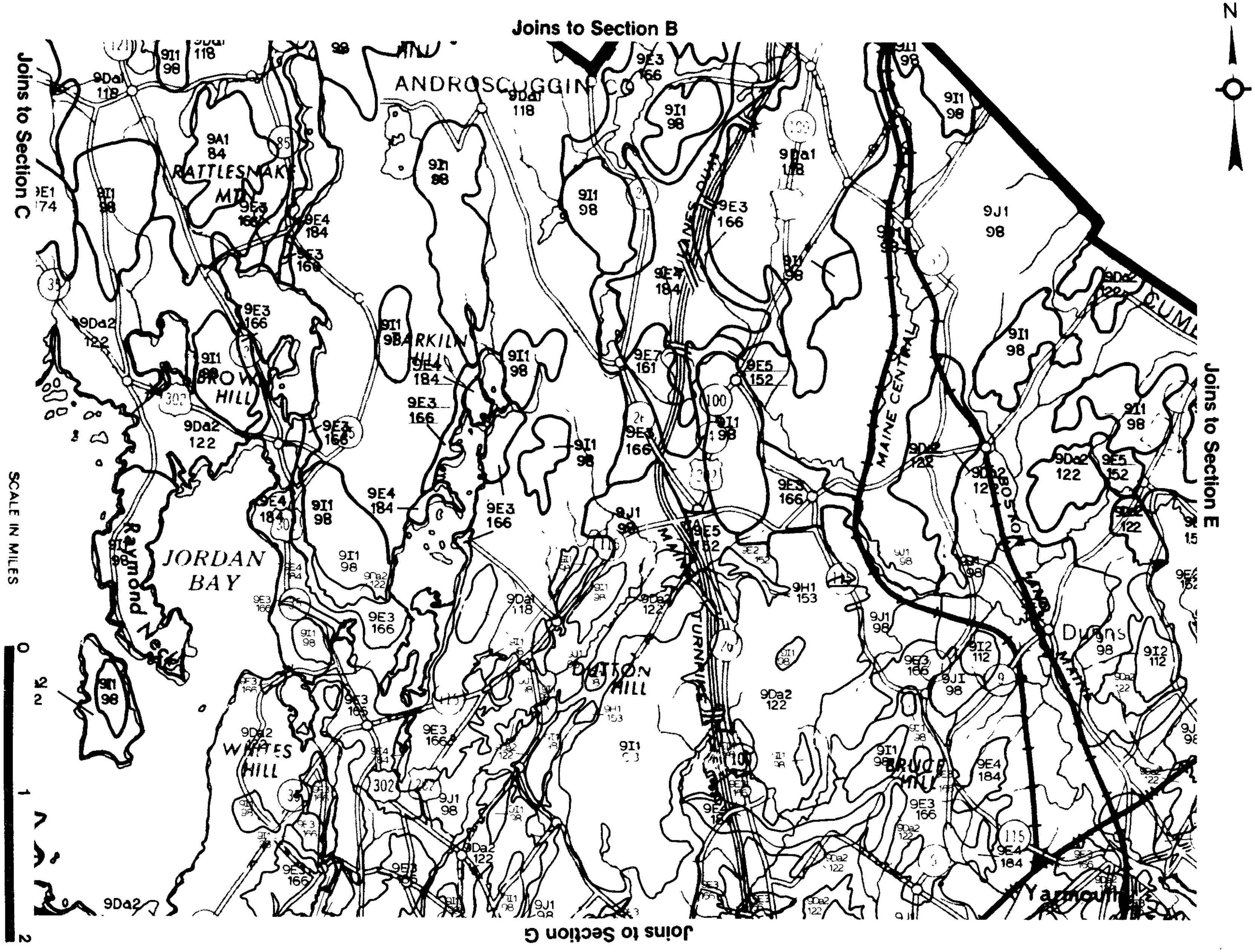
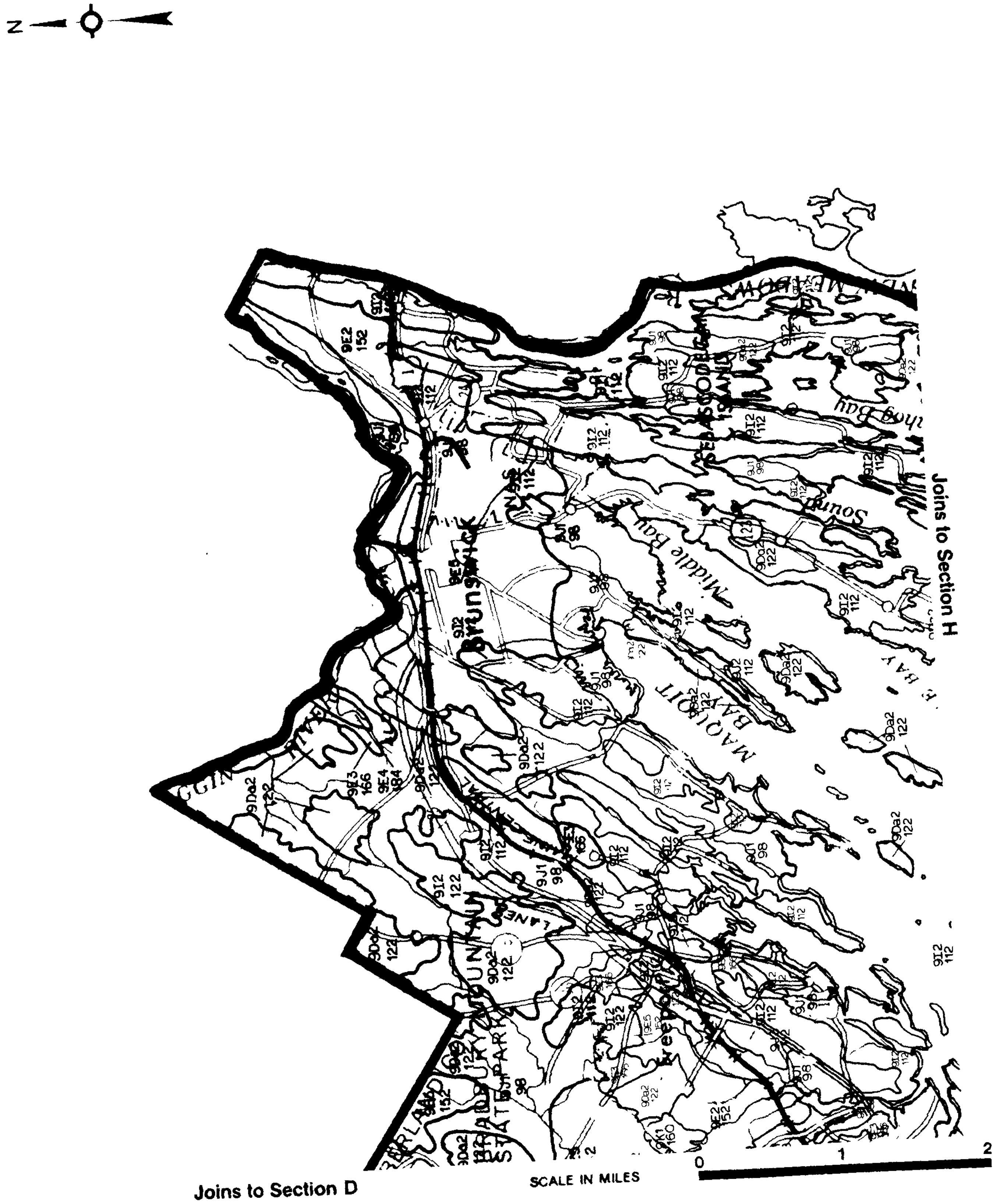
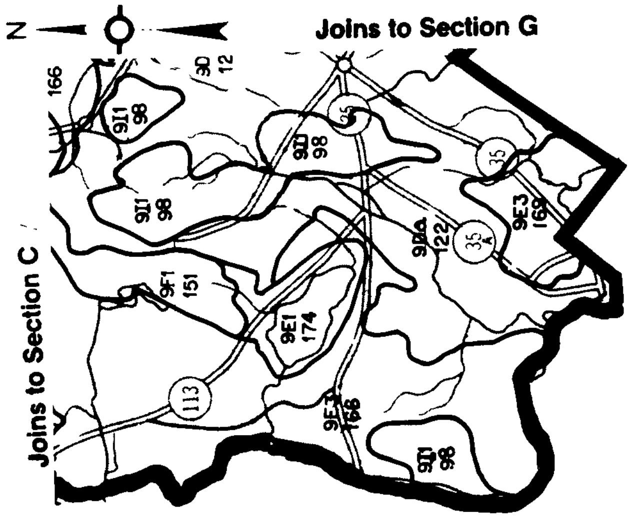
Index Sheet C



Index Sheet D

Index Sheet E





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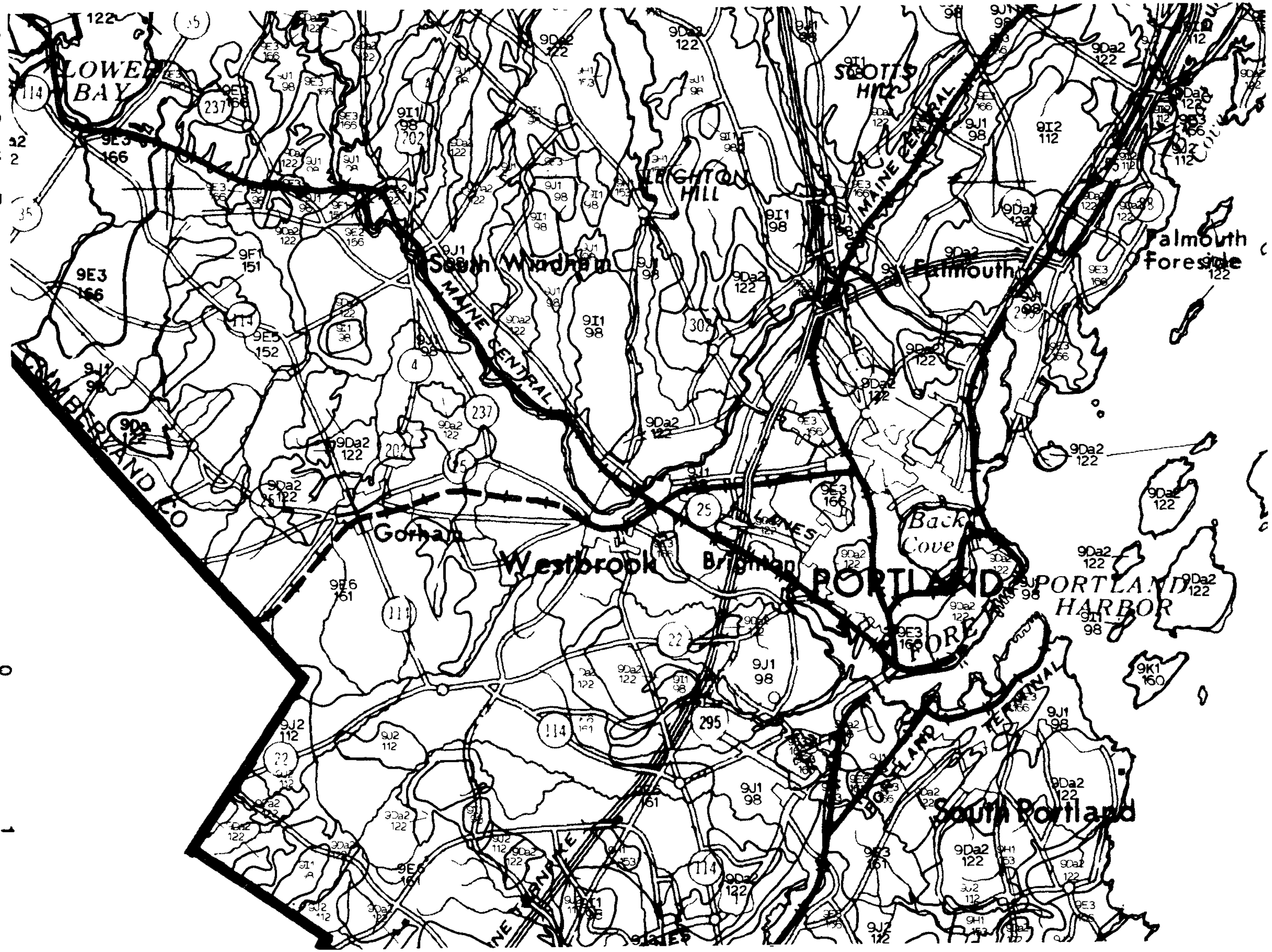
Index Sheet I

Index Sheet G

N

Joins to Section D

Joins to Section F



Joins to Section H

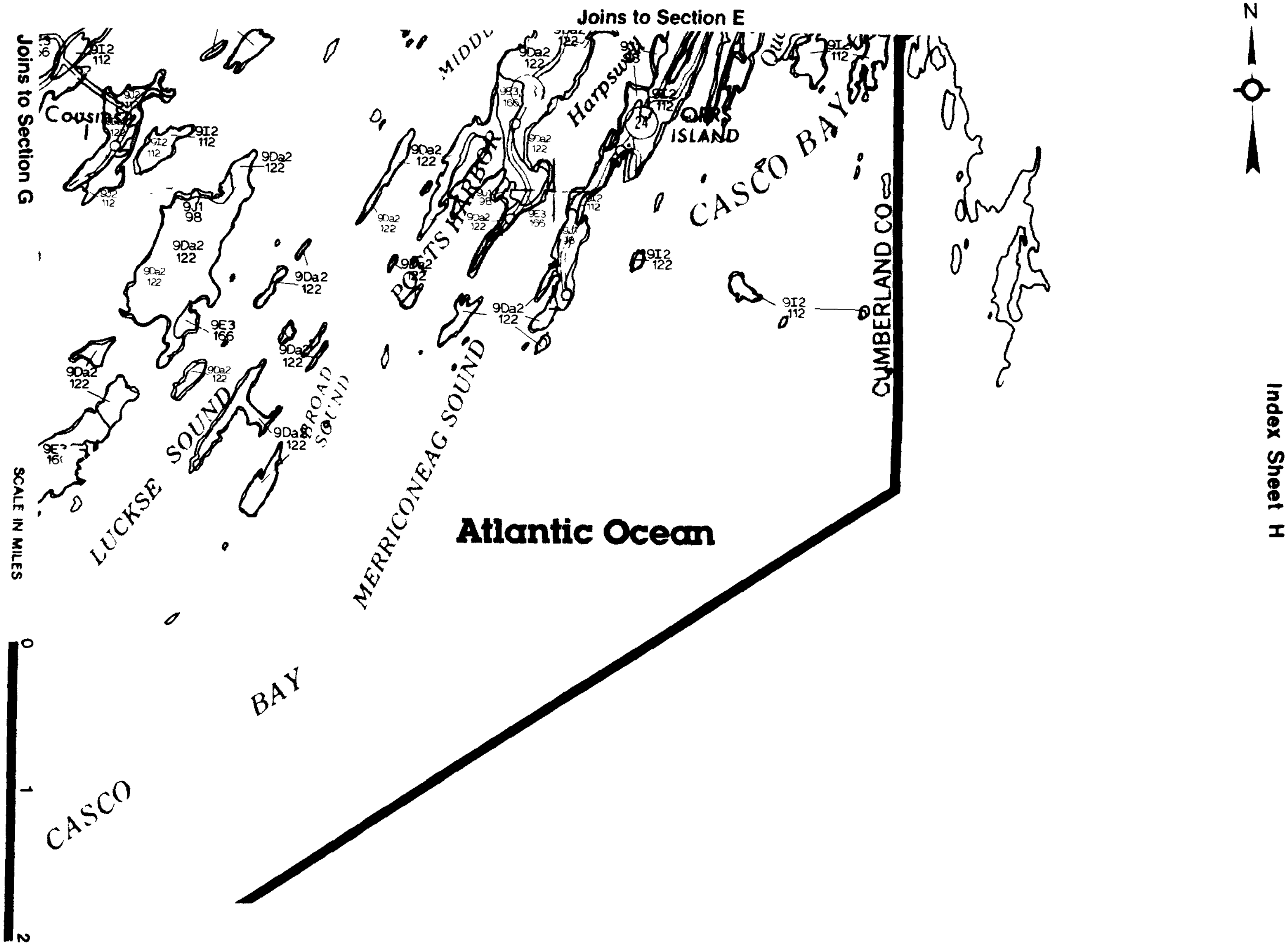
Joins to Section I

SCALE IN MILES

0

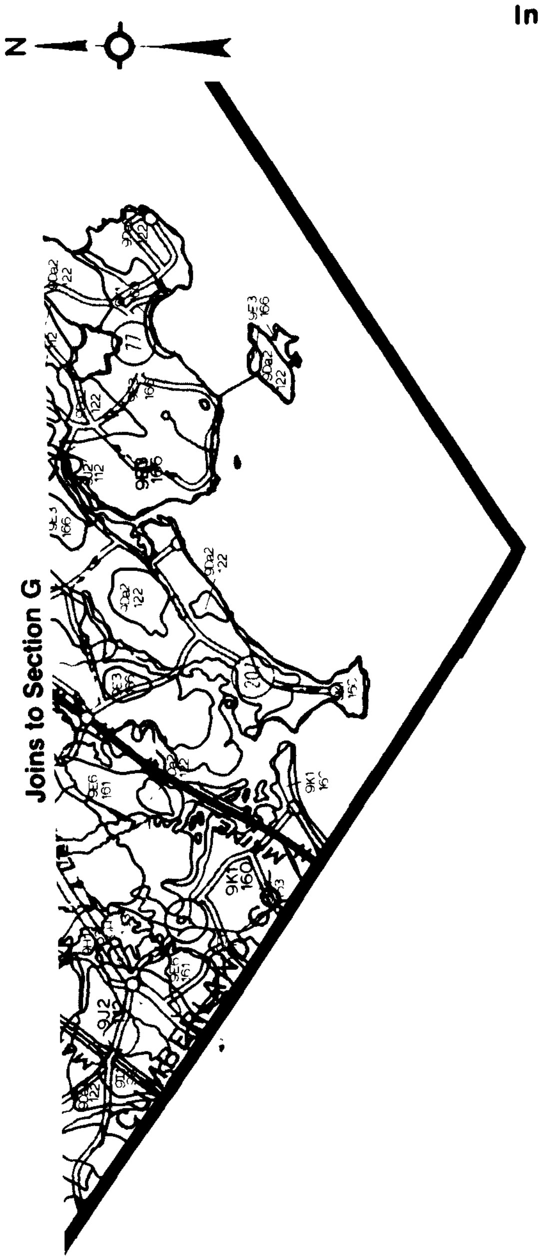
1

2



Index Sheet H

Index Sheet I

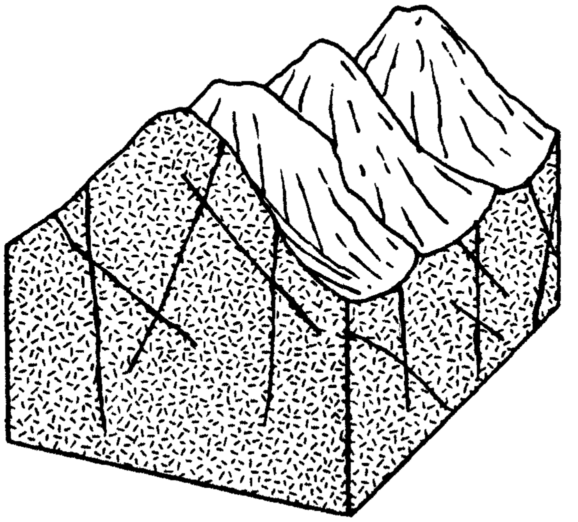


SCALE IN MILES 0 1 2

NORTHEAST AND SUPERIOR UPLANDS

(9A) Mountain Slopes

This hydrogeologic setting is characterized by steep slopes on the side of mountains, a thin soil cover and fractured bedrock. Ground water is obtained primarily from the fractures in the bedrock which may be of sedimentary, metamorphic or igneous origin but which is commonly metamorphic or igneous. The fractures provide localized sources of ground water, and well yields are typically limited. Although precipitation is abundant, due to the steep slopes, thin soil cover and small storage capacity of the fractures, runoff is significant and ground-water recharge is moderate. Water levels are extremely variable but are commonly deep.

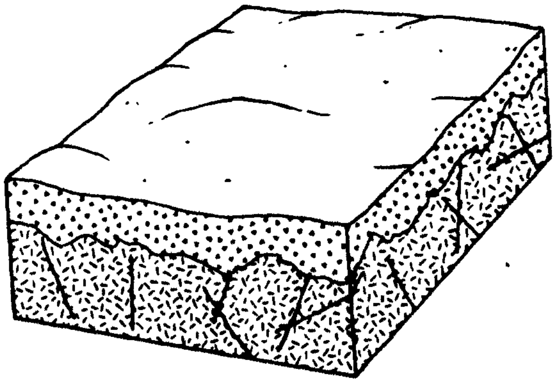


SETTING 9A1 Mountain Slopes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	4-7	4	6	24
Aquifer Media	M/I	3	3	9
Soil Media	Sandy Loam	2	6	12
Topography	18+	1	1	1
Impact Vadose Zone	M/I	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	84

NORTHEAST AND SUPERIOR UPLANDS

(9Da) Glacial Till Over Crystalline Bedrock

This hydrogeologic setting is characterized by moderately low topographic relief and varying thicknesses of glacial till overlying severely fractured, folded and faulted bedrock of igneous and metamorphic origin with minor occurrences of bedded sedimentary rocks. The till is principally unsorted deposits which may be interbedded with localized deposits of sand and gravel. Although ground water occurs in both the glacial deposits and fractured bedrock, the bedrock is typically the principal aquifer. The glacial till serves as a recharge source. Although precipitation is abundant, recharge is only moderately high because of the low permeability of the glacial till and the surficial deposits which typically weather to loam. Depth to water is extremely variable depending in part on the thickness of the glacial till, but is typically moderately shallow.



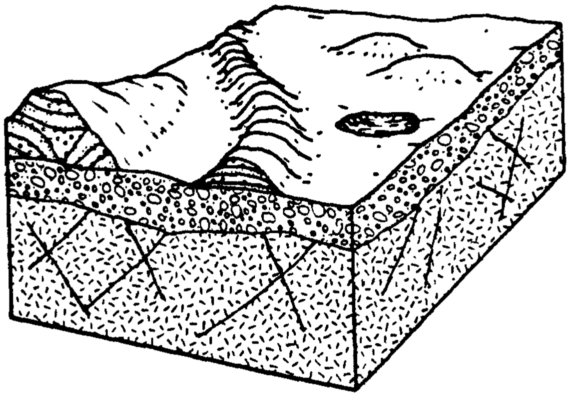
SETTING 9Da1 Glacial Till over Crystalline Bedrock		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	M/I	3	3	9
Soil Media	Sandy Loam	2	6	12
Topography	6-12	1	5	5
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	118

SETTING 9Da2 Glacial Till over Crystalline Bedrock		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	M/I	3	3	9
Soil Media	Sandy Loam	2	6	12
Topography	2-6	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	122

NORTHEAST AND SUPERIOR UPLANDS

(9E) Outwash

This hydrogeologic setting is characterized by moderate topographic relief and varying thickness of outwash which overlie fractured bedrock of sedimentary, metamorphic or igneous origin. The outwash consists of water- washed deposits of sand and gravel which often serve as the principal aquifers in the area, and which typically have a sandy loam surficial layer. The outwash also serves as a source of recharge to the underlying bedrock. Recharge is abundant and ground-water recharge is high. Water levels are extremely variable, but are relatively shallow.



SETTING 9E1 Outwash		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand/Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6	1	9	9
Impact Vadose Zone	Sand/Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	174

SETTING 9E2 Outwash		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand/Gravel	3	7	21
Soil Media	Sandy Loam	2	6	12
Topography	2-6	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	156

SETTING 9E3 Outwash		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand/Gravel	3	7	21
Soil Media	Sandy Loam	2	6	12
Topography	2-6	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	166

SETTING 9E4 Outwash		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	6	18
			Drastic Index	184

SETTING 9E5 Outwash		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Silt Loam	2	4	8
Topography	2-6	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	5	25
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	152

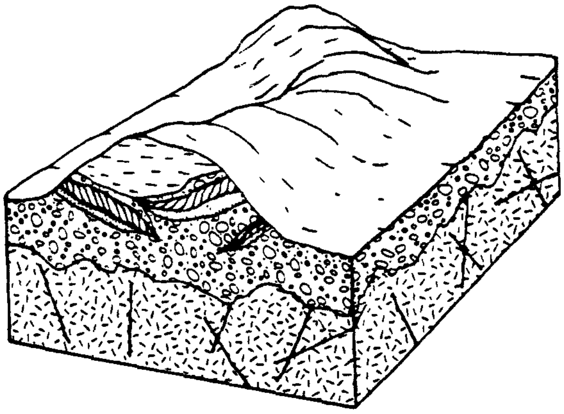
SETTING 9E6 Outwash		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand/Gravel	3	7	21
Soil Media	Sandy Loam	2	6	12
Topography	2-6	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	161

SETTING 9E7 Outwash		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silt Loam	2	4	8
Topography	2-6	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	5	25
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	161

NORTHEAST AND SUPERIOR UPLANDS

(9F) Moraine

This hydrogeologic setting is characterized by moderate topography and varying thicknesses of mixed glacial deposits which overlie fractured bedrock of sedimentary, igneous or metamorphic origin. This setting is similar to (9E) Outwash in that the sand and gravel within the morainal deposits is well-sorted and serves as the principal aquifer in the area. These deposits also serve as a source of recharge for the underlying bedrock. Moraines also contain sediments that are typically unsorted and unstratified; these deposits contain more fines than outwash deposits, are less permeable and characteristically more like glacial till. Moraines are typically mounds or ridges of till which were deposited along the margin of a stagnant or retreating glacier. Surficial deposits often weather to a sandy loam. Precipitation is abundant throughout the region and ground-water recharge is moderately high. Water levels are extremely variable, based in part on the thickness of the glacial till, but are typically fairly shallow.

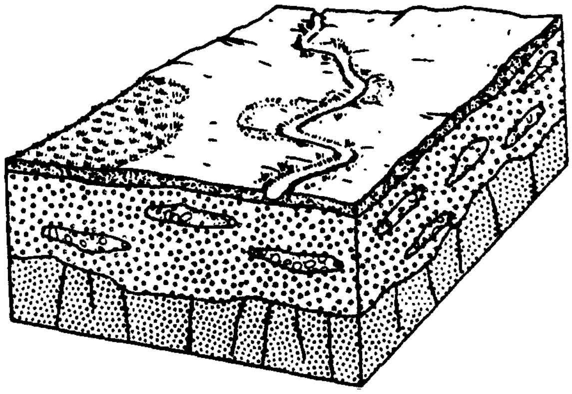


SETTING 9F1 Moraine		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Sandy Loam	2	6	12
Topography	2-6	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	151

NORTHEAST AND SUPERIOR UPLANDS

(9H) Swamp/Marsh

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

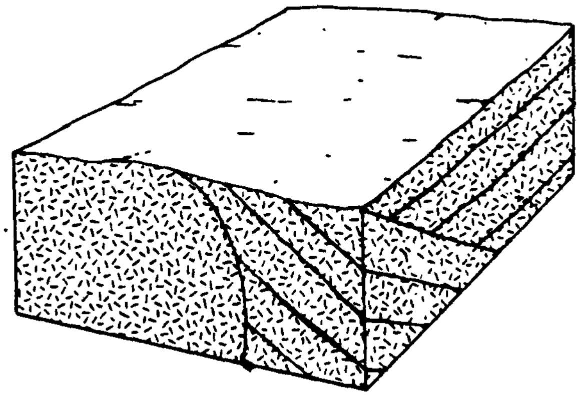


SETTING 9H1 Swamp/Marsh		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Muck	2	2	4
Topography	0-2	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	153

NORTHEAST AND SUPERIOR UPLANDS

(9I) Bedrock Uplands

This hydrogeologic setting is characterized by moderately low topographic relief and exposed fractured, folded and faulted bedrock of igneous and low-grade metamorphic origin with minor occurrences of bedded sedimentary rocks. Recharge is primarily controlled by precipitation but is limited by the hydraulic conductivity of the rock. Where present, soils are commonly sandy. These areas typically serve as limited aquifers.



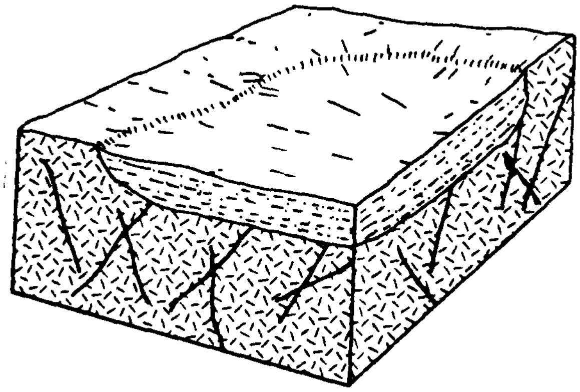
SETTING 9I1 Bedrock Uplands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	M/I	3	3	9
Soil Media	Sandy Loam	2	6	12
Topography	6-12	1	5	5
Impact Vadose Zone	M/I	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	98

SETTING 9I2 Bedrock Uplands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	M/I	3	3	9
Soil Media	Sandy Loam	2	6	12
Topography	2-6	1	9	9
Impact Vadose Zone	M/I	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	112

NORTHEAST AND SUPERIOR UPLANDS

(9J) Glacial Lake/Glacial Marine Deposits

This hydrogeologic setting is characterized by relatively flat to gently rolling topography and varying thicknesses of fine-grained sediments that overly sequences of fractured igneous and metamorphic rocks. The deposits are composed of fine-grained silts and clays interlayered with fine sand that settled out in glacial lakes and submerged coastal areas and exhibit alternating layers relating to seasonal fluctuations. Due to their fine- grained nature, these deposits range in permeabilities reflecting variations in sand content.



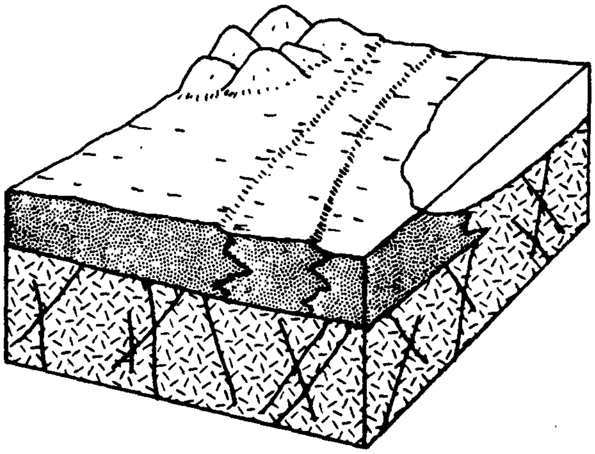
SETTING 9J1 Glacial Lake/Glacial Marine		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	M/I	3	3	9
Soil Media	Silt Loam	2	4	8
Topography	2-6	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	98

SETTING 9J2 Glacial Lake/Glacial Marine		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	M/I	3	3	9
Soil Media	Sandy Loam	2	6	12
Topography	2-6	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	112

NORTHEAST AND SUPERIOR UPLANDS

(9K) Beaches, Beach Ridges and Sand Dunes

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



SETTING	9K1 Beaches, Beach Ridges and Sand Dunes	GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	M/I	3	3	9
Soil Media	Sand	2	9	18
Topography	2-6	1	9	9
Impact Vadose Zone	Sand/Gravel	5	8	40
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	160

APPENDIX E

FINNEY COUNTY, KANSAS

Finney County, Kansas, is situated within two ground-water regions; the western half of the county is located in the High Plains region and the eastern half of the county is predominantly in the Non-Glaciated Central region. Ground-water resources in the High Plains region of the county are derived primarily from the poorly-sorted, unconsolidated sands and gravels of the Ogallala Formation which has been extensively developed for irrigation. This usage has resulted in historicaly declining ground-water levels. In the northwestern corner of the county, the Ogallala is dewatered and small domestic ground-water yields are supplied from the underlying consolidated chalky limestone. A shallow, unconfined river alluvium aquifer also occurs in the Arkansas River valley. This alluvium aquifer is in hydraulic connection with the underlying poorly sorted clay, silt, sand and gravel deposits south of the river. The DRASTIC Index numbers reflect evaluation of water table and confined aquifers. Computed DRASTIC Index values range from 50 to 166.

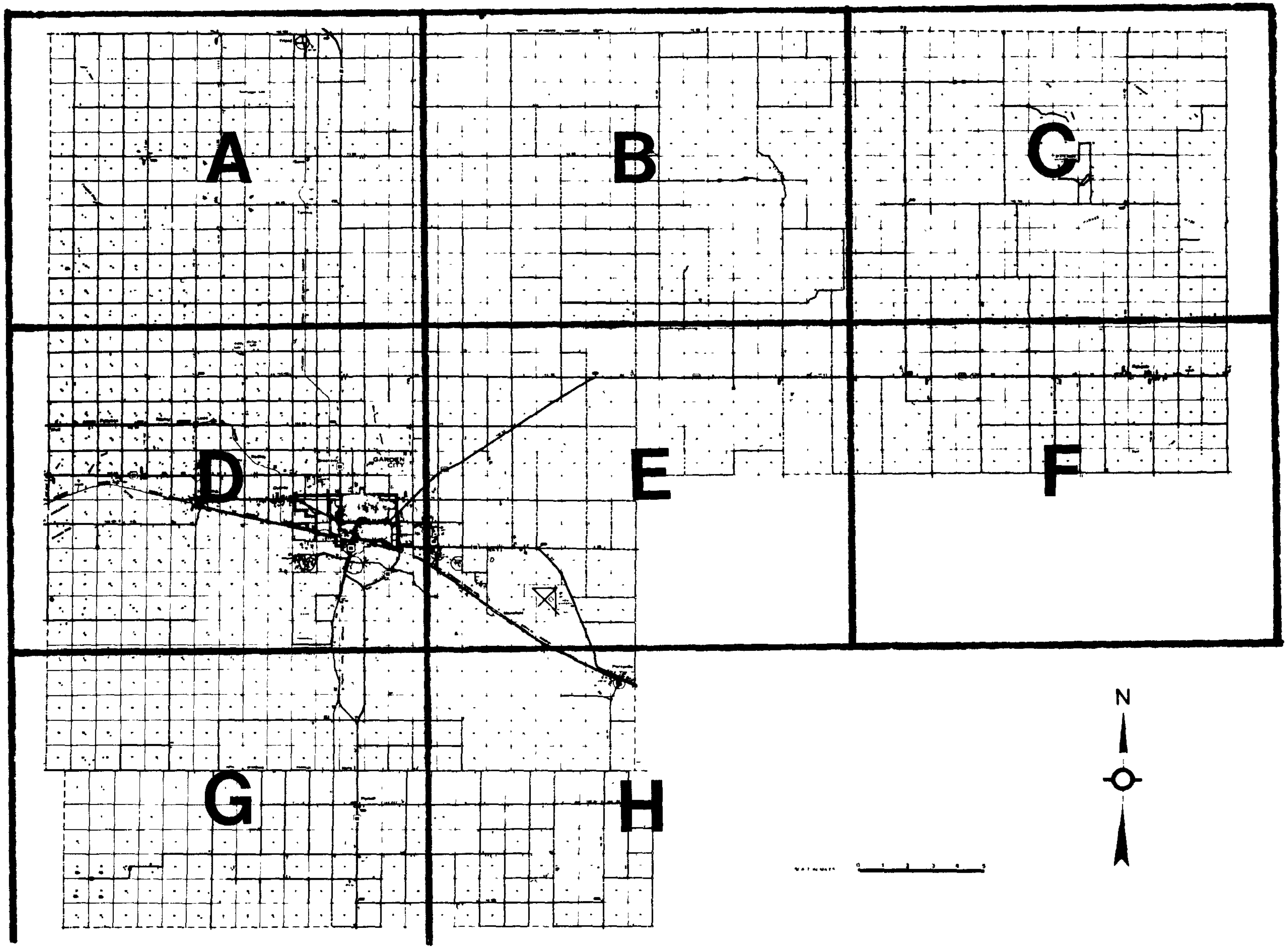
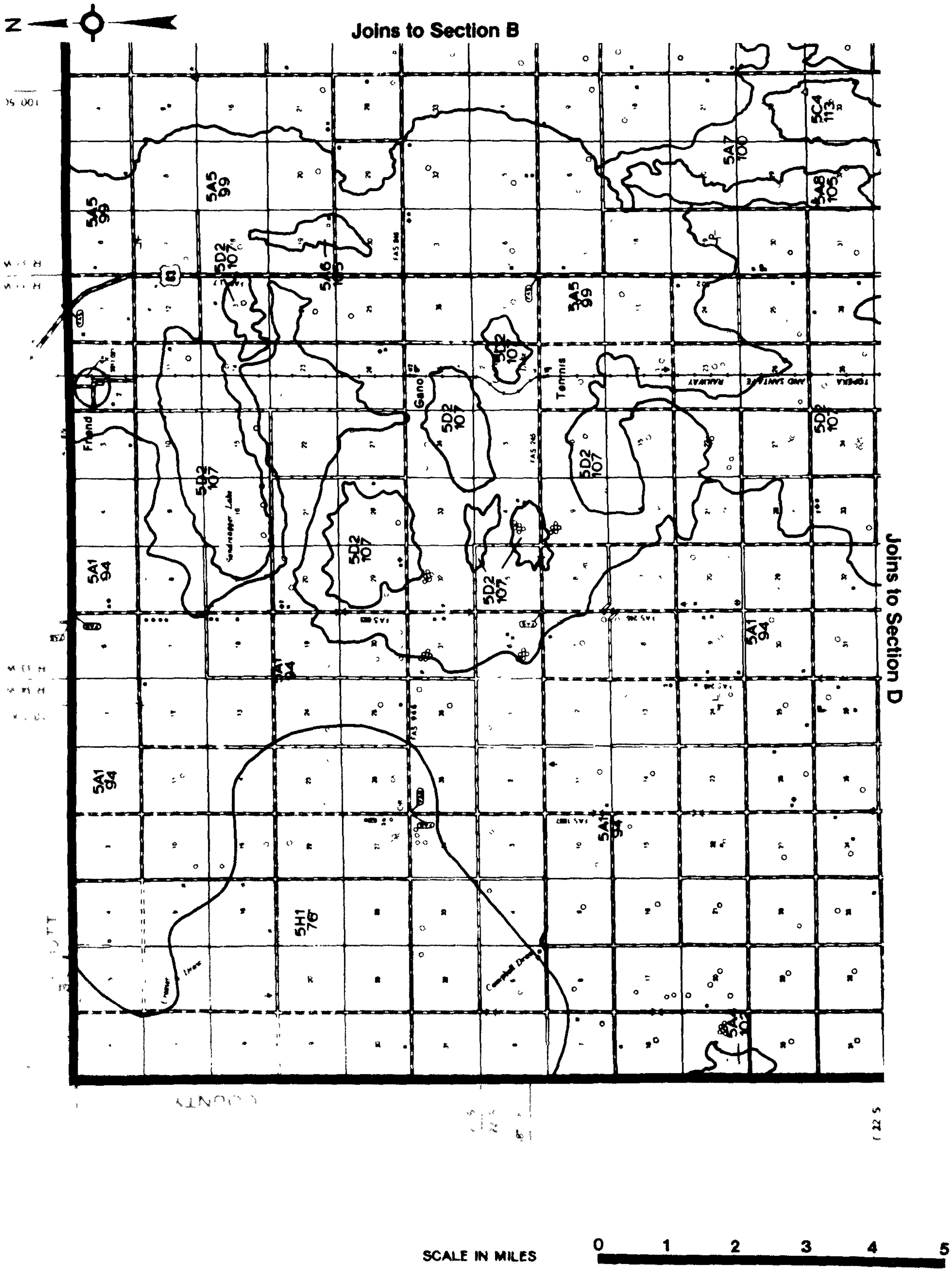
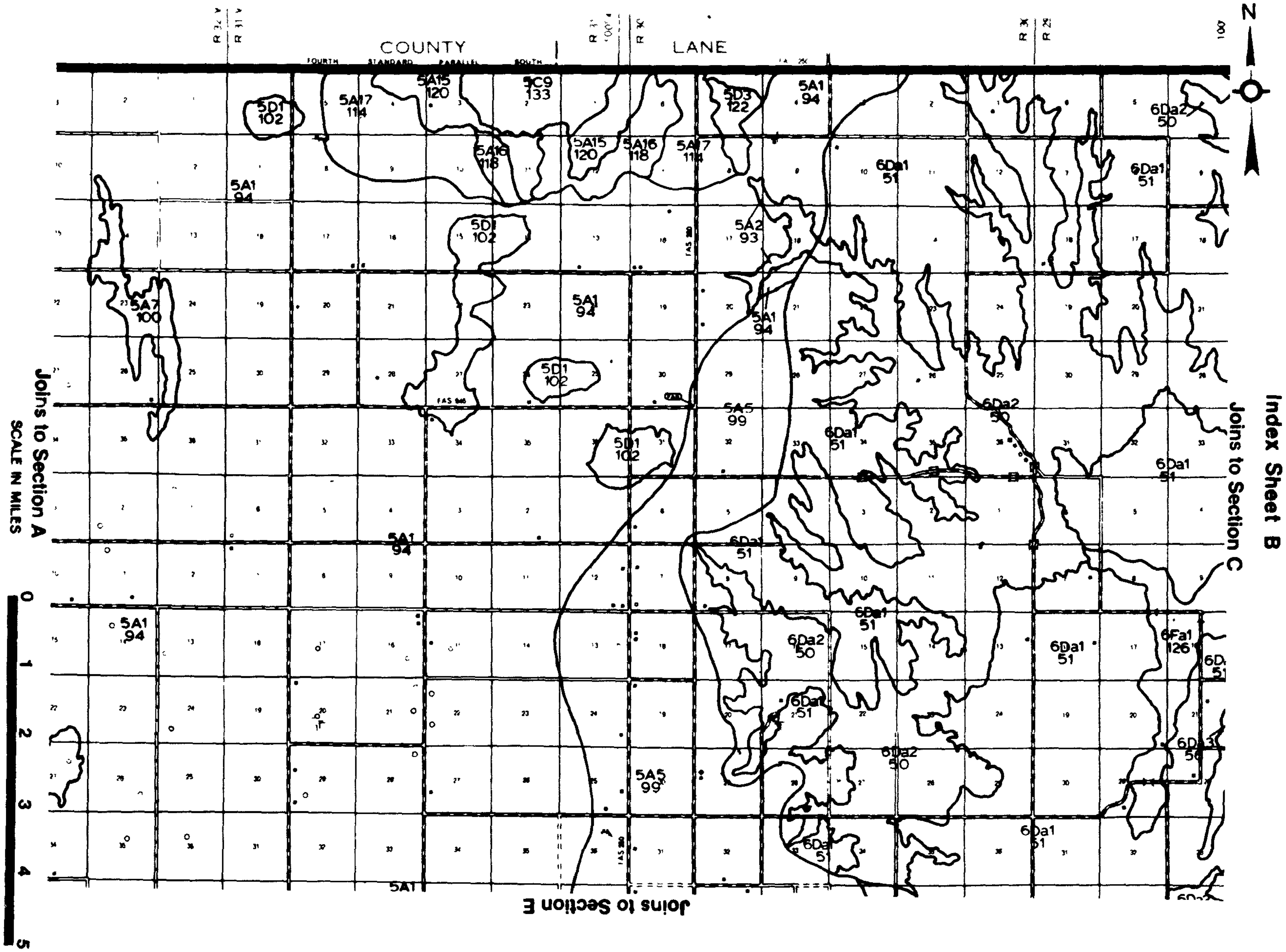


Figure E-1. Index to map sheets, detailed pollution potential map, Finney County, Kansas.



Index Sheet A


Index Sheet B
Joins to Section C
Joins to Section A
Joins to Section E
SCALE IN MILES
0
1
2
3
4
5
N
COUNTY
LANE
FOURTH STANDARD PARALLEL SOUTH
R 31 W
R 30 W
R 29 W
100
FAS 260
FAS 940
5D1 102
5A17 114
5A15 120
5C9 133
5D3 122
5A1 94
6Da2 50
5A16 118
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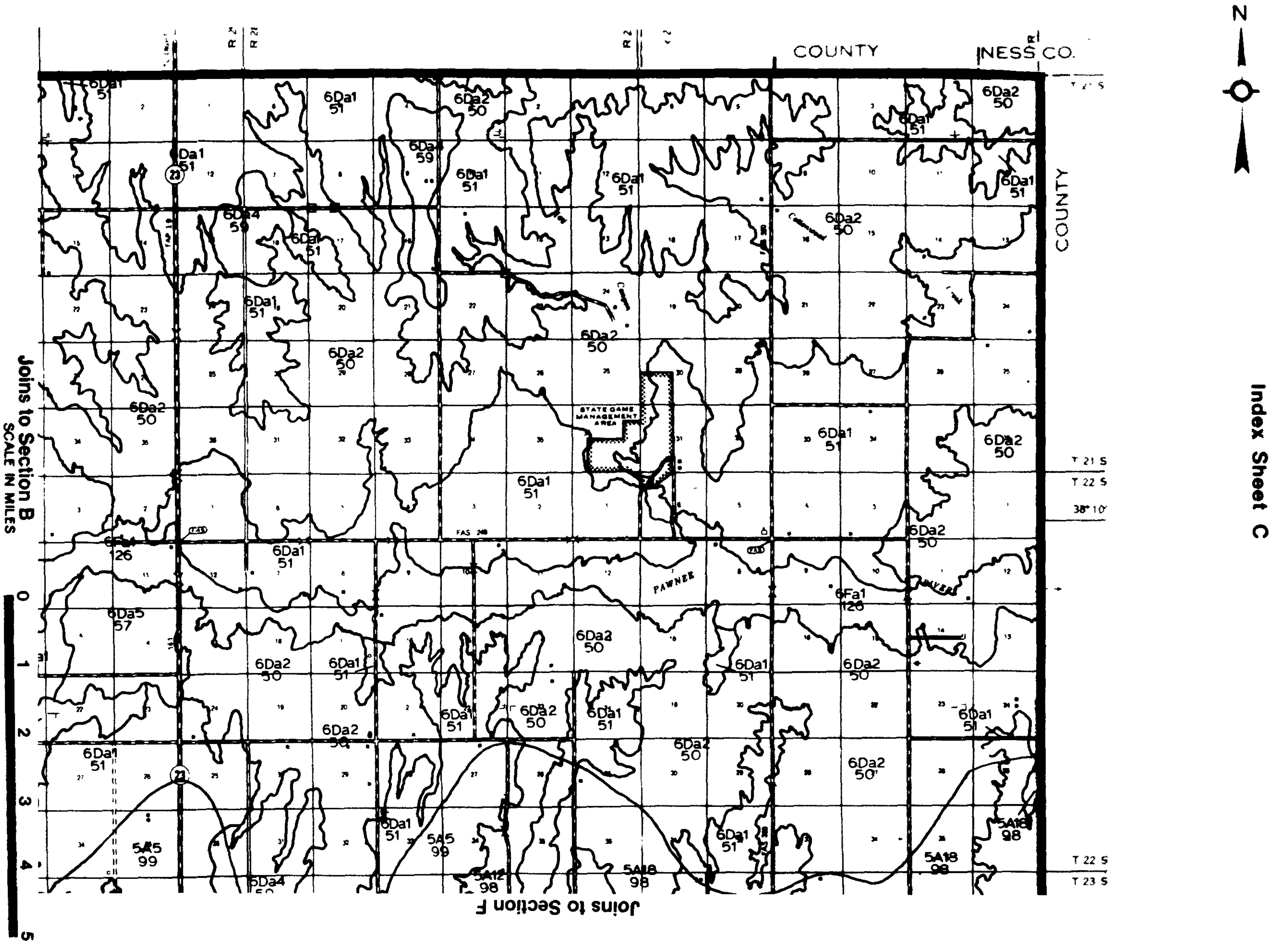
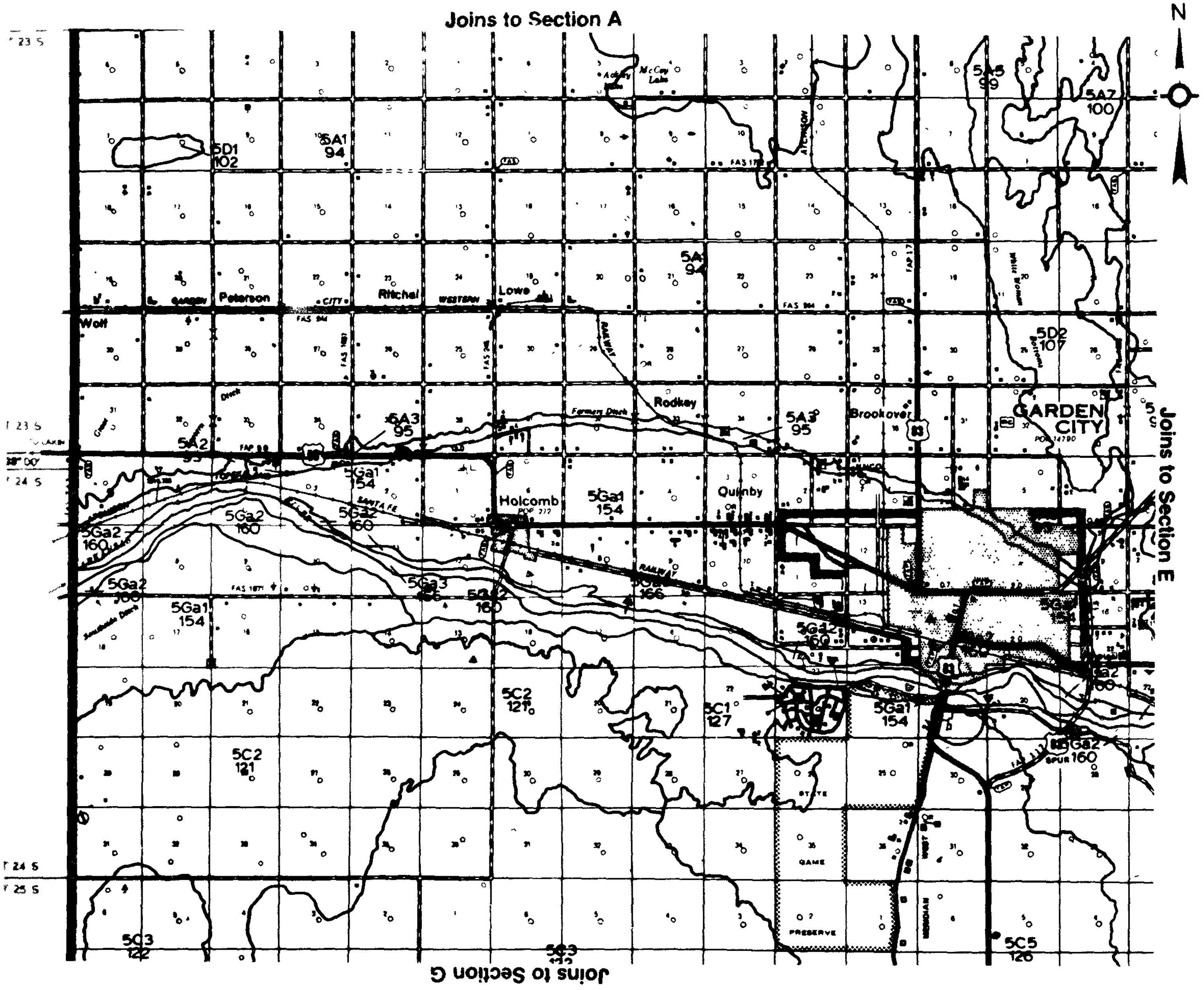
5A2 93
5A7 100
5A5 99
6Fa1 126

Index Sheet C



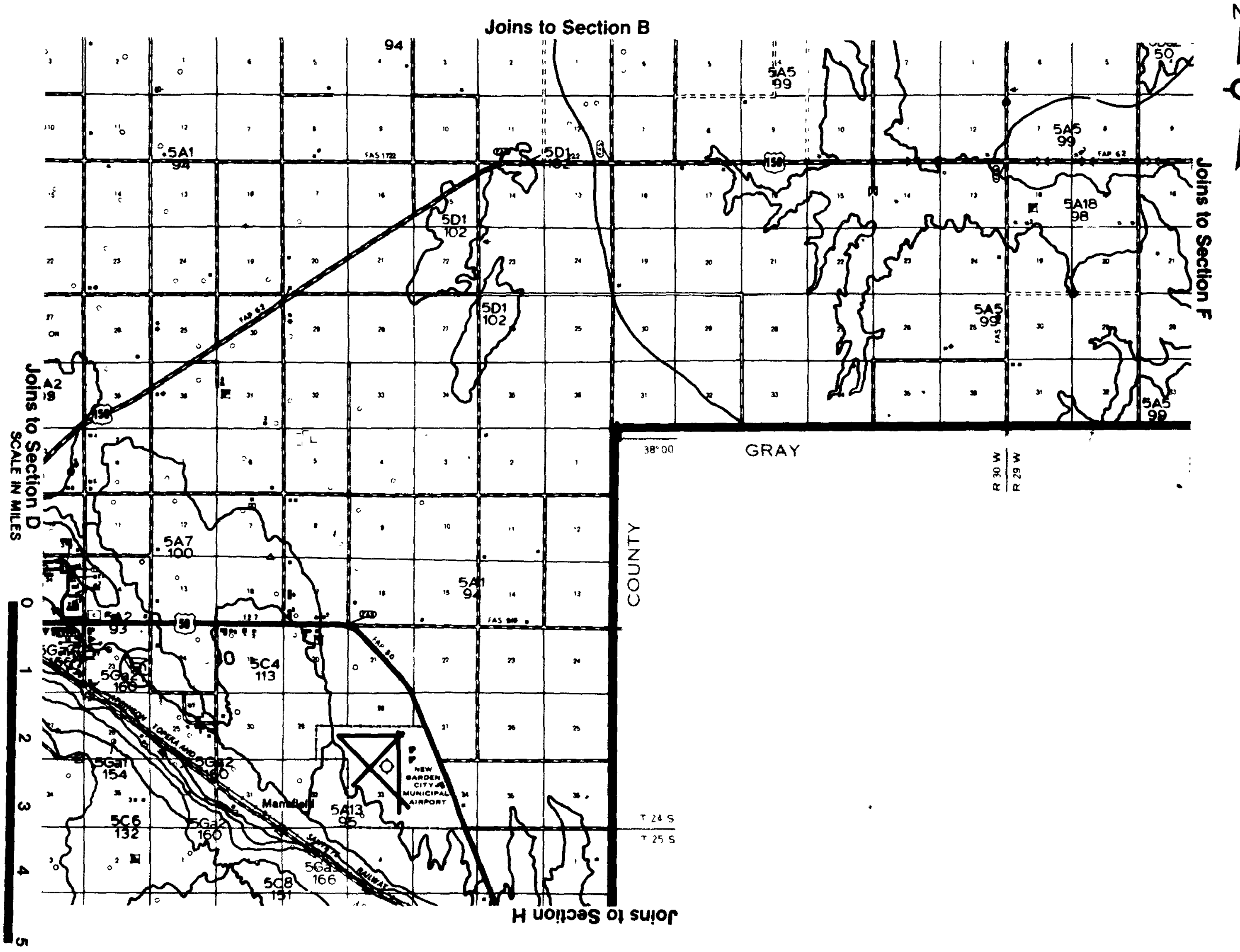


SCALE IN MILES

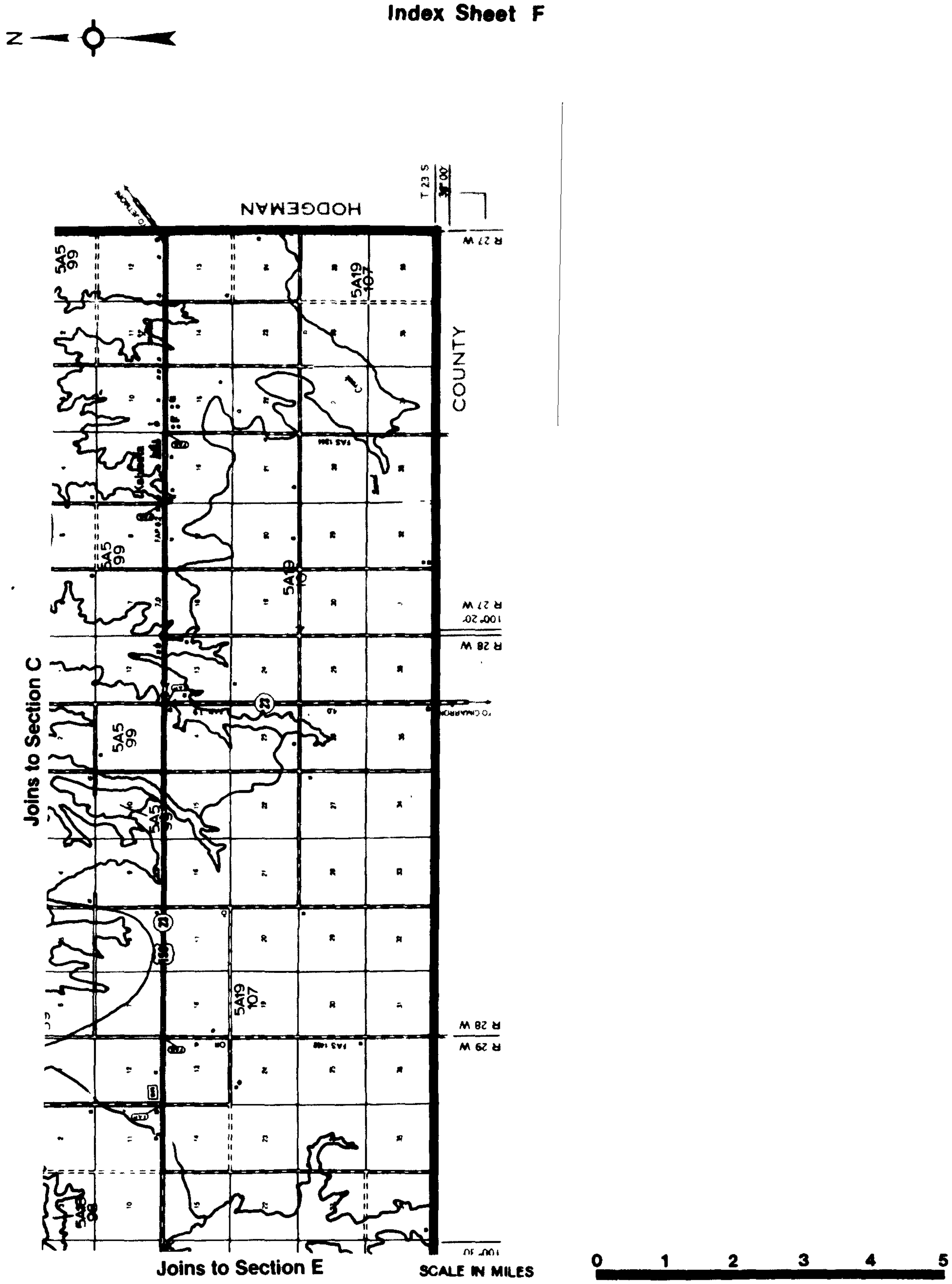
0 1 2 3 4 5

Index Sheet D

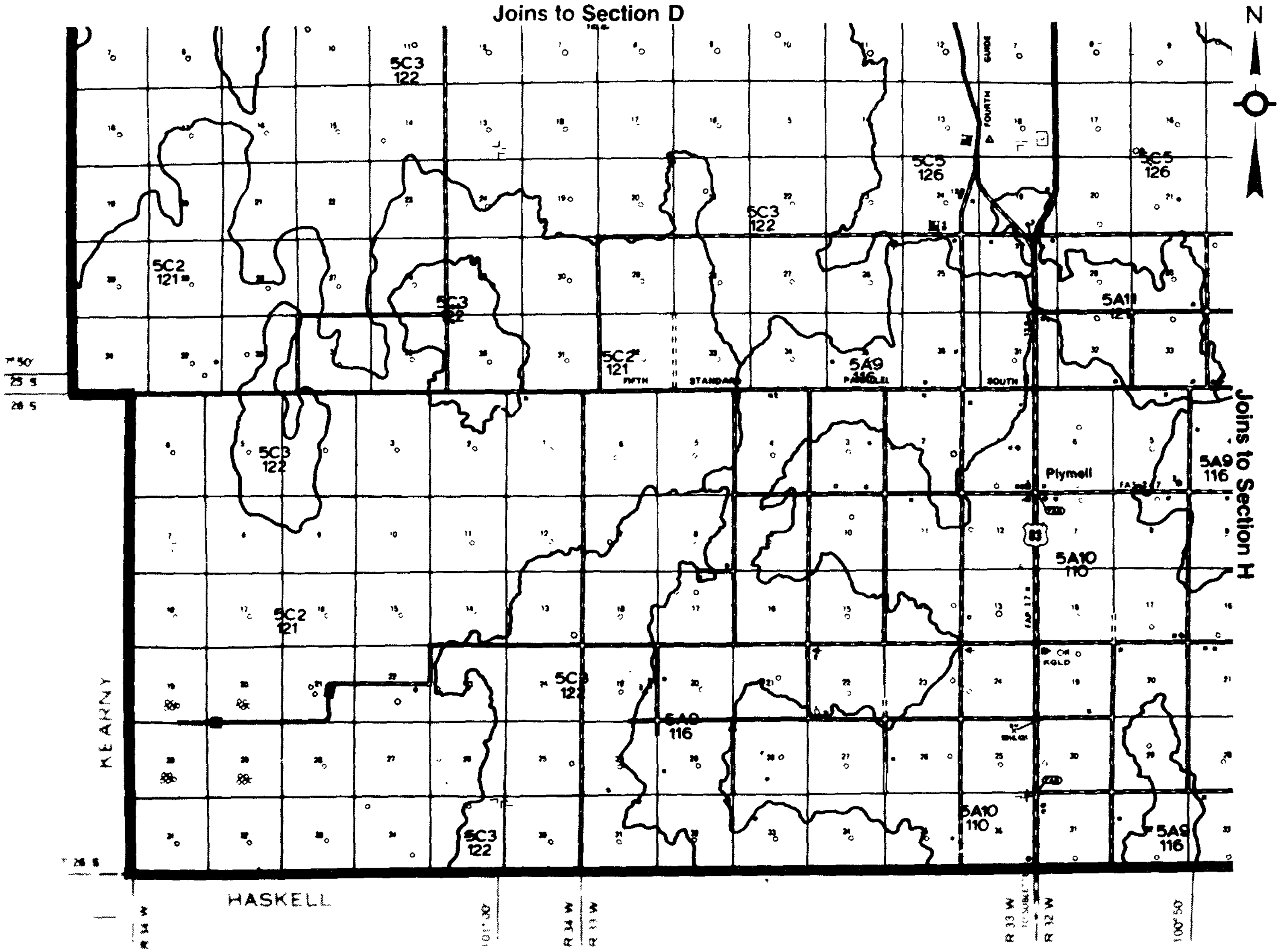
Index Sheet E



Index Sheet F

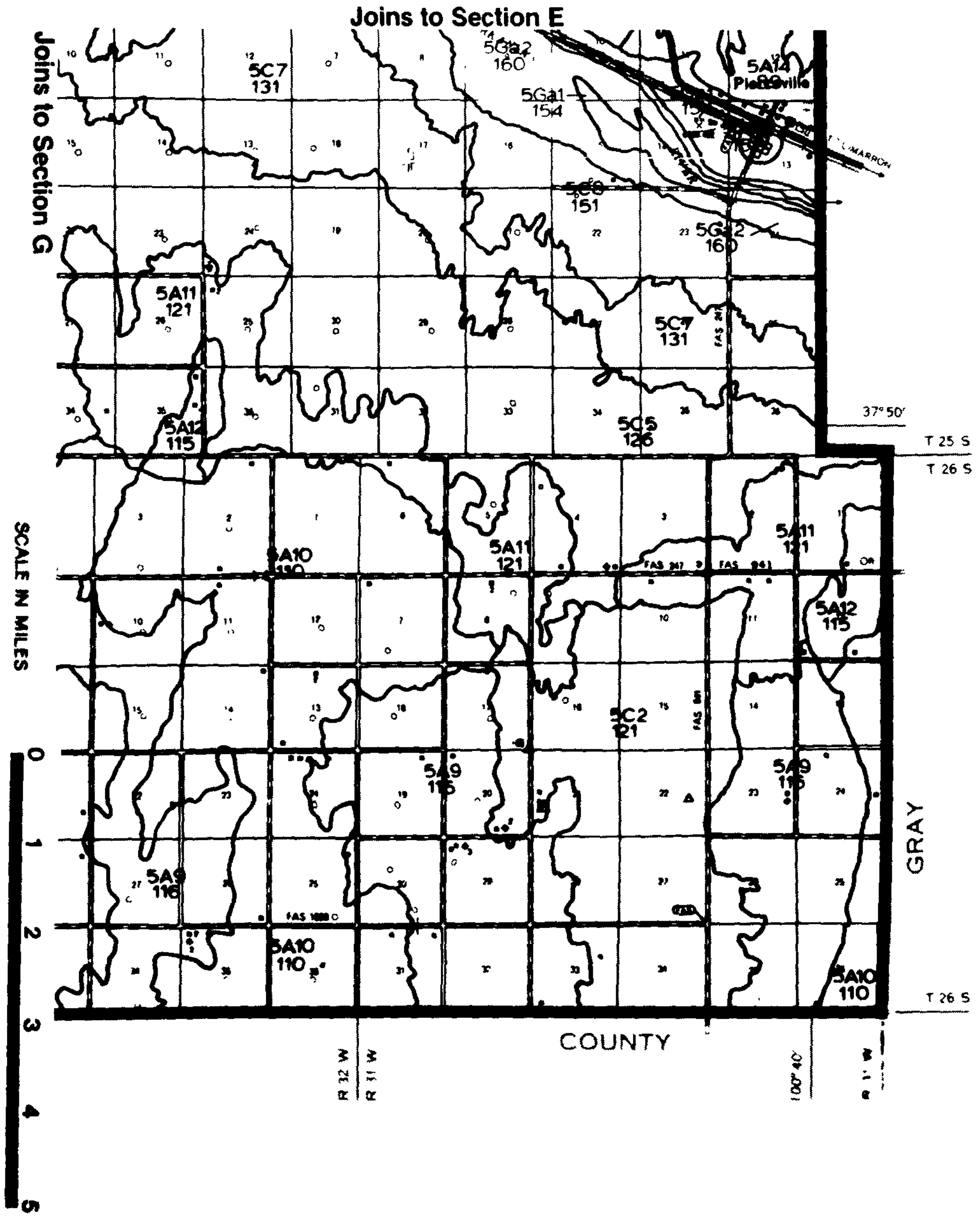


Index Sheet G



SCALE IN MILES

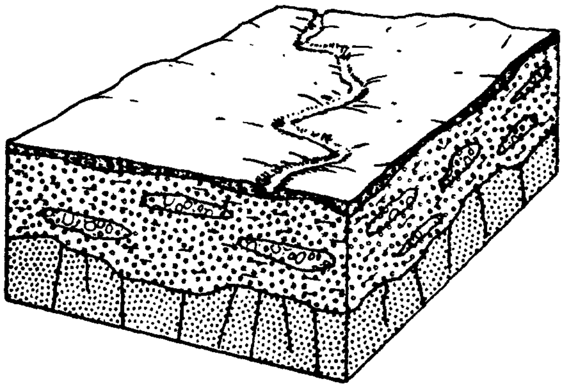
Index Sheet H



HIGH PLAINS

(5A) Ogallala

This hydrogeologic setting is characterized by moderately flat topography and thick deposits of poorly-sorted, semi-consolidated, clay, silt, sand and gravel that may be underlain by fractured sedimentary rock which is in hydraulic connection with overlying deposits. In some parts of the High Plains, especially in the southern part, shallow zones of the unconsolidated deposits have been cemented with calcium carbonate. The permeability of this caliche layer varies with the degree of cementation, fracturing and clay mineral content. Precipitation averages less than 20 inches per year and recharge is very low throughout most of this water- deficient area. The bedrock and the overlying semi-consolidated deposits both serve as extensive sources of ground water. Water levels are typically deep, but extremely variable. The Ogallala is underlain by bedded, unconsolidated deposits of fractured sandstone, limestone, volcanic ash, silty sand, sandy clay and shales. These formations are hydraulically connected to the Ogallala and the overlying alluvium, from which they derive their recharge.



SETTING 5 A1 Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Clay Loam	2	3	6
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	94

SETTING 5 A2 Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	93

SETTING 5 A3 Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Silt Loam	2	4	8
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	95

SETTING 5 A4 Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Sh and/or Agg. Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	102

SETTING 5 A5 Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Clay Loam	2	3	6
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	99

SETTING 5 A6 Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	105

SETTING 5 A7 Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	100

SETTING 5 A8 Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	105

SETTING 5 A9 Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	116

SETTING 5 A10 Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Clay Loam	2	3	6
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	110

SETTING 5 A11 Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	121

SETTING 5 A12 Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Clay Loam	2	3	6
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	115

SETTING 5 A13 Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Sandy Loam	2	6	12
Topography	6-12%	1	5	5
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	95

SETTING 5 A14 Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Clay Loam	2	3	6
Topography	6-12%	1	5	5
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	89

SETTING 5 A15 Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	120

SETTING 5 A16 Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Loam	2	5	10
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	118

SETTING 5 A17 Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Clay Loam	2	3	6
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	114

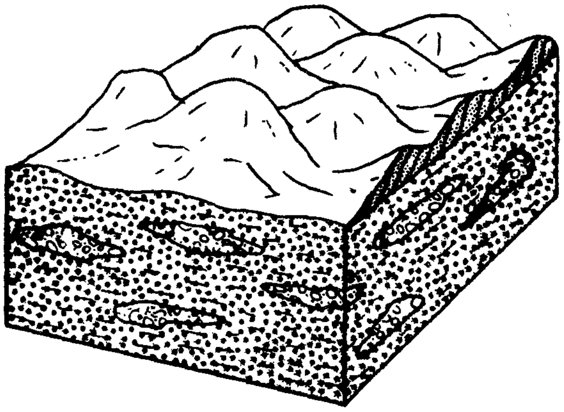
SETTING 5 A18 Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	98

SETTING 5 A19 Ogallala		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Sh and/or Agg. Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	107

HIGH PLAINS

(5C) Sand Dunes

This hydrogeologic setting is characterized by hilly topography comprised of sand dunes which overlie thick poorly-sorted sand and gravel deposits. The sand dunes are in direct hydraulic connection with the underlying deposits. Because of their relatively low water table, these dunes do not serve as sources of ground water, but serve as local recharge areas. In contrast to other areas of the High Plains, recharge rates are higher due to lower evaporation and permeable sandy soils, but are limited by available precipitation.



SETTING 5 C1 Sand Dunes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	127

SETTING 5 C2 Sand Dunes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	121

SETTING 5 C3 Sand Dunes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	122

SETTING 5 C4 Sand Dunes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	113

SETTING 5 C5 Sand Dunes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	126

SETTING 5 C6 Sand Dunes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	132

SETTING 5 C7 Sand Dunes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	131

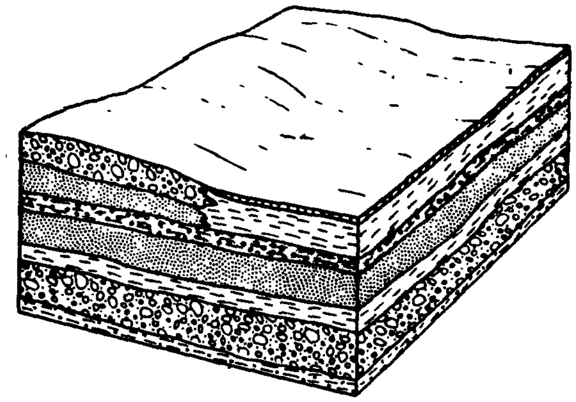
SETTING 5 C8 Sand Dunes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	9	45
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	151

SETTING 5 C9 Sand Dunes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	133

HIGH PLAINS

(5D) Playa Lakes

This hydrogeologic setting is characterized by low topographic relief and thin layers of clays and other fine-grained sediments which overlie the alluvial deposits. The playa areas serve as a catchment for water during periods of significant runoff. Ground water is obtained from the layers of sand which underlie the finer-grained deposits. Water levels are extremely variable, but are typically deep. The playa beds are significant recharge areas due to the rainfall that collects in them. The rate of recharge, as compared to evaporation, is largely a function of the permeability of the materials forming the bed of the playa, and the precipitation distribution over time.



SETTING 5 D1 Playa Lake		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Sh and/or Agg. Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	102

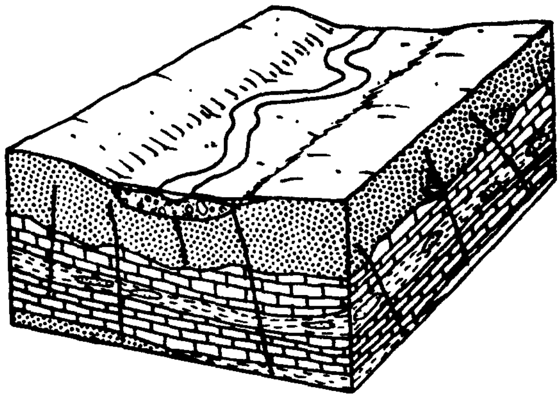
SETTING 5 D2 Playa Lake		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Sh and/or Agg. Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	107

SETTING 5 D3 Playa Lake		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Sh and/or Agg. Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	122

HIGH PLAINS

(5Ga) River Alluvium With Overbank Deposits

This hydrogeologic setting is characterized by low to moderate topography and thin to moderately thick deposits of alluvium along parts of river valleys. The alluvium is underlain by either unconsolidated deposits or fractured bedrock of sedimentary or igneous origin. Water is obtained from sand and gravel layers which are interbedded with finer-grained alluvial deposits. The alluvium may or may not be in direct hydraulic connection with the underlying units. The alluvium typically serves as a significant source of water. The flood plain is covered by varying thicknesses of fine-grained silt and clay, called overbank deposits. The overbank thickness is usually greater along major streams and thinner along minor streams but typically averages approximately 5 to 10 feet. Recharge is limited throughout most of the area by low precipitation. Water levels are typically moderately shallow and may be hydraulically connected to the stream or river.



SETTING 5 Ga1 River Alluvium With Overbank		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	9	27
Soil Media	Clay Loam	2	3	6
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	154

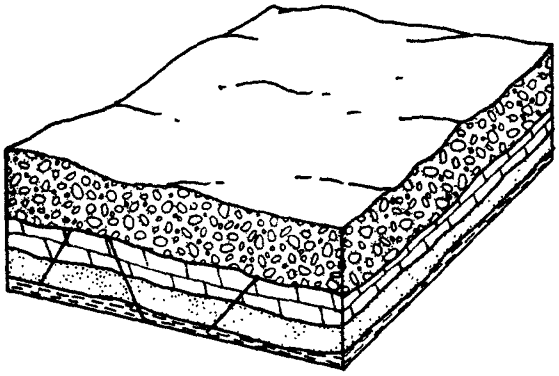
SETTING 5 Ga2 River Alluvium With Overbank		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	9	27
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	160

SETTING 5 Ga3 River Alluvium With Overbank		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	9	27
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	166

HIGH PLAINS

(5H) Alternating Sandstone, Limestone and Shale Sequences

This hydrogeologic setting is characterized by low topographic relief and loamy soils which overlie thick deposits of poorly sorted, semi- consolidated clay, silt, sand and gravel. These unconsolidated deposits are underlain by horizontal or slightly dipping alternating layers of fractured consolidated sedimentary rocks. Precipitation averages less than 20 inches per year and recharge is very low throughout most of this water-deficient area. In areas where the unconsolidated deposits are not saturated, ground water is obtained primarily from fractures along bedding planes or intersecting vertical fractures. Where the unconsolidated deposits contain water, they are typically in direct hydraulic connection with the underlying bedrock.

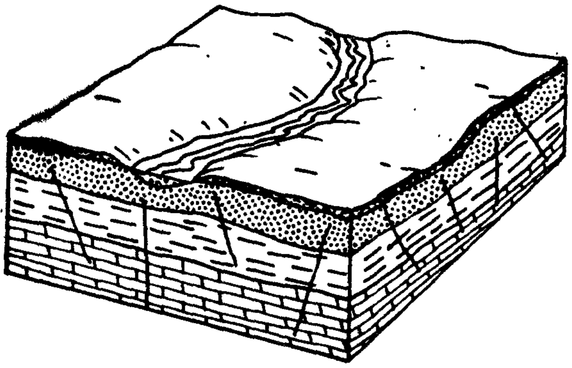


SETTING 5 H1 Alternating SS, LS, SH Sequences		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Massive Limestone	3	6	18
Soil Media	Clay Loam	2	3	6
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	76

NON-GLACIATED CENTRAL

(6Da) Alternating Sandstone, Limestone and Shale - Thin Soil

This hydrogeologic setting is characterized by low to moderate topographic relief, relatively thin loamy soils overlying horizontal or slightly dipping alternating layers of fractured consolidated sedimentary rocks. Ground water is obtained primarily from fractures along bedding planes or intersecting vertical fractures. Precipitation varies widely in the region, but recharge is moderate where precipitation is adequate. Water levels are extremely variable but on the average moderately shallow. Shale or clayey layers often form aquitards, and where sufficient relief is present, perched ground water zones of local domestic importance are often developed.



SETTING 6 Da1 Alternating SS, LS, SH - Thin Soil		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Massive Sandstone	3	6	18
Soil Media	Clay Loam	2	3	6
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	1	5
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	51

SETTING 6 Da2 Alternating SS, LS, SH - Thin Soil		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Massive Sandstone	3	6	18
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	1	5
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	50

SETTING 6 Da3 Alternating SS, LS, SH - Thin Soil		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Massive Sandstone	3	6	18
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	1	5
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	56

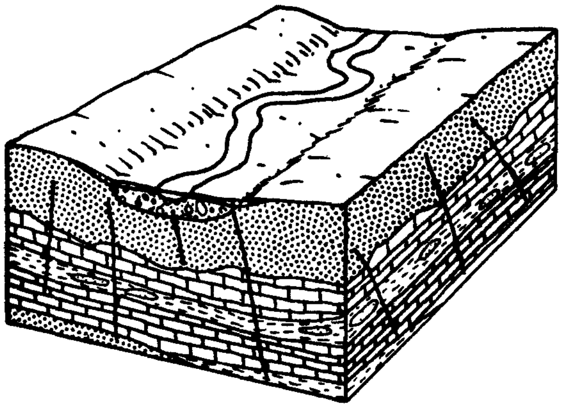
SETTING 6 Da4 Alternating SS, LS, SH - Thin Soil		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Massive Sandstone	3	6	18
Soil Media	Sh and/or Agg. Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	1	5
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	59

SETTING 6 Da5 Alternating SS, LS, SH - Thin Soil		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Massive Sandstone	3	6	18
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	1	5
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	57

NON-GLACIATED CENTRAL

(6Fa) River Alluvium with Overbank Deposits

This hydrogeologic setting is characterized by low topography and deposits of alluvium along parts of stream valleys. Water is obtained from sand and gravel layers which are interbedded with finer-grained alluvial deposits. The floodplain is covered by varying thicknesses of fine-grained silt and clay called overbank deposits. The overbank thickness is usually thicker along major streams (commonly as much as 40 feet), and thinner along minor streams. Precipitation varies widely over the region, but recharge is somewhat reduced because of the impermeable nature of the overbank deposits and subsequent clayey loam soils which typically cover the surface. There is usually substantial recharge, however, due to infiltration from the associated stream, water levels are typically moderately shallow. The alluvium is commonly in direct hydraulic connection with the underlying sedimentary rocks.



SETTING 6 Fa1 River Alluvium With Overbank		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	0-2	4	1	4
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Clay Loam	2	3	6
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	126

APPENDIX F

GILLESPIE COUNTY, TEXAS

Gillespie County, Texas, lies within the Nonglaciated Central Hydrogeologic Region. Several different aquifers occur within the county which provide adequate municipal and domestic supplies of ground water. The western portion of the county is covered by a thick sequence of bedded dolomitic limestones, which contain water in solution cavities and fractures. The central area of the county is covered by unconsolidated sands and silts, which provide moderate well yields from lenses of sand and gravel. Where these deposits are locally non-water bearing or absent, ground water is supplied from deeper, more permeable sandstones and limestones. Igneous and metamorphic rocks, which outcrop in the northeastern part of the county, contain ground water in fractures and faults and only provide small quantities of water to domestic wells. The DRASTIC Index numbers reflect evaluation of water table aquifers only. Computed DRASTIC Index values range from 63 to 126.

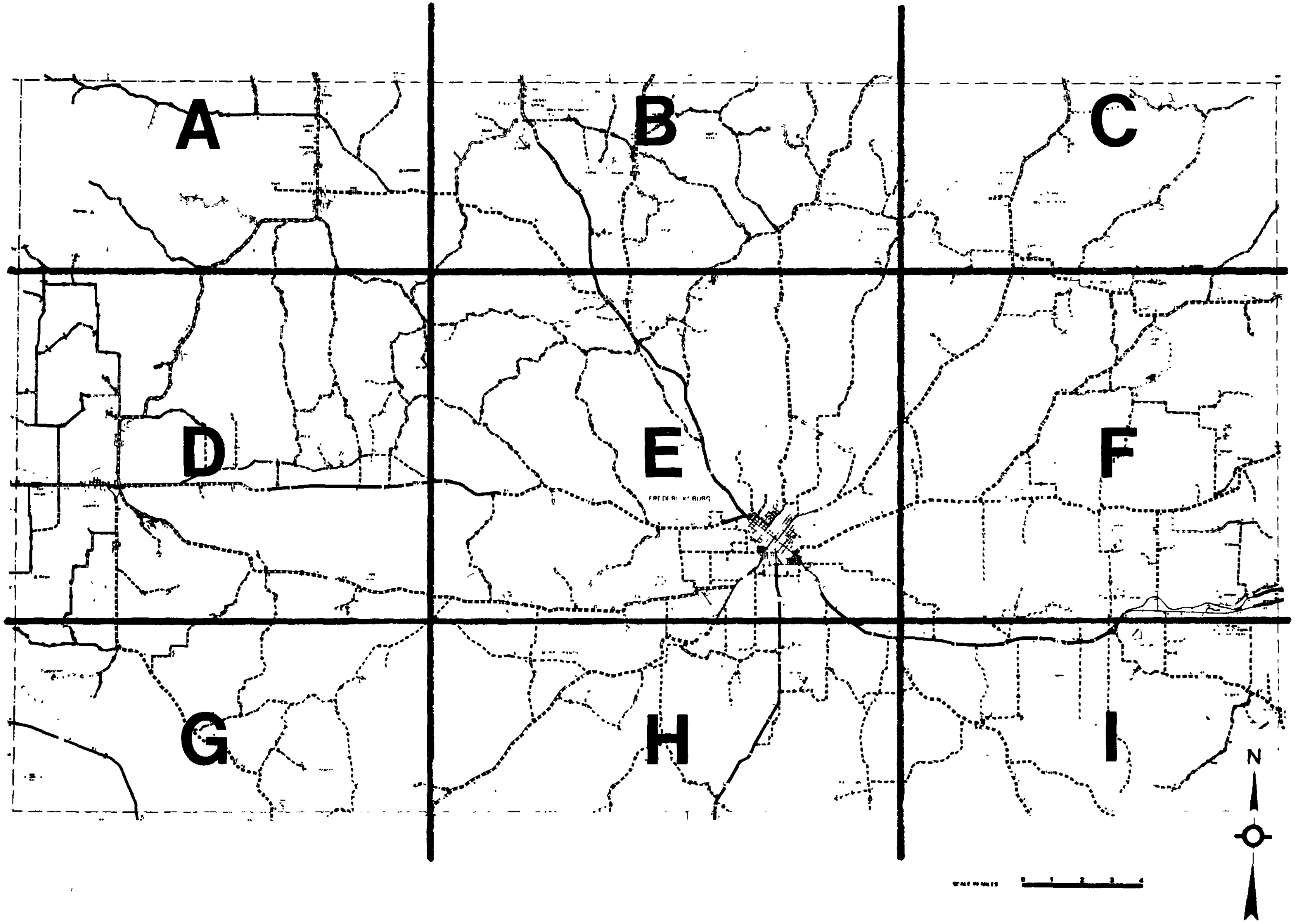
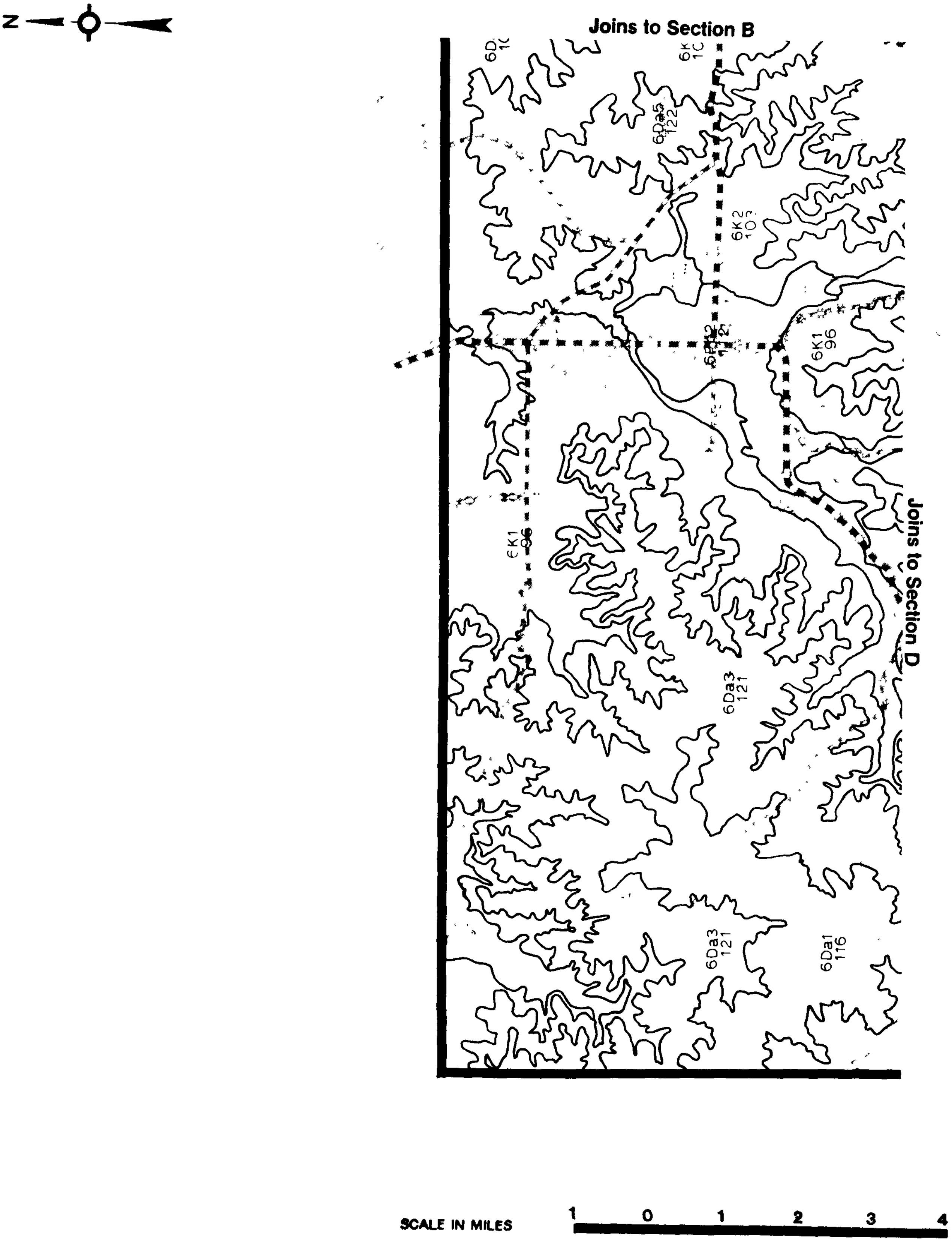
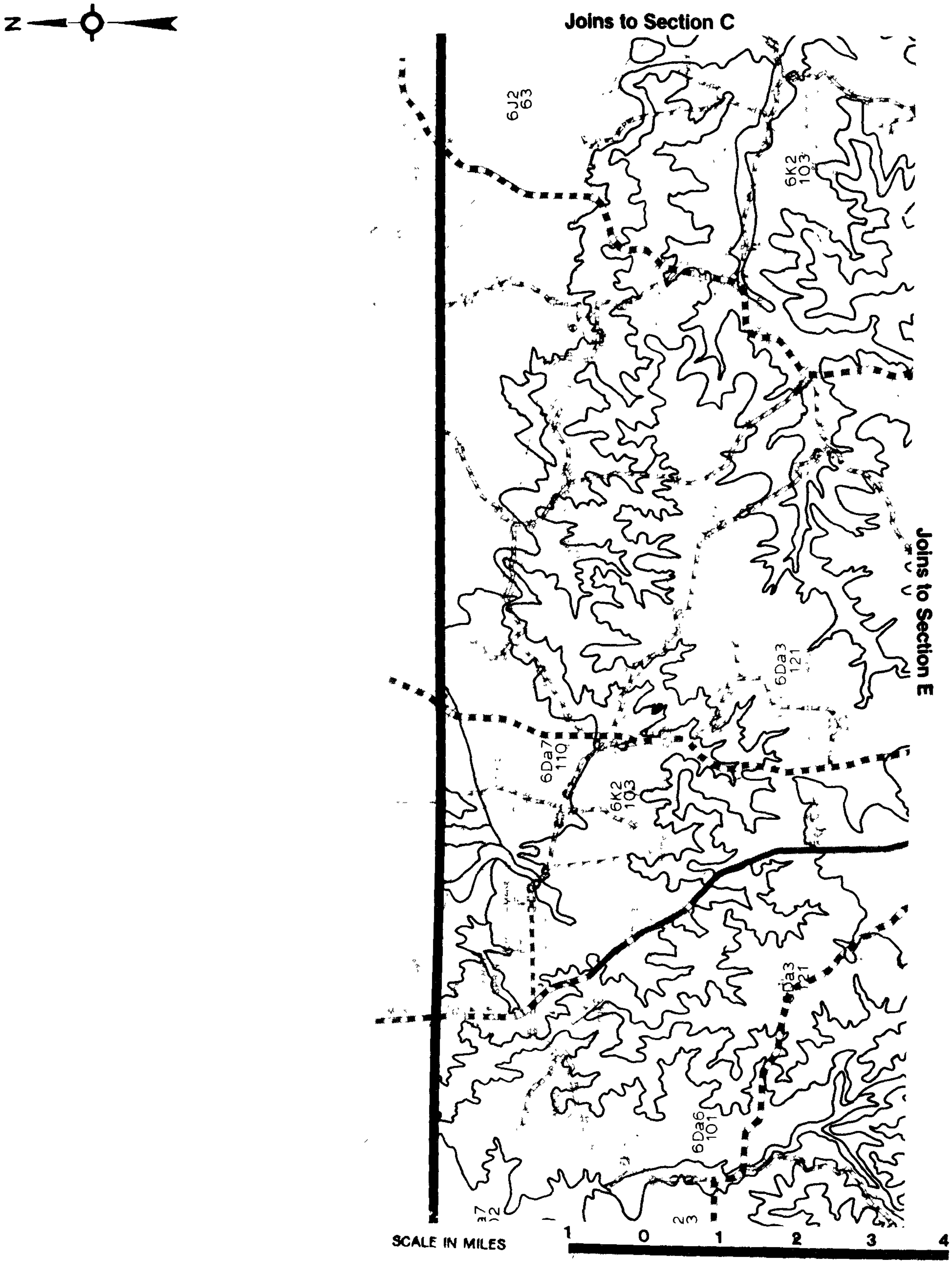


Figure F-1. Index to map sheets, detailed pollution potential map, Gillespie County, Texas.



Index Sheet A



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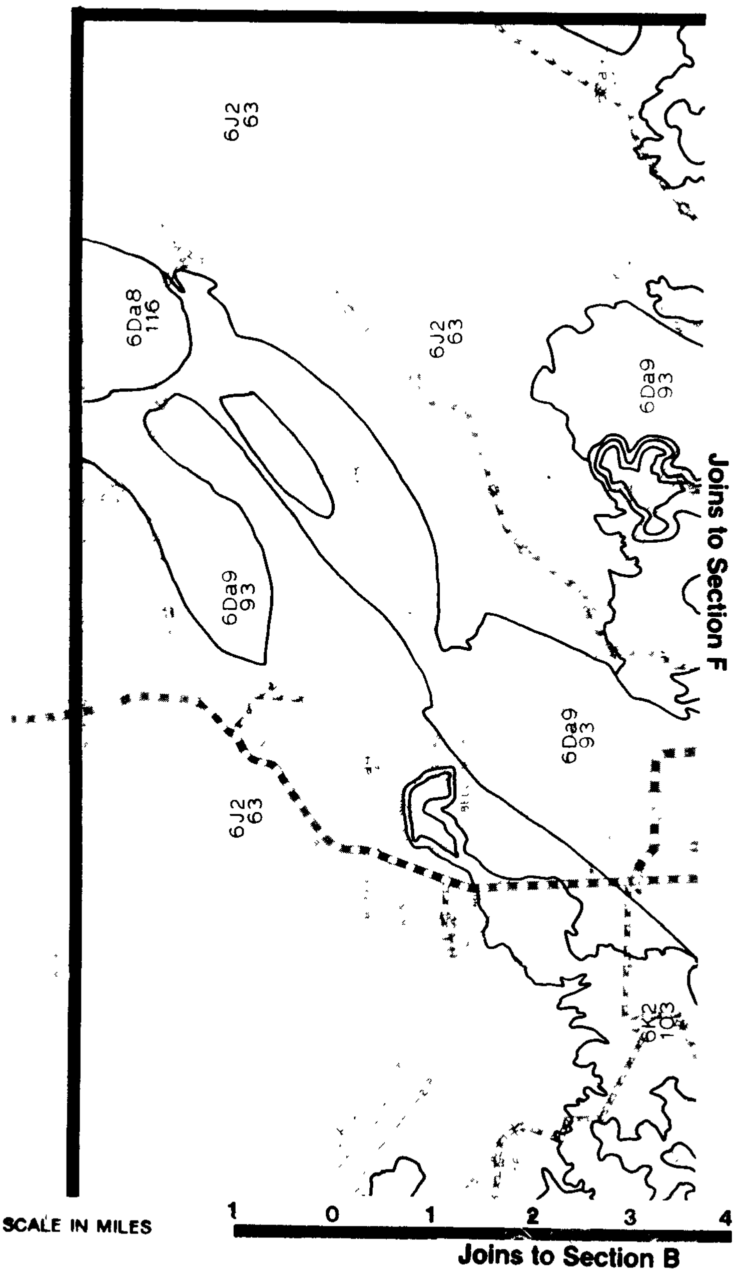
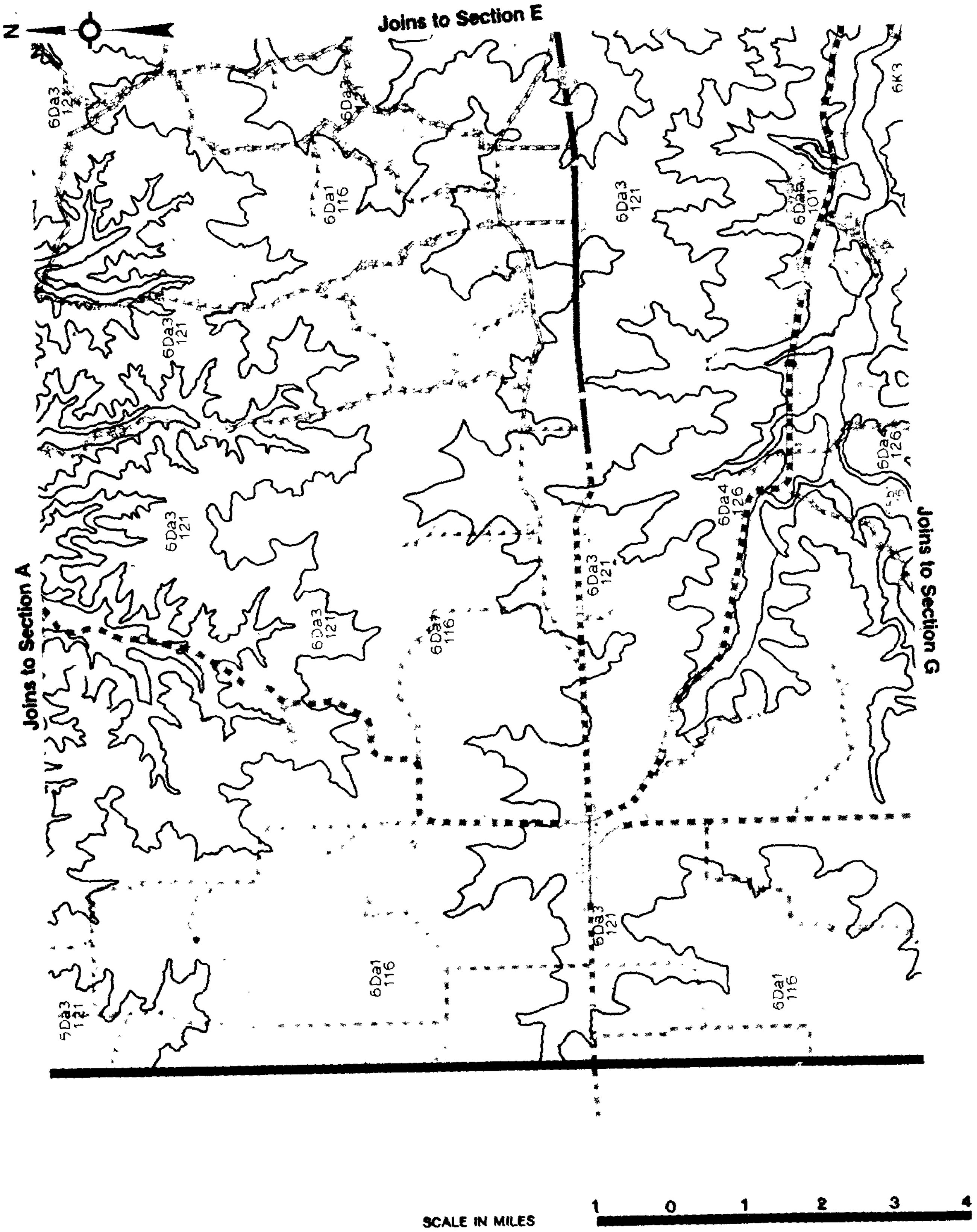
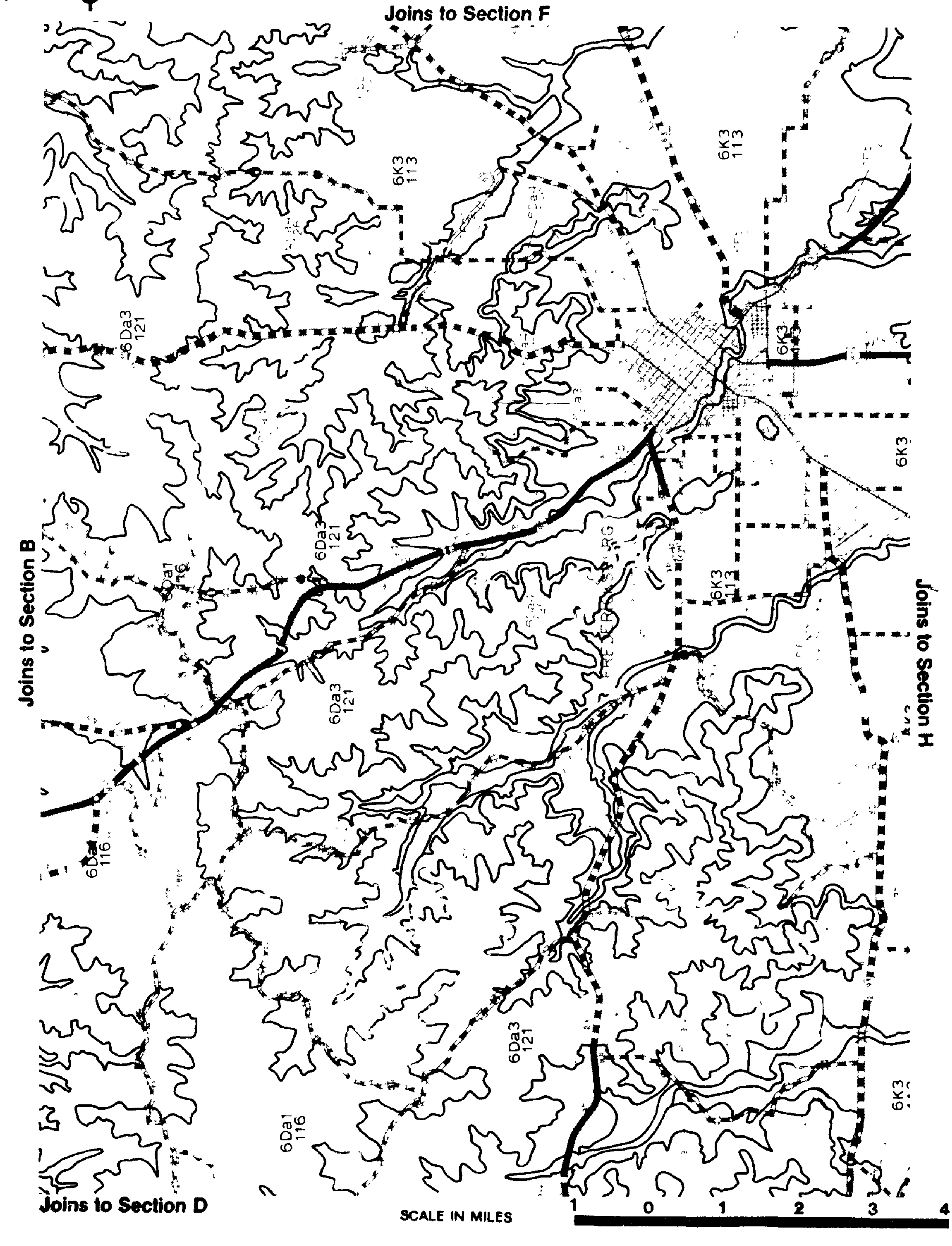
Index Sheet C





Index Sheet D

Index Sheet E



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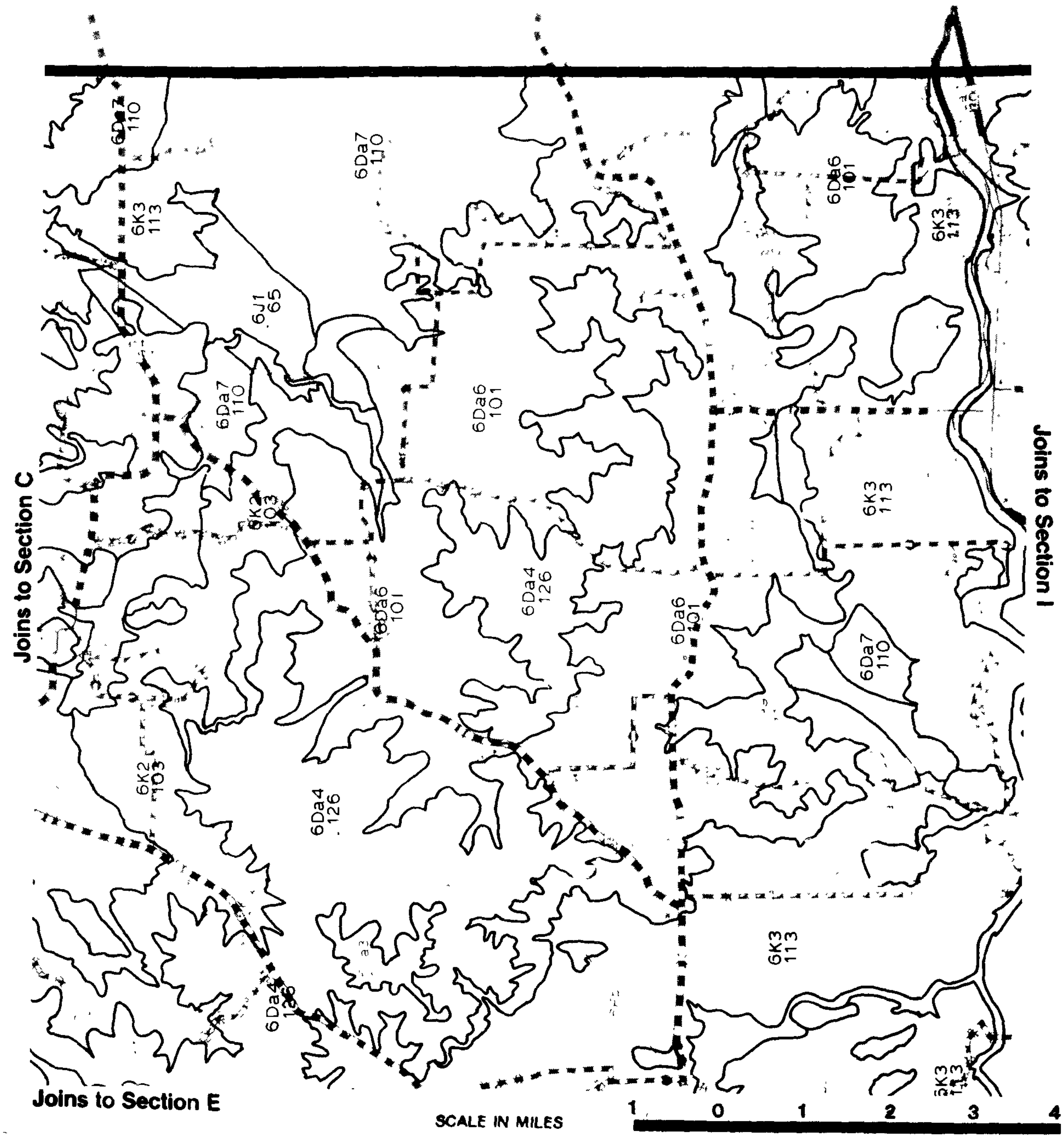
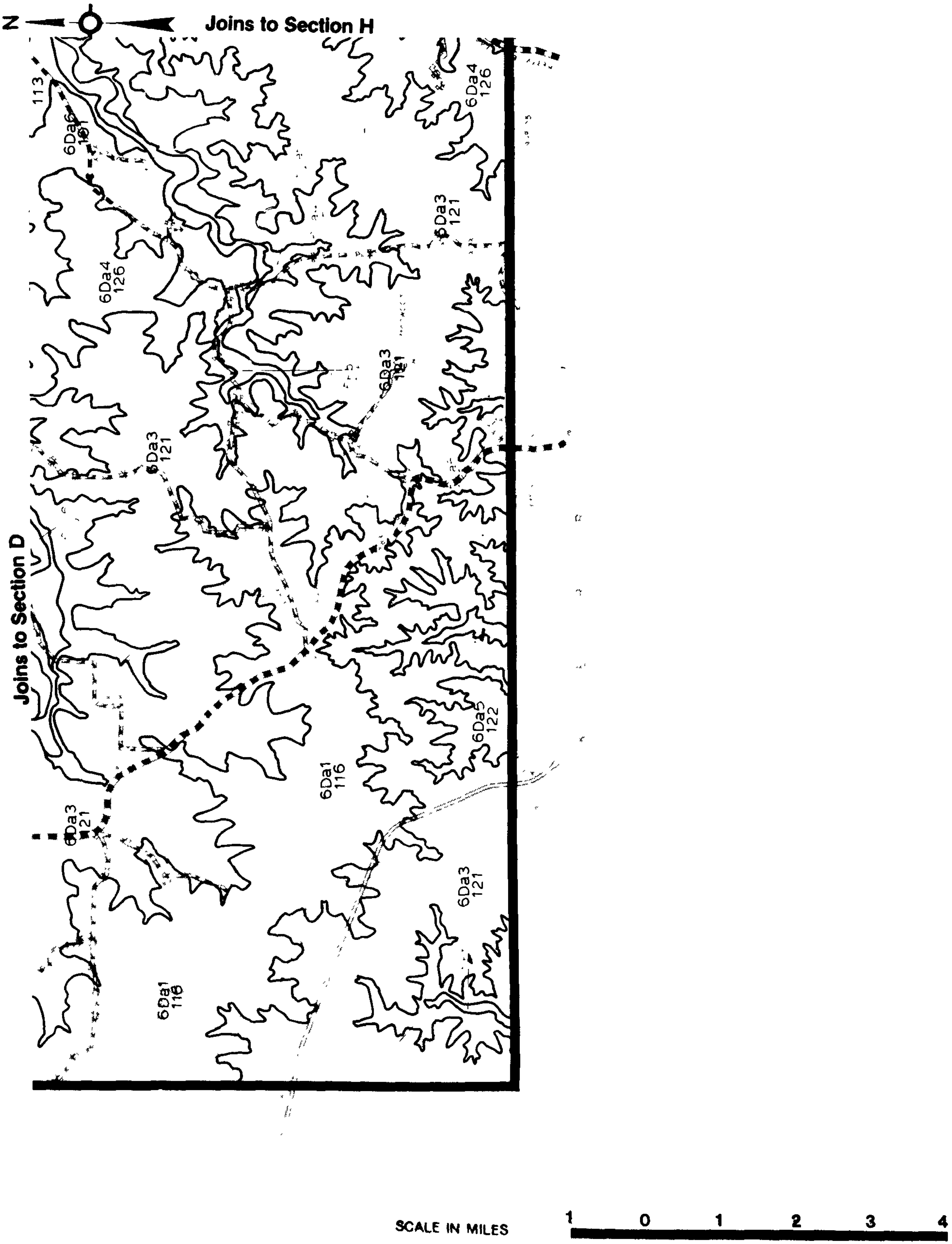
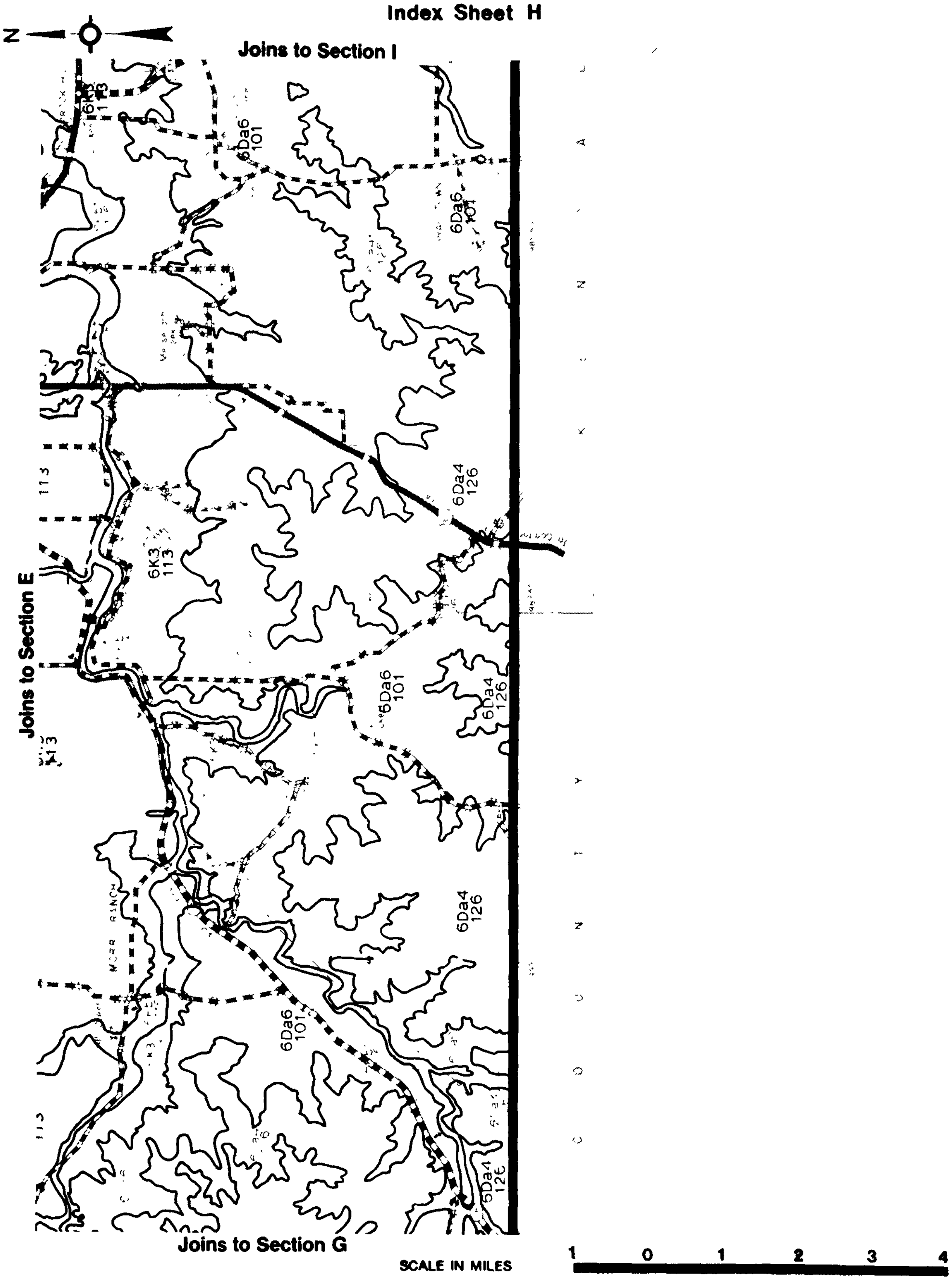


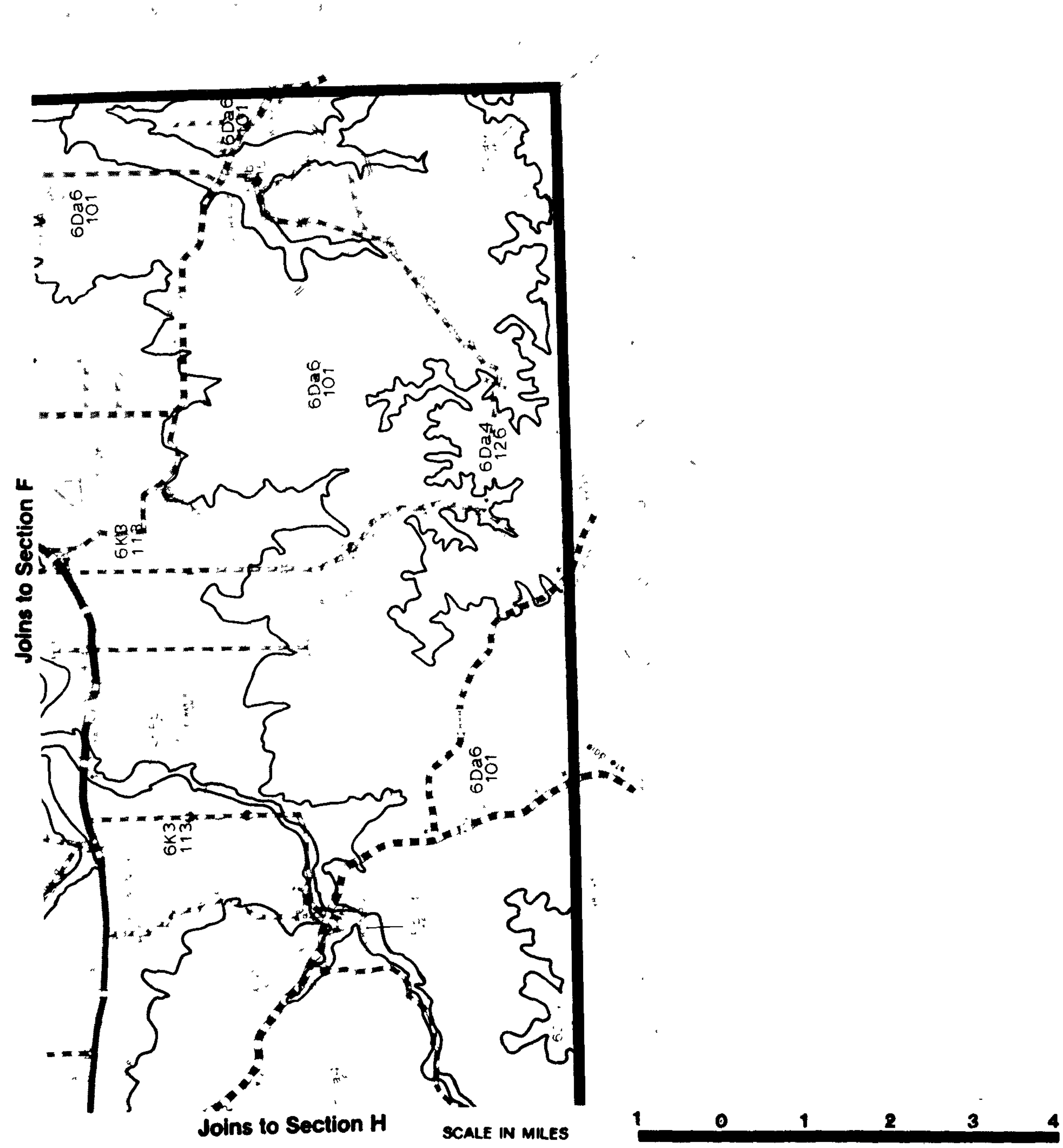


Index Sheet G

Index Sheet H



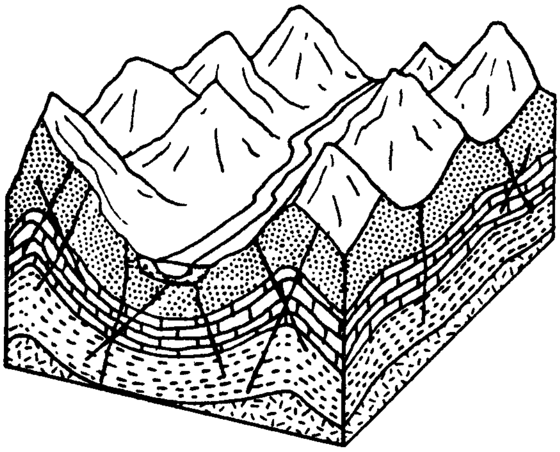
Index Sheet I



NON-GLACIATED CENTRAL

(6B) Alluvial Mountain Valleys

This hydrogeologic setting is characterized by thin bouldery alluvium which overlies fractured bedrock of sedimentary, metamorphic or igneous origin but which is commonly comprised of alternating sedimentary layers. The alluvium, which is derived from the surrounding slopes serves as a localized source of water. Water is obtained from sand and gravel layers which are interspersed between finer-grained deposits. Surficial deposits have typically weathered to a sandy loam. Water levels are relatively shallow but may be extremely variable. Ground water may also be obtained from the fractures in the underlying bedrock which are typically in direct hydraulic connection with the overlying alluvium.

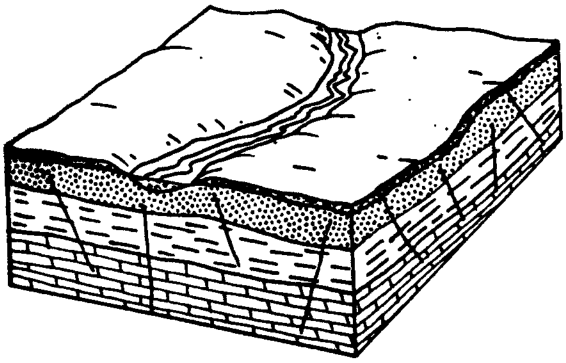


SETTING 6B1 Alluvial Mt. Valleys		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	S/G	3	7	21
Soil Media	Silty Loam	2	4	8
Topography	2-6	1	9	9
Impact Vadose Zone	S/G w/sig. Silt /Clays	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	94

NON-GLACIATED CENTRAL

(6Da) Alternating Sandstone, Limestone and Shale - Thin Soil

This hydrogeologic setting is characterized by low to moderate topographic relief, relatively thin loamy soils overlying horizontal or slightly dipping alternating layers of fractured consolidated sedimentary rocks. Ground water is obtained primarily from fractures along bedding planes or intersecting vertical fractures. Precipitation varies widely in the region, but recharge is moderate where precipitation is adequate. Water levels are extremely variable but on the average moderately shallow. Shale or clayey layers often form aquitards, and where sufficient relief is present, perched ground water zones of local domestic importance are often developed.



SETTING 6Da1 - Alt. SST. LST. SH.		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	LST	3	8	24
Soil Media	Thin/Abs.	2	10	20
Topography	2-6	1	9	9
Impact Vadose Zone	LST	5	6	30
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	116

SETTING 6Da2 - Alt. SST. LST. SHALE		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	LST	3	8	24
Soil Media	Thin/Abs	2	10	20
Topography	6-12	1	5	5
Impact Vadose Zone	LST	5	6	30
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	117

SETTING 6Da3 - Alt. SST. LST. Shale		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	LST	3	8	24
Soil Media	Thin/Abs	2	10	20
Topography	2-6	1	9	9
Impact Vadose Zone	LST	5	6	30
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	121

SETTING 6Da4 - Alt. SST. LST. Shale		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	LST	3	8	24
Soil Media	Thin/Abs	2	10	20
Topography	2-6	1	9	9
Impact Vadose Zone	LST	5	6	30
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	126

SETTING 6Da5 - Alt. SST. LST. Shale		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	LST	3	8	24
Soil Media	Thin/Abs	2	10	20
Topography	6-12	1	5	5
Impact Vadose Zone	LST	5	6	30
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	122

SETTING 6Da6 - Alt. SST. LST. Shale		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	0-2	4	1	4
Aquifer Media	LST	3	6	18
Soil Media	Silt Loam	2	4	8
Topography	2-6	1	9	9
Impact Vadose Zone	LST	5	5	25
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	101

SETTING 6Da7 - Alt. SST. LST. Shale		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	LST	3	8	24
Soil Media	Loam	2	5	10
Topography	2-6	1	9	9
Impact Vadose Zone	LST	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	110

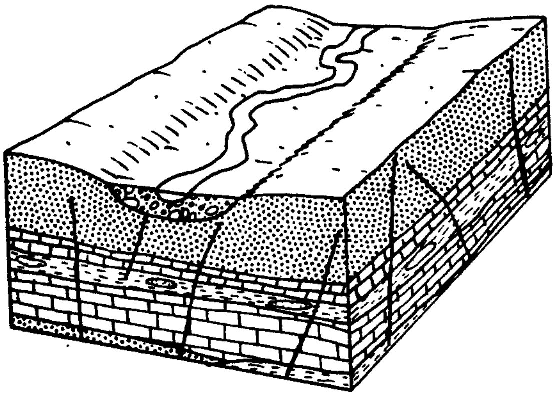
SETTING 6Da8 - Alt SST. LST Shale		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	LST	3	8	24
Soil Media	Thin/Abs	2	10	20
Topography	6-12	1	5	5
Impact Vadose Zone	LST	5	6	30
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	116

SETTING 6Da9 - Alt. SST. LST. Shale		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	SST	3	6	18
Soil Media	Loam	2	5	10
Topography	2-6	1	9	9
Impact Vadose Zone	LST	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	93

NON-GLACIATED CENTRAL

(6Fb) River Alluvium without Overbank Deposits

This setting is identical to (6Fa) River Alluvium with Overbank Deposits except that no significant fine-grained floodplain deposits occupy the stream valley. This results in significantly higher recharge where precipitation is adequate and sandy loam soils occur at the surface. Water levels are typically closer to the surface because the fine-grained overbank deposits are not present.



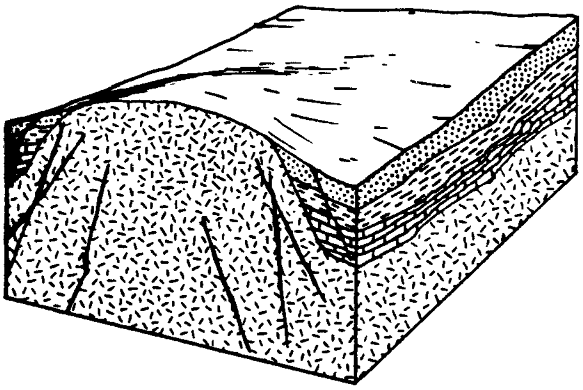
SETTING 6Fb1 Alluvium w/o Overbank		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	0-2	4	1	4
Aquifer Media	S/G	3	7	21
Soil Media	Loam	2	5	10
Topography	2-6	1	9	9
Impact Vadose Zone	S/G w/sig Silts/Clays	5	7	35
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	116

SETTING 6Fb2 Alluvium w/o Overbank		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	0-2	4	1	4
Aquifer Media	S/G	3	7	21
Soil Media	Clay Loam	2	3	6
Topography	2-6	1	9	9
Impact Vadose Zone	S/G w/sig Silts/Clays	5	7	35
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	112

NON-GLACIATED CENTRAL

(6J) Metamorphic/Igneous Domes and Fault Blocks

This hydrogeologic setting is characterized by metamorphic and igneous rocks exposed at the surface. The rocks are typically more highly fractured and faulted along the flanks of the domes. The domes are flanked by gently dipping deposits of sedimentary rocks which may also be faulted adjacent to the dome. Soil is typically thin or absent and water levels are extremely variable. Recharge rates are typically low because of excessive surface runoff and low permeabilities. Water yields are extremely variable depending on the degree of folding and faulting but typically are higher along the more fractured flank zones. Where few fractures exist, water yields are very low or non-existent.



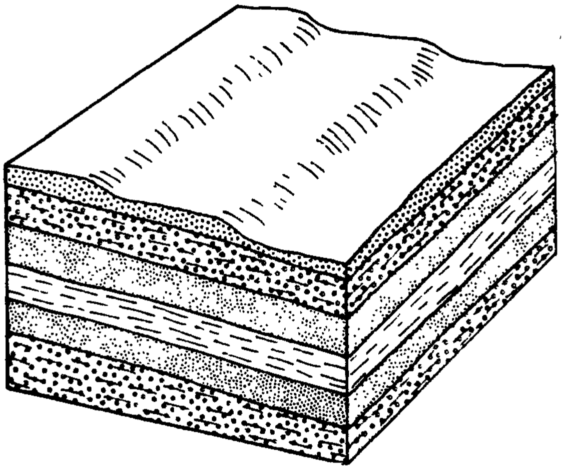
SETTING 6J1 Meta/Igneous Domes & Fault Blocks		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	M/I	3	3	9
Soil Media	Loam	2	5	10
Topography	2-6	1	9	9
Impact Vadose Zone	M/I	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	65

SETTING 6J2 Meta/Igneous Domes & Fault Blocks		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	M/I	3	3	9
Soil Media	Sandy Loam	2	6	12
Topography	6-12	1	5	5
Impact Vadose Zone	M/I	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	63

NON-GLACIATED CENTRAL

(6K) Unconsolidated and Semi-Consolidated Aquifers

This hydrogeologic setting is characterized by moderately low topographic relief and interbedded deposits which consist primarily of sand, silt and clay. Although soils are typically loamy or sandy, recharge is limited because of only moderate precipitation and high evapotranspiration. Water levels are extremely variable but are typically not less than 50 feet. Hydraulic conductivities are also extremely variable also depending on the amount of fine materials which are interbedded with the sands.



SETTING 6K1 Unconsolidated & Semi-Consolidated Aquifers		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	0-2	4	1	4
Aquifer Media	Sand & Gravel	3	7	21
Soil Media	Loam	2	5	10
Topography	2-6	1	9	9
Impact Vadose Zone	S & G w/sig Silt/Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	96

SETTING 6K2 Unconsolidated & Semi-Consolidated Aquifers		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	S/G	3	7	21
Soil Media	Sandy Loam	2	6	12
Topography	2-6	1	9	9
Impact Vadose Zone	S/G w/Sig Silts/Clays	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	103

SETTING 6K3 Unconsolidated & Semi-Consolidated Aquifers		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	0-2	4	1	4
Aquifer Media	S/G	3	7	21
Soil Media	Sandy Loam	2	6	12
Topography	2-6	1	9	9
Impact Vadose Zone	S/G w/sig Silts/Clays	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	113

APPENDIX G

GREENVILLE COUNTY, SOUTH CAROLINA

Greenville County, South Carolina, lies within the Piedmont and Blue Ridge ground-water region. The primary ground-water resources of the county are derived from igneous and metamorphic rocks covered by variable thicknesses of saprolite. Ground water in the igneous/metamorphic aquifer system provides moderate yields from fractures and faults. Unconfined ground water accumulates in the saprolite overlying the parent rock and often serves as a recharge source for these aquifers. Although saprolite is an easily developed source of ground water, low yields and seasonal fluctuations typically limit the development of this resource. Although limited in aerial extent, alluvial deposits of sand and gravel adjacent to rivers and overlying the saprolite may also constitute a source of ground water. The DRASTIC Index numbers reflect evaluation of water table aquifers only. Computed DRASTIC Index values range from 87 to 152.

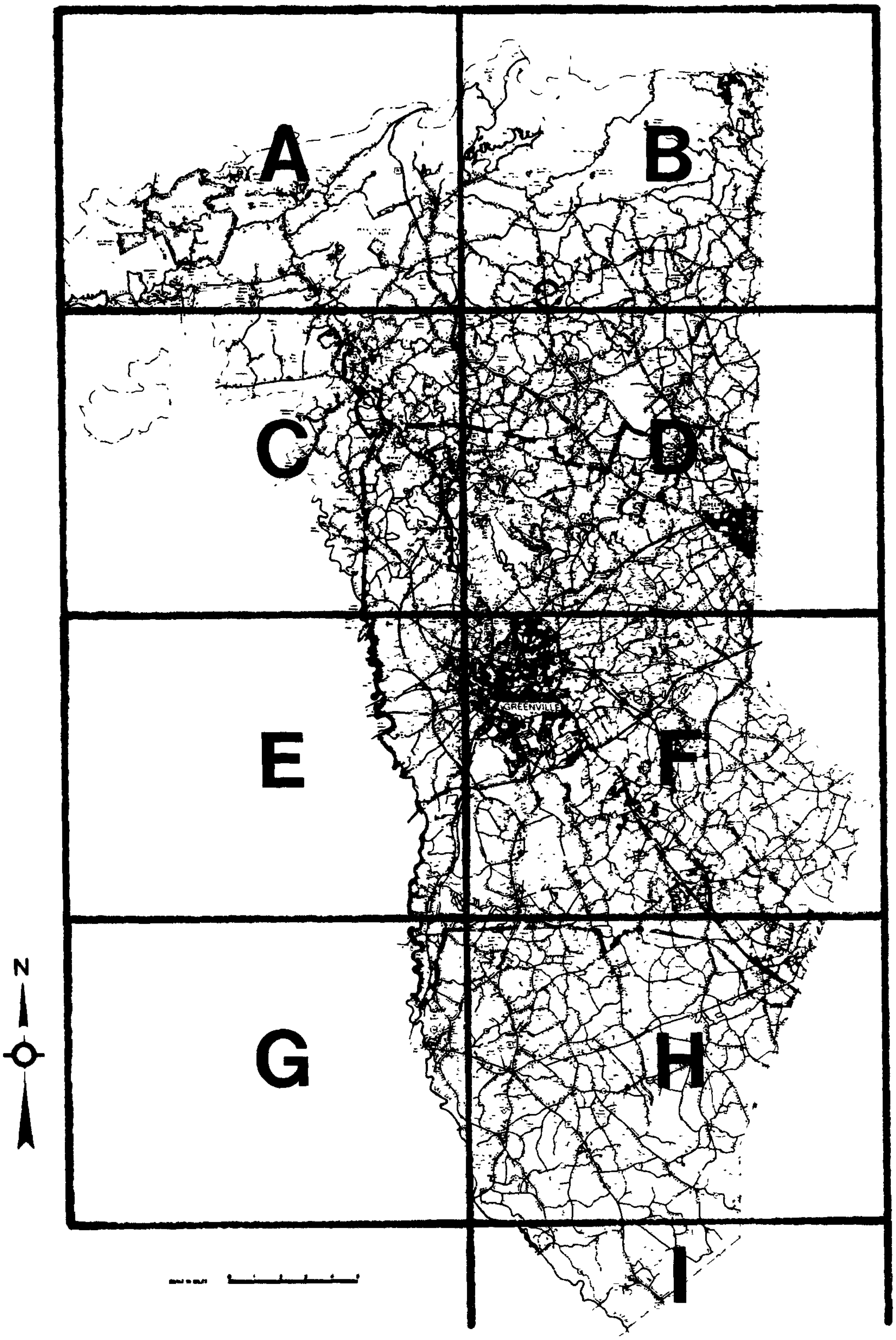
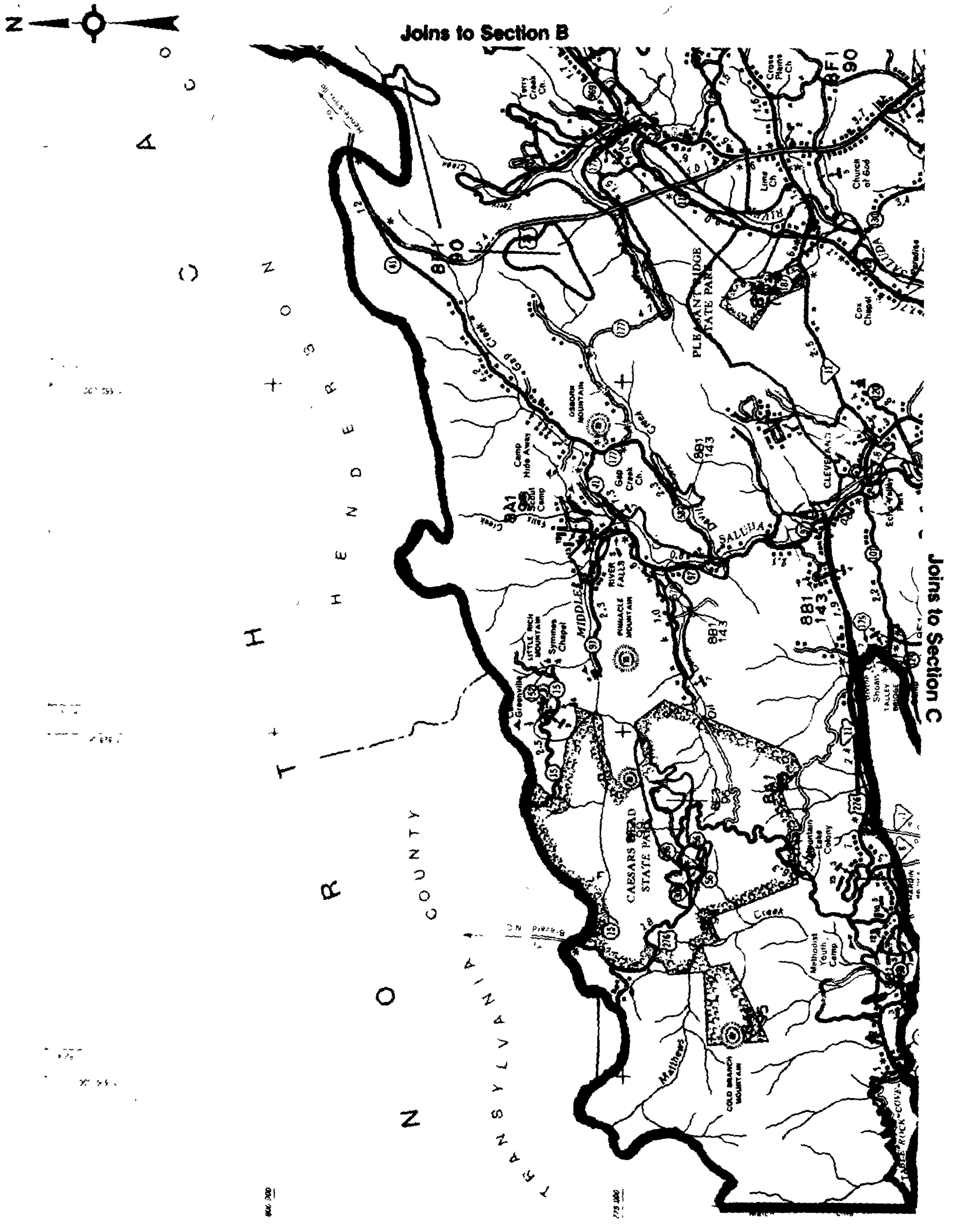
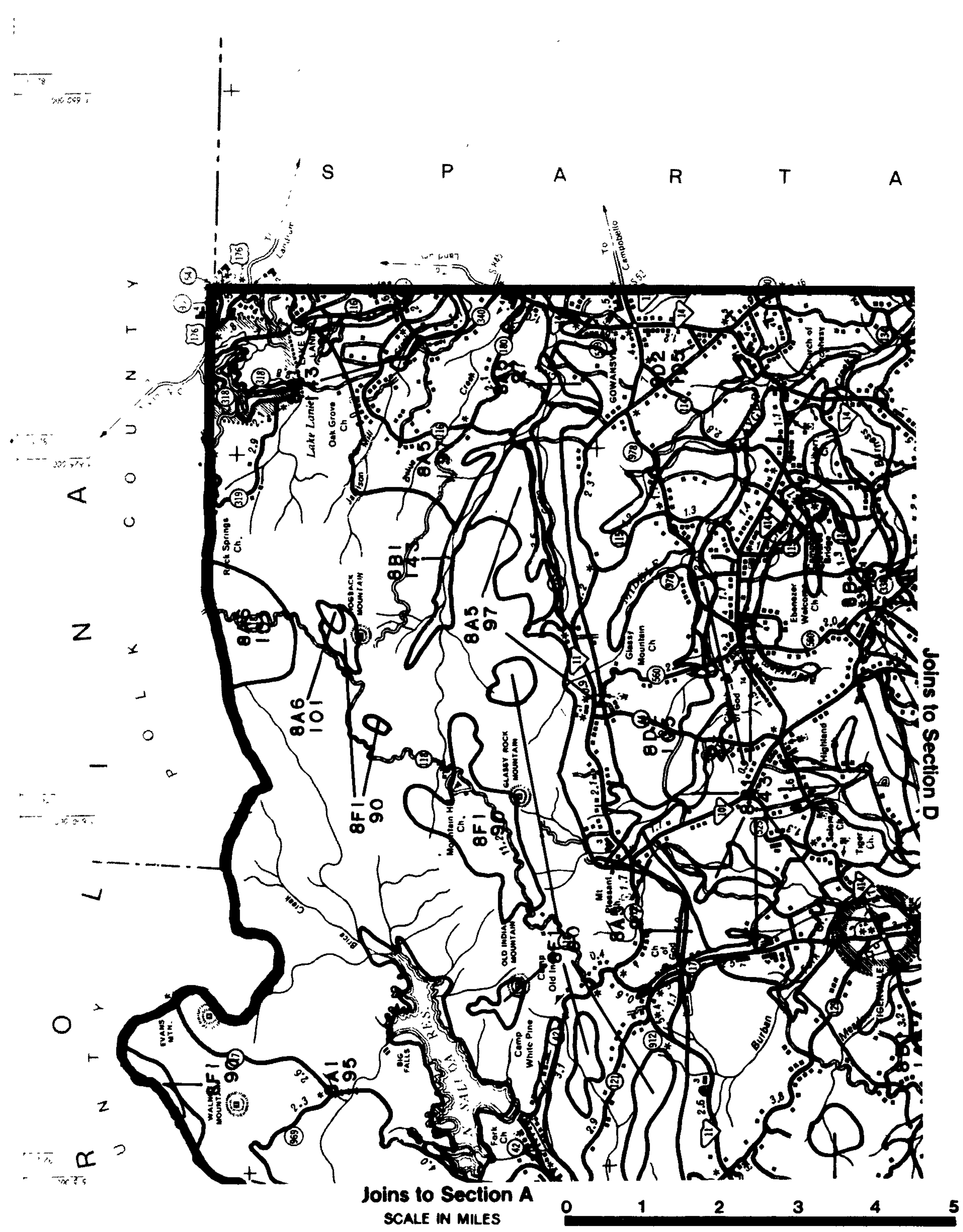


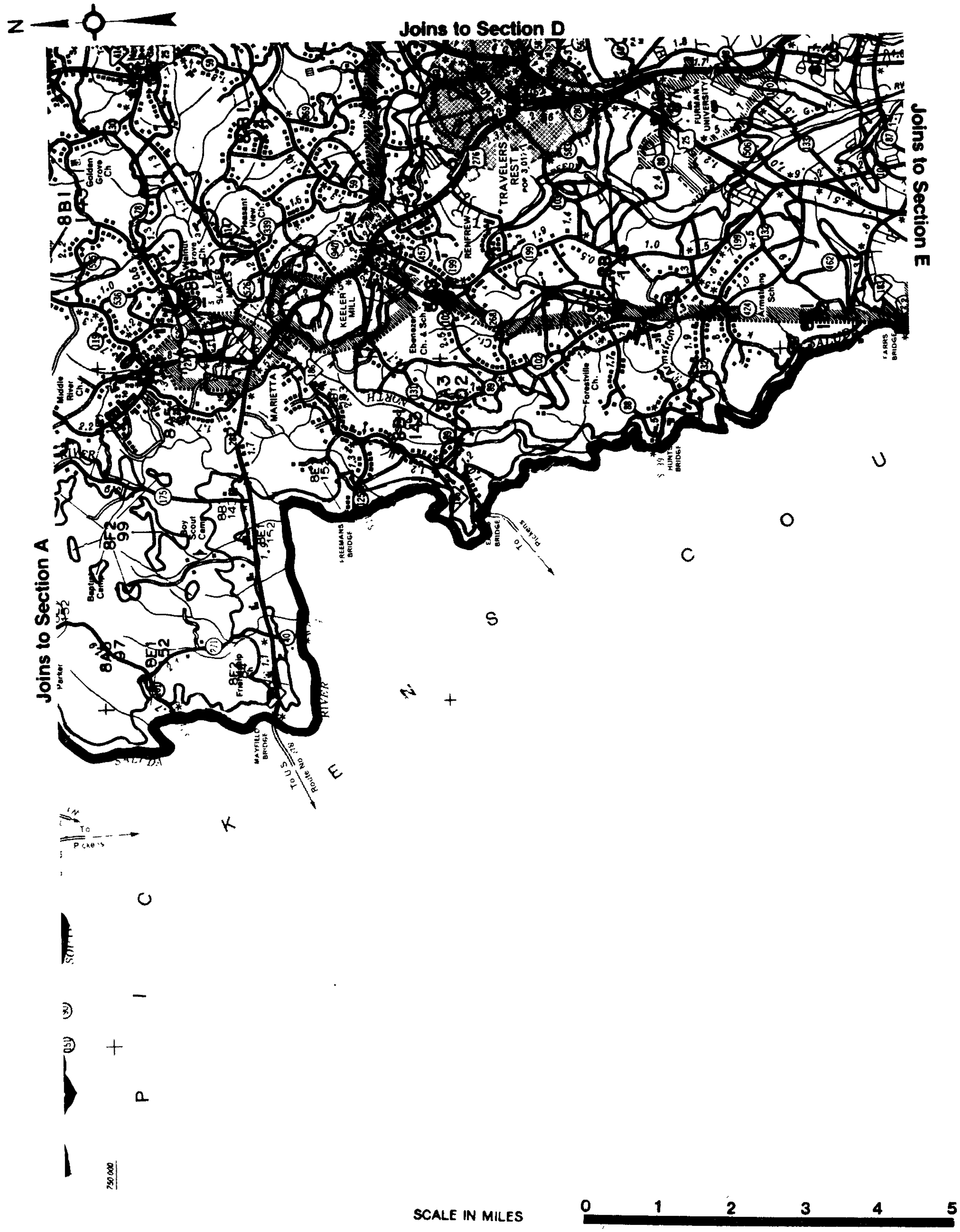
Figure G-1. Index to map sheets, detailed pollution potential map, Greenville County, South Carolina.



Index Sheet A

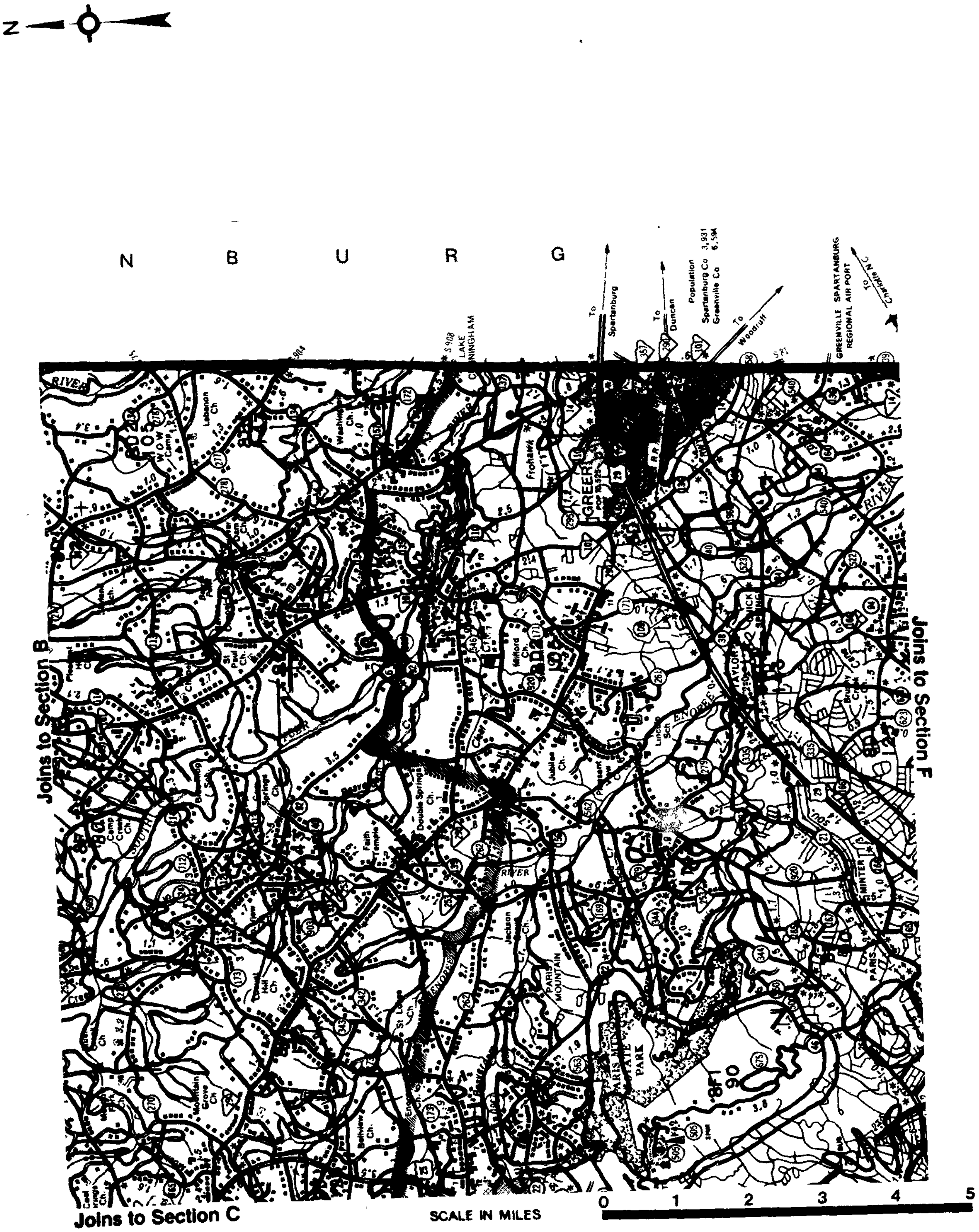
Index Sheet B

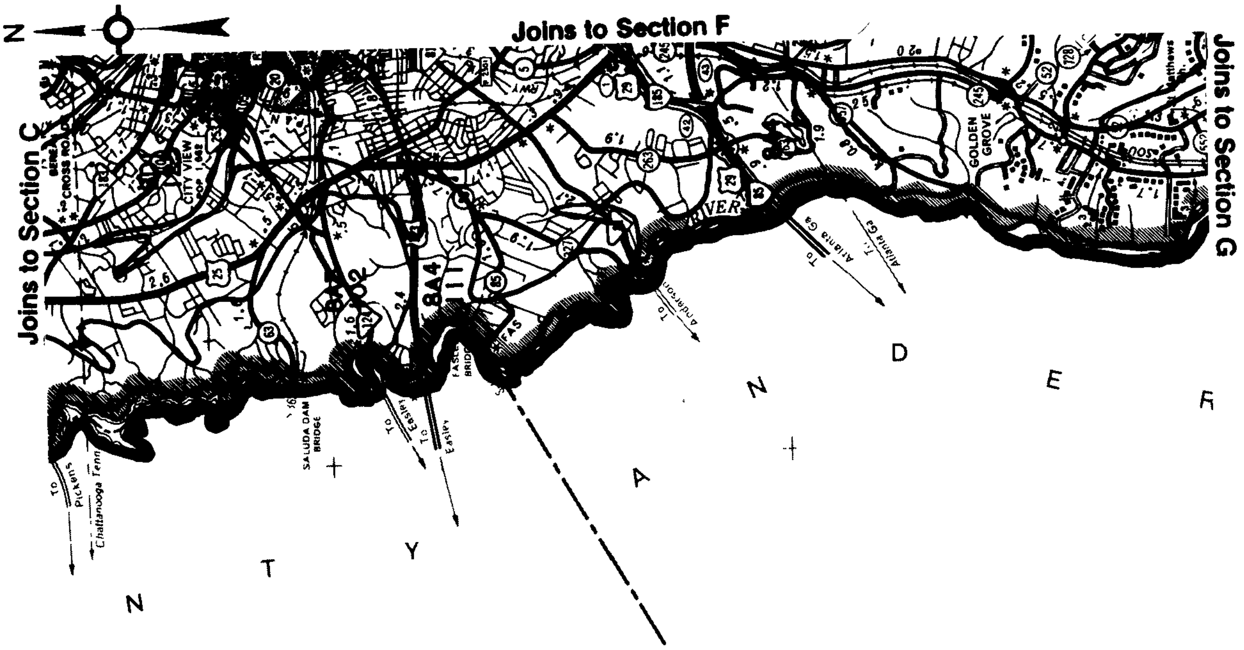




Index Sheet C

Index Sheet D





SCALE IN MILES 0 1 2 3 4 5

Index Sheet E

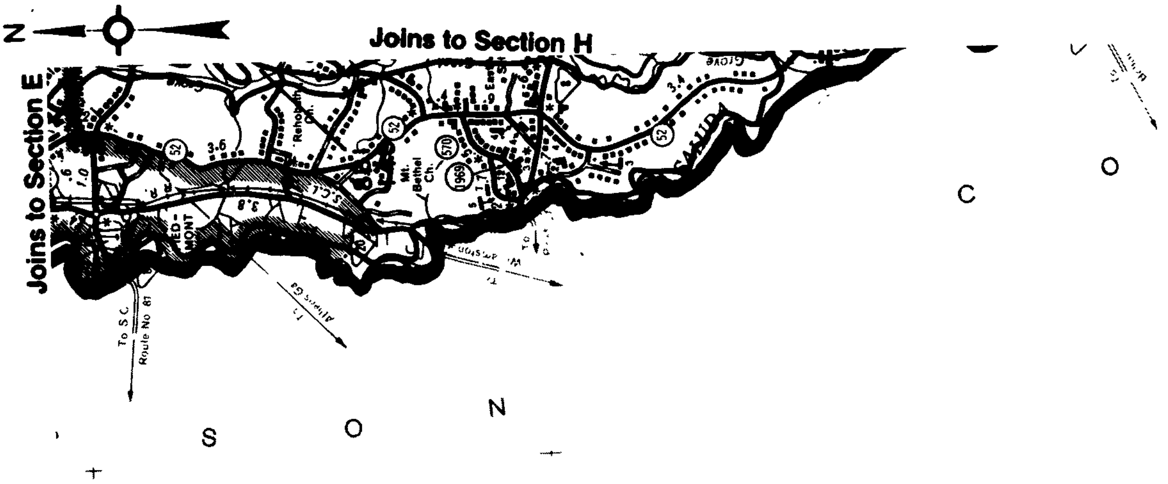
Index Sheet F

Joins to Section D

Joins to Section E

N

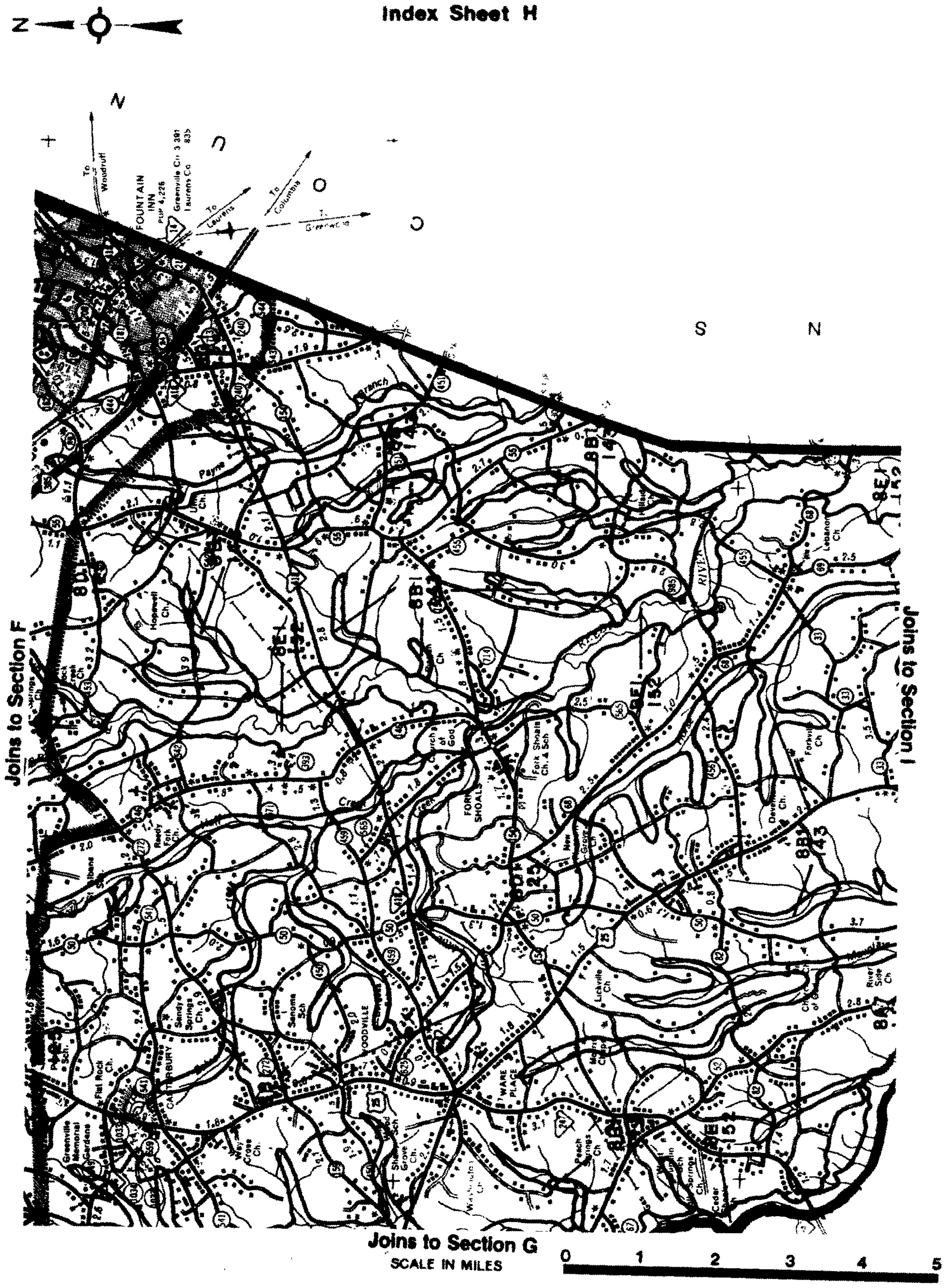
Joins to Section H



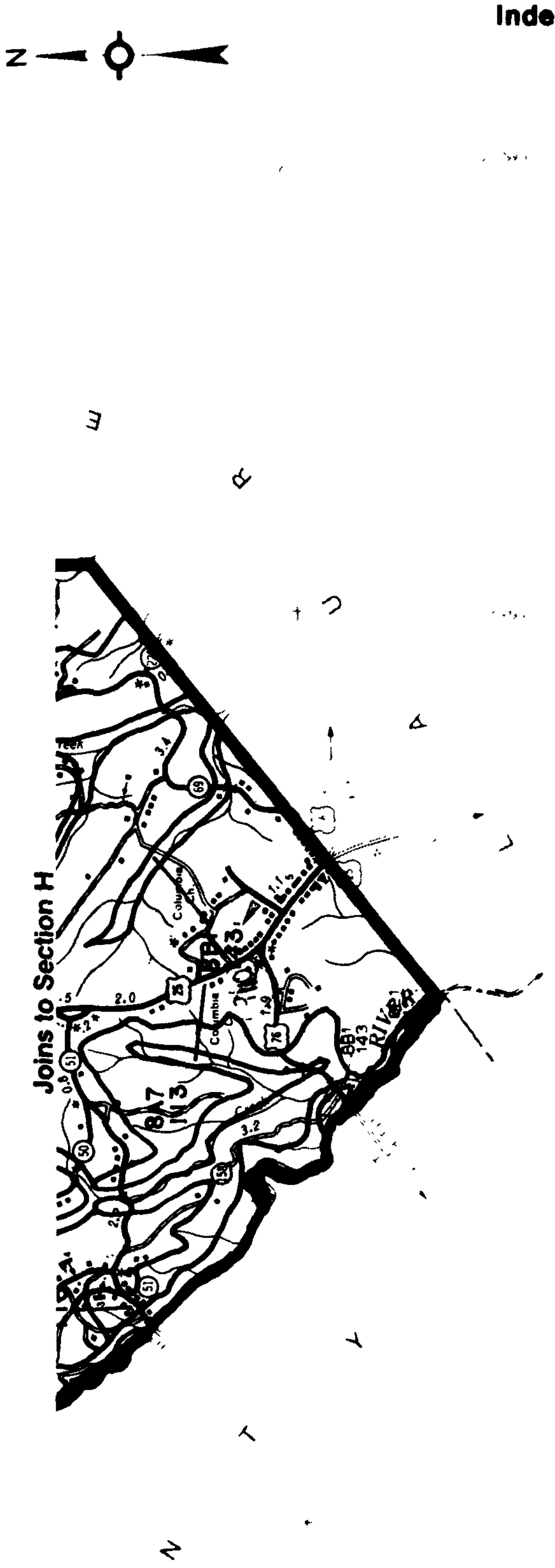
SCALE IN MILES 0 1 2 3 4 5

Index Sheet G

Index Sheet H



Index Sheet I

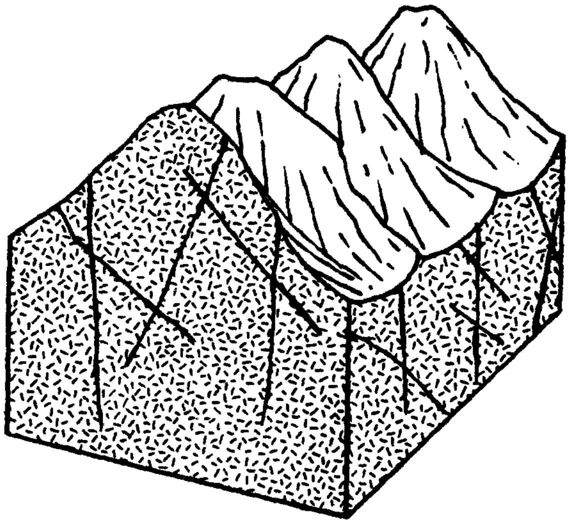


SCALE IN MILES 0 1 2 3 4 5

PIEDMONT AND BLUE RIDGE

(8A) Mountain Slopes

This hydrogeologic setting is characterized by steep slopes on the side of mountains, a thin soil cover and fractured bedrock. Ground water is obtained primarily from the fractures in the bedrock which may be of sedimentary, metamorphic or igneous origin, but which is commonly metamorphic or igneous. The fractures provide localized sources of ground water and well yields are typically limited. Although precipitation is abundant, due to the steep slopes, thin soil cover and small storage capacity of the fractures, runoff is significant and ground-water recharge is only moderate. Water levels are extremely variable but are commonly deep.



SETTING 8A1 Mountain Slopes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	7-10	4	8	32
Aquifer Media	Weathered Metamorphic/ Igneous	3	3	9
Soil Media	Loam	2	5	10
Topography	18+	1	1	1
Impact Vadose Zone	S&G w/sig. Silt & Clay	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	95

SETTING 8A2 Mountain Slopes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	7-10	4	8	32
Aquifer Media	Weathered Metamorphic/ Igneous	3	3	9
Soil Media	non shrinking non aggregate clay	2	1	2
Topography	18+	1	1	1
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	87

SETTING 8A3 Mountain Slopes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	7-10	4	8	32
Aquifer Media	Weathered Metamorphic/ Igneous	3	3	9
Soil Media	non shrinking non aggregate clay	2	1	2
Topography	18+	1	1	1
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	102

SETTING 8A4 Mountain Slopes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	7-10	4	8	32
Aquifer Media	Weathered Metamorphic/ Igneous	3	5	15
Soil Media	non shrinking non aggregate clay	2	1	2
Topography	18+	1	1	1
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	111

SETTING 8A5 Mountain Slopes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	7-10	4	8	32
Aquifer Media	Weathered Metamorphic/ Igneous	3	3	9
Soil Media	Loam	2	5	10
Topography	12-18	1	3	3
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	97

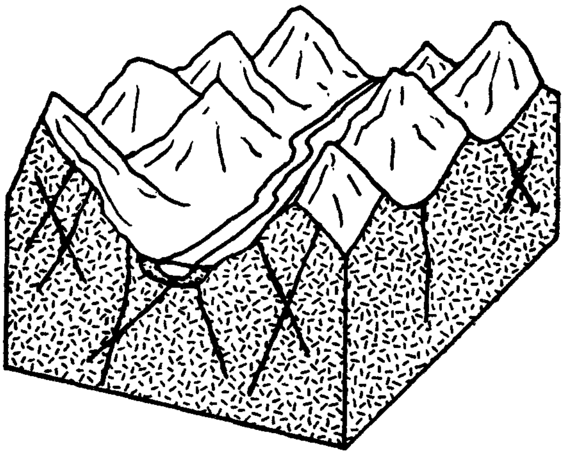
SETTING 8A6 Mountain Slopes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	7-10	4	8	32
Aquifer Media	Weathered Metamorphic/ Igneous	3	5	15
Soil Media	Loam	2	5	10
Topography	18+	1	1	1
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	1-100	3	1	3
		Drastic Index		101

SETTING 8A7 Mountain Slopes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	7-10	4	8	32
Aquifer Media	Weathered Metamorphic/ Igneous	3	5	15
Soil Media	non shrinking non aggregate clay	2	1	2
Topography	12-18	1	3	3
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	100-300	3	2	6
		Drastic Index		113

PIEDMONT AND BLUE RIDGE

(8B) Alluvial Mountain Valleys

This hydrogeologic setting is characterized by thin, bouldery alluvium which overlies fractured bedrock of sedimentary, metamorphic or igneous origin. The alluvium, which includes both mass-wastage and water-sorted debris, is derived from the surrounding slopes, and serves as a localized source of water. Water is obtained from sand and gravel layers which are interspersed between finer-grained deposits. Surficial deposits have typically weathered to a loam. Water levels are usually relatively shallow but are extremely variable. Ground water is also obtained from the fractures in the underlying bedrock, which are typically in direct hydraulic connection with the overlying alluvium.

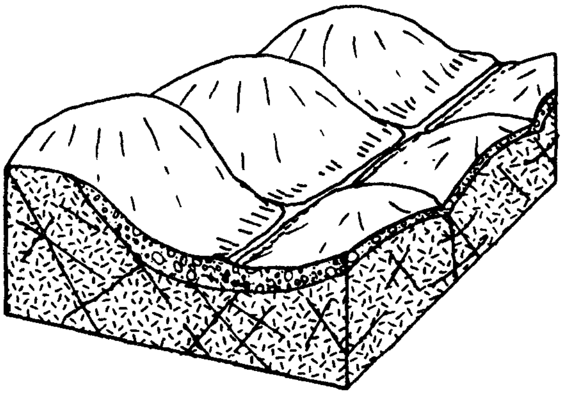


SETTING 8B1 Alluvial Mountain Valleys		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Weathered Metamorphic/ Igneous	3	4	12
Soil Media	Loam	2	5	10
Topography	2-6	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	5	25
Hydraulic Conductivity	100-300	3	2	6
		Drastic Index		143

PIEDMONT AND BLUE RIDGE

(8D) Regolith

This hydrogeologic setting is characterized by moderate to low slopes covered by regolith and underlain by fractured bedrock of igneous, sedimentary or metamorphic origin. The regolith is typically clay-rich but may also serve as a source of ground water for low-yield wells. The regolith functions as a reservoir for ground-water recharge to the bedrock which is in direct hydraulic connection with the overlying regolith. The bedrock typically yields larger amounts of ground water than the regolith when the well intersects fractures in the bedrock.



SETTING 8D1 Regolith		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Weathered Metamorphic/ Igneous	3	5	15
Soil Media	non shrinking non aggregate clay	2	1	2
Topography	6-12	1	5	5
Impact Vadose Zone	S&G w/sig Silt & Clay	5	5	25
Hydraulic Conductivity	100-300	3	2	6
		Drastic Index		125

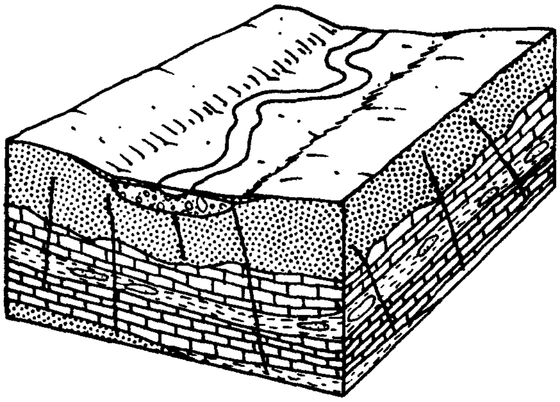
SETTING 8D2 Regolith		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	10+	4	9	36
Aquifer Media	Weathered Metamorphic/ Igneous	3	3	9
Soil Media	non shrinking non aggregate clay	2	1	2
Topography	6-12	1	5	5
Impact Vadose Zone	S&G w/sig Silt & Clay	5	5	25
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	105

SETTING 8D3 Regolith		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Weathered Metamorphic/ Igneous	3	5	15
Soil Media	non shrinking non aggregate clay	2	1	2
Topography	2-6	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	5	25
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	128

PIEDMONT AND BLUE RIDGE

(8E) River Alluvium

This hydrogeologic setting is characterized by low topography and deposits of varying thickness of alluvium along parts of stream valleys. The alluvium is underlain by fractured igneous, metamorphic or consolidated sedimentary rocks. Water is obtained from sand and gravel which is overlain and interbedded with finer-grained alluvial deposits. Surficial deposits usually weather to a sandy loam. The sand and gravel within the alluvium serves as the principal aquifer, but the alluvium also serves as the source of ground-water recharge for the underlying aquifer. Precipitation is abundant and recharge is moderately high, limited only by the loamy surficial deposits. Water levels are extremely variable, but are typically moderately shallow.

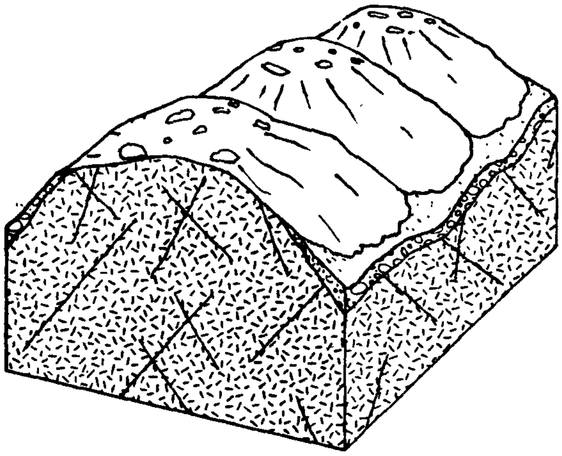


SETTING 8E1 River Alluvium		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	5	15
Soil Media	Loam	2	5	10
Topography	2-6	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	5	25
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	152

PIEDMONT AND BLUE RIDGE

(8F) Mountain Crests

This hydrogeologic setting is characterized by moderate to steep topography on the crests of mountains with thin soil cover and exposed fractured bedrock. Ground water is obtained primarily from the fractures in the bedrock which may be of sedimentary, metamorphic or igneous origin but which is commonly metamorphic or igneous. The fractures provide localized sources of ground water and well yields are typically limited. Although precipitation is abundant, due to the slopes, thin soil cover and small storage capacity of the fractures, runoff is significant and ground-water recharge is low. Water levels are extremely variable but commonly deep.



SETTING 8F1 Mountain Crest		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	7-10	4	8	32
Aquifer Media	Weathered Metamorphic/ Igneous	3	3	9
Soil Media	Loam	2	5	10
Topography	18+	1	1	1
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	90

SETTING 8F2 Mountain Crests		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	7-10	4	8	32
Aquifer Media	Weathered Metamorphic/ Igneous	3	3	9
Soil Media	Loam	2	5	10
Topography	6-12	1	5	5
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	99

SETTING 8F3 Mountain Crests		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	10+	4	9	36
Aquifer Media	Weathered Metamorphic/ Igneous	3	3	9
Soil Media	Loam	2	5	10
Topography	12-18	1	3	3
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	96

APPENDIX H

LAKE COUNTY, FLORIDA
(SURFICIAL AQUIFER)

Lake County, Florida, lies within the Southeast Coastal Plain ground-water region. The county is characterized by low to moderate relief with karst topography and numerous sinkholes, lakes and swampy areas. Water depths are typically shallow and soils are highly permeable. Ground-water resources within Lake County are derived from either a near-surface sand aquifer or an underlying carbonate rock aquifer, which is in hydraulic connection with the overlying sand deposits. The aquifers are separated by a confining bed comprised of an interbedded mixture of clayey sand and clay. This confining layer is extensive throughout the county, although variable in thickness and discontinuous in local sections. Yields from the surficial sand aquifer are usually sufficient for domestic purposes. Because of the highly permeable overlying soils and shallow water table, the surficial aquifer is vulnerable to pollution from the surface. The carbonate rock aquifer is referred to as the "Floridan" aquifer and is the major ground-water resource in the county. The susceptibility of this aquifer to pollution from the surface depends on the degree or confinement of the limestone aquifer and the amount of recharge received from the more vulnerable surficial sand aquifer. The DRASTIC Index numbers reflect evaluation of water table aquifers only. Computed DRASTIC indexes range from 134 to 190.

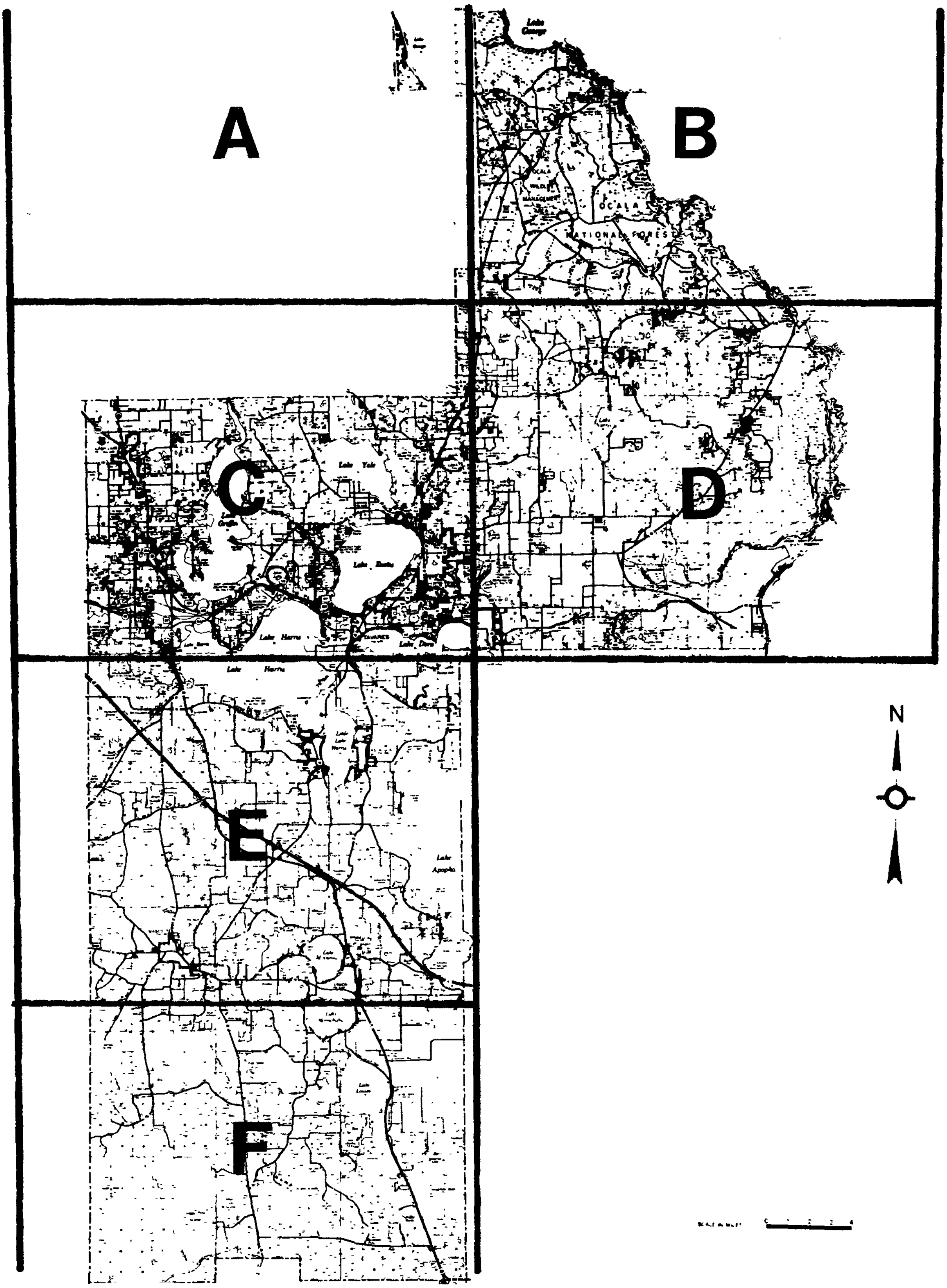
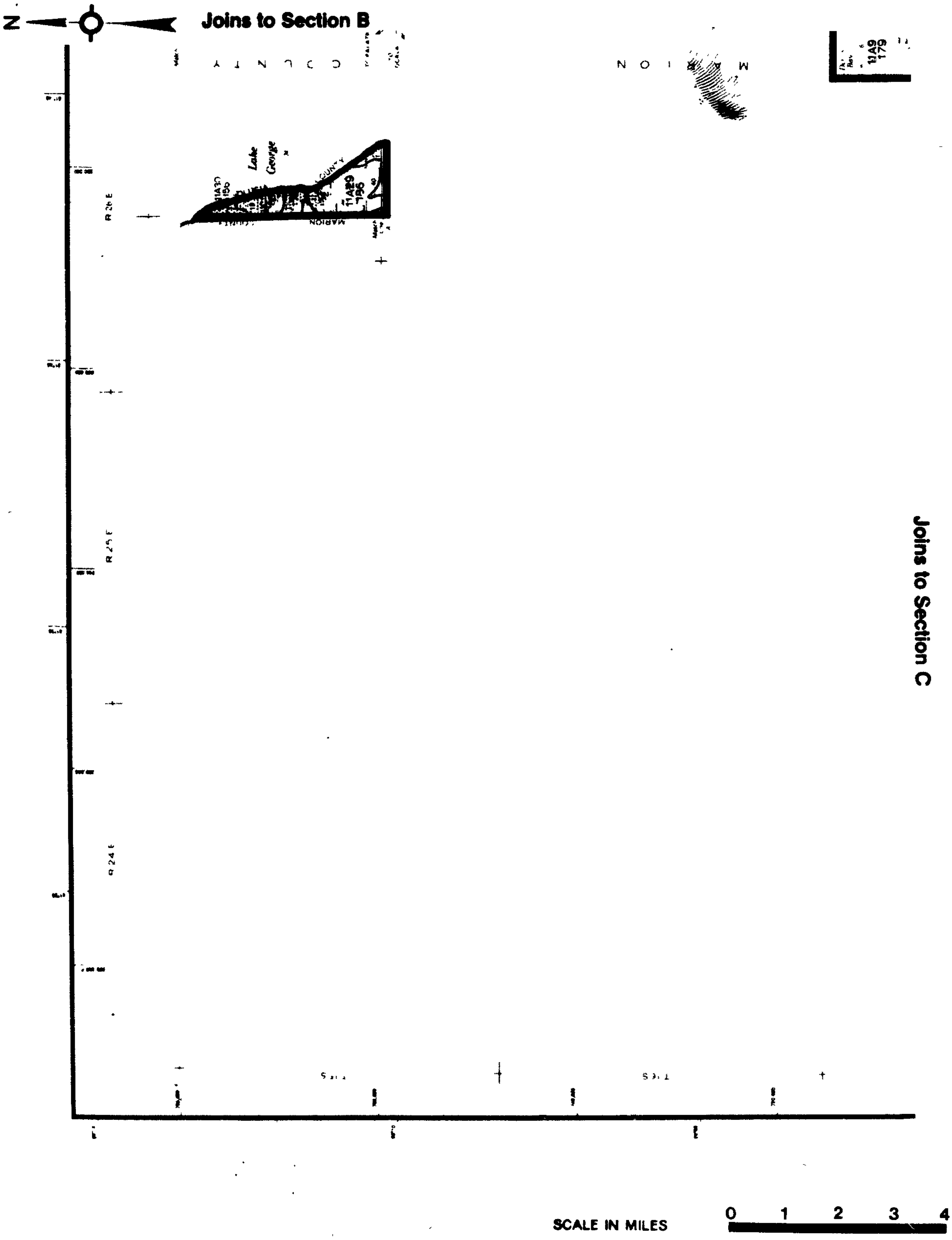
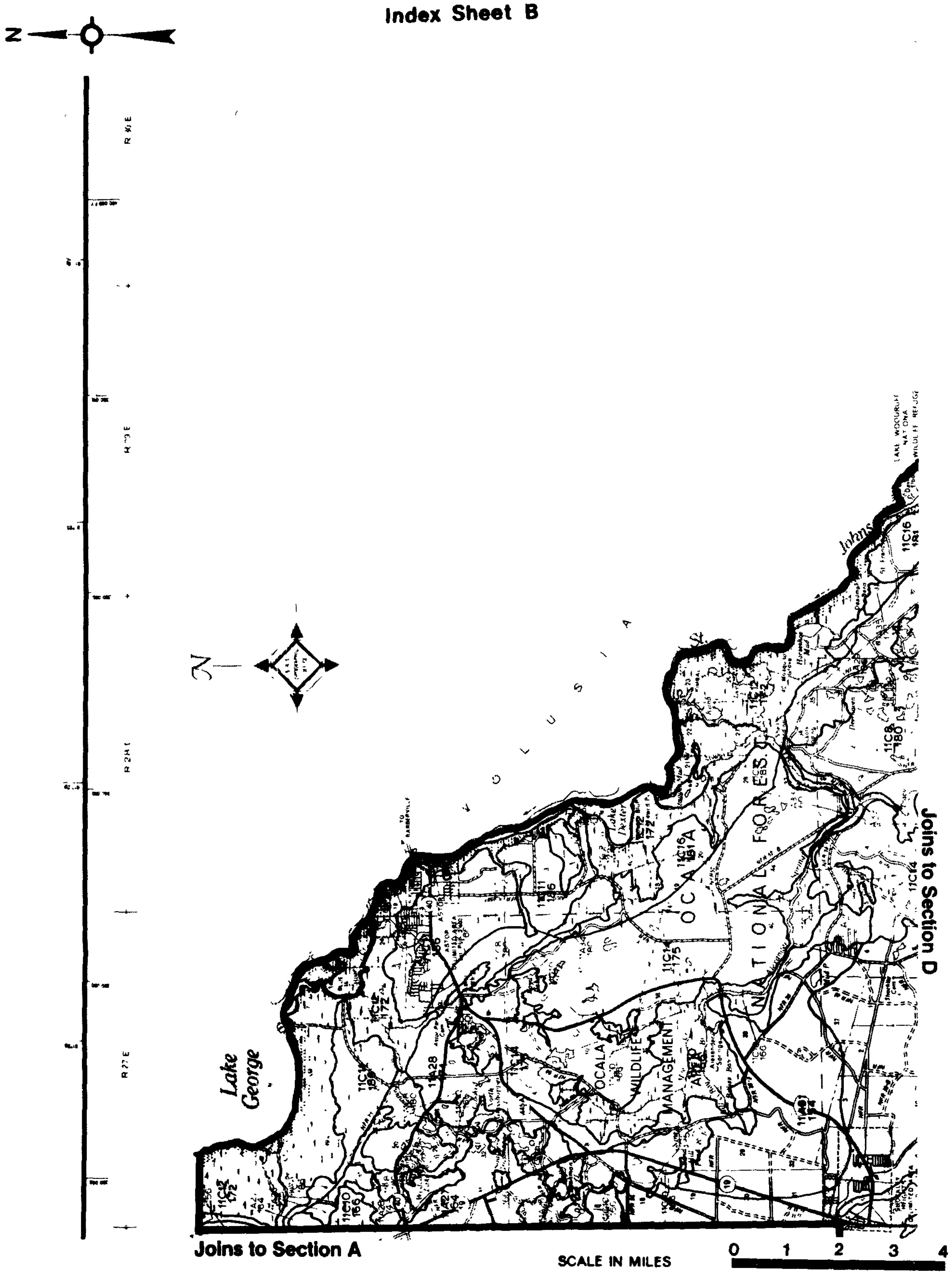


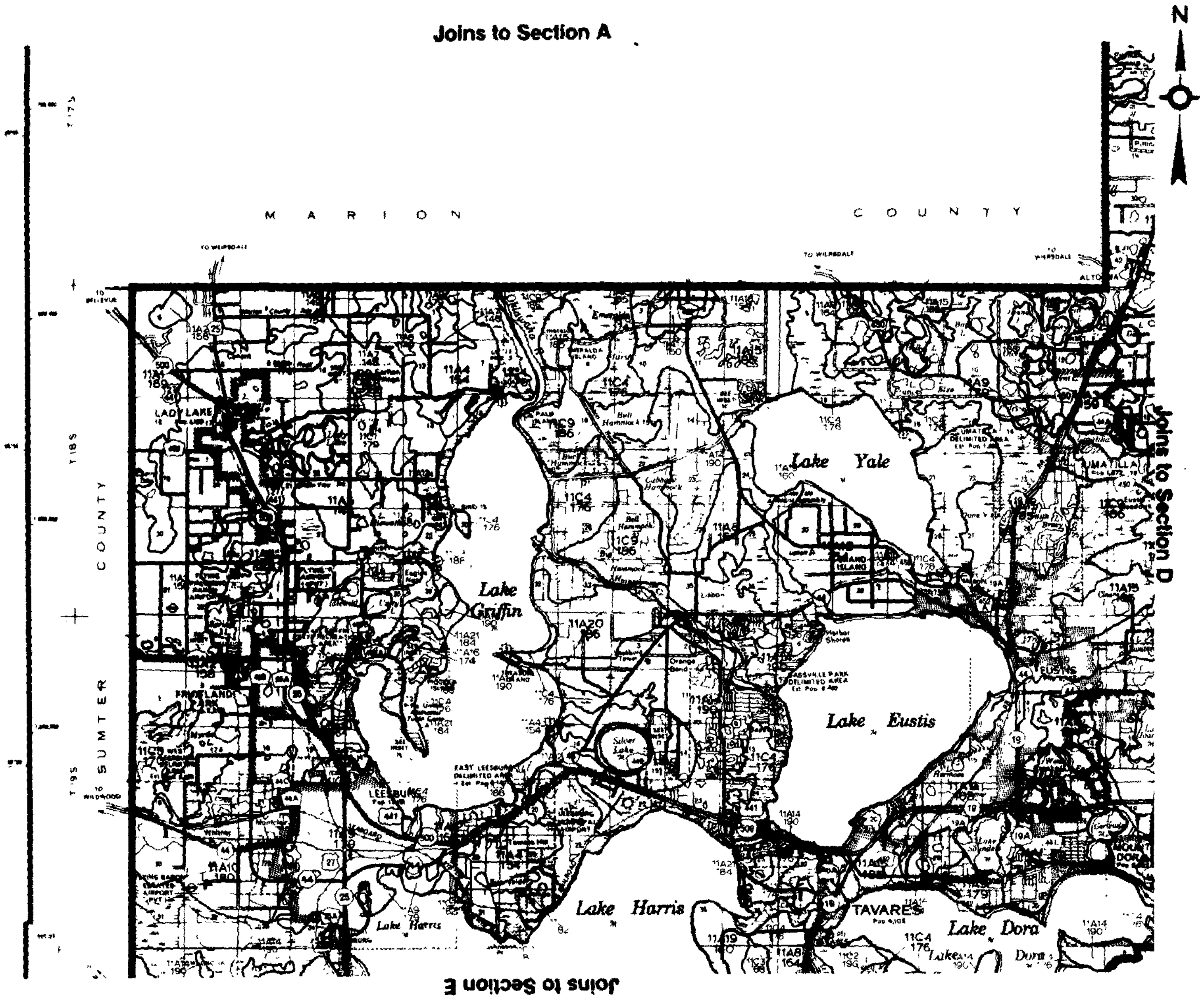
Figure H-1. Index to map sheets, detailed pollution potential map, surficial aquifer, Lake County, Florida.



Index Sheet A

Index Sheet B





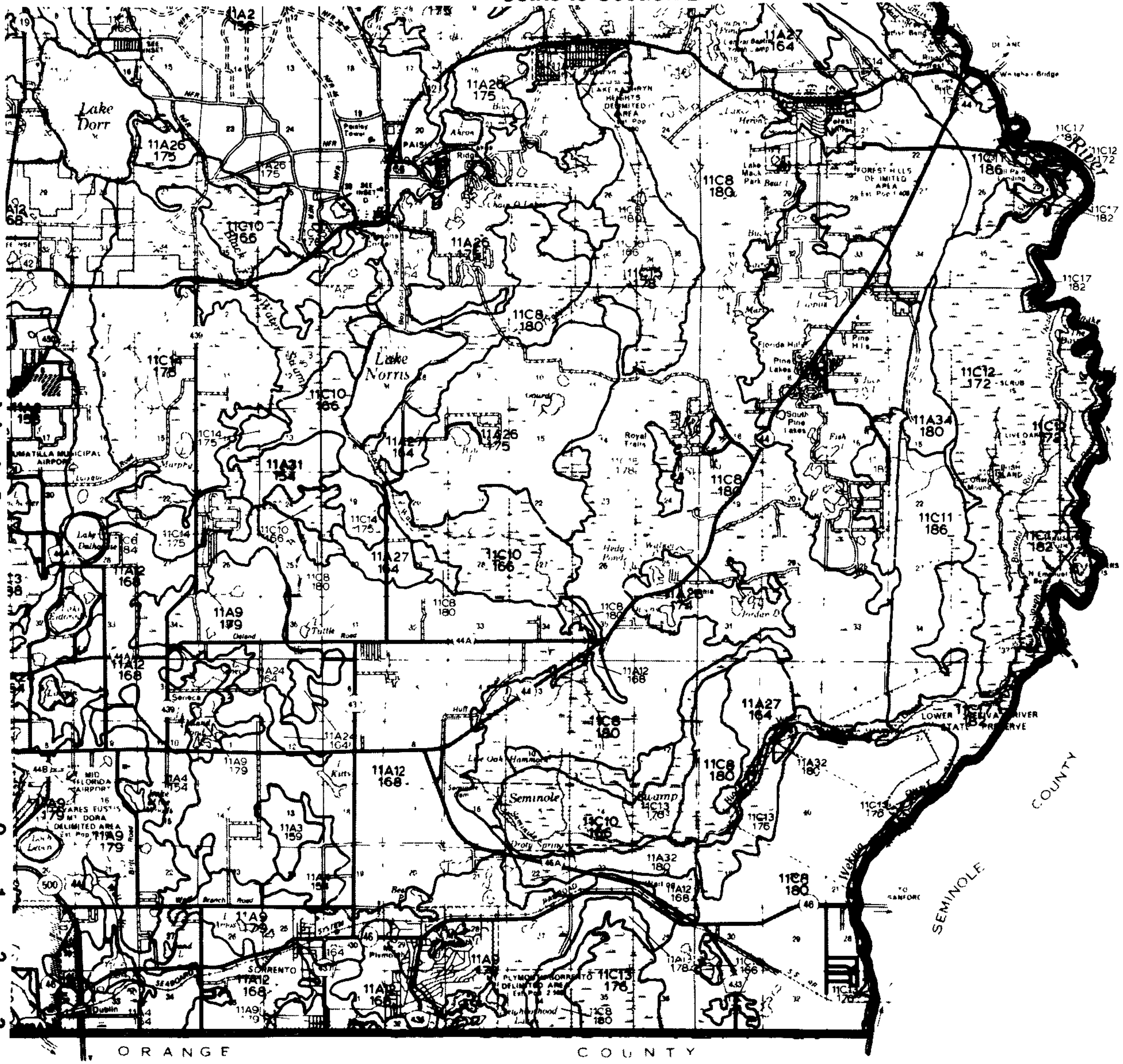
Index Sheet C

SCALE IN MILES

0 1 2 3 4

Index Sheet D

Joins to Section B

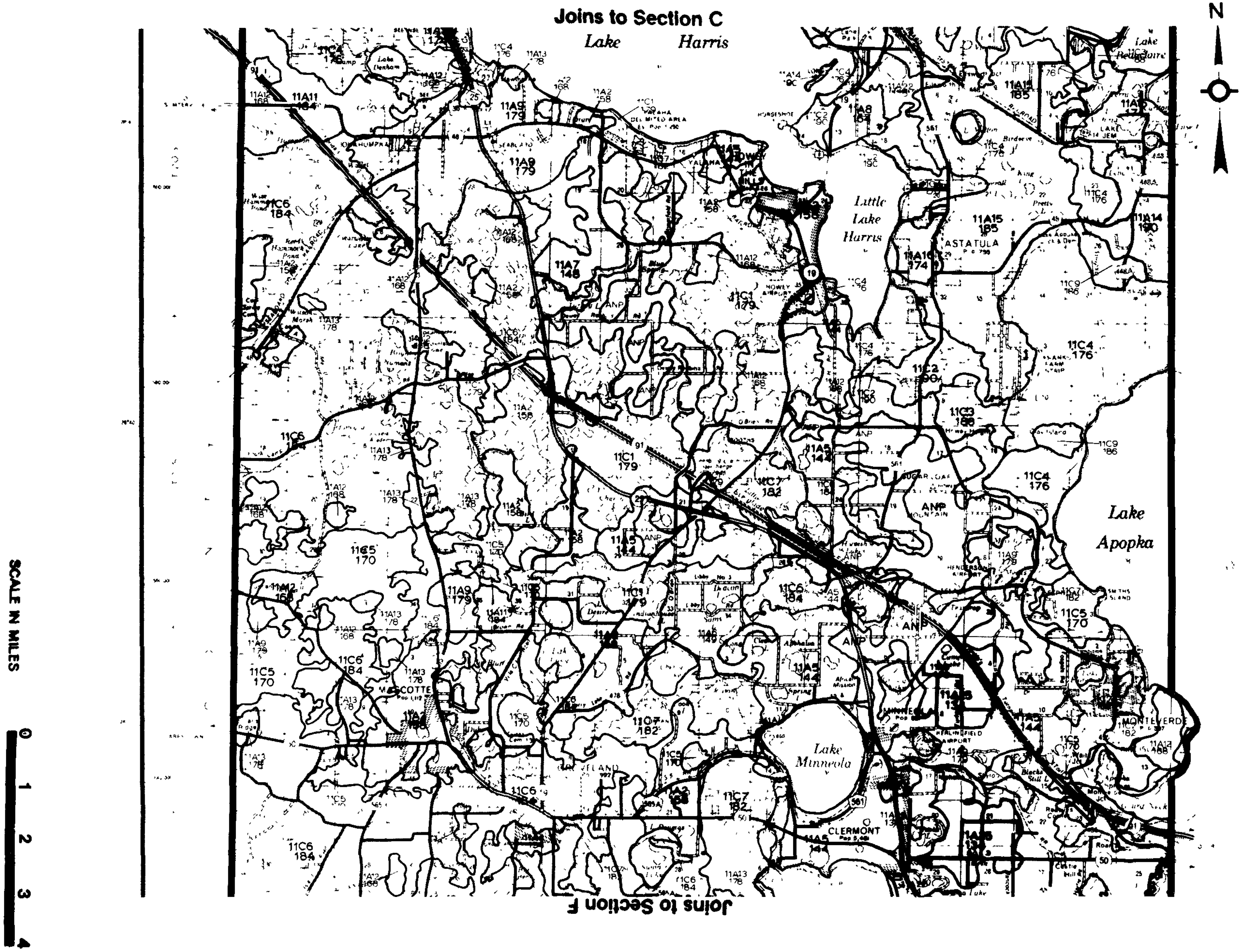


Joins to Section C

SCALE IN MILES

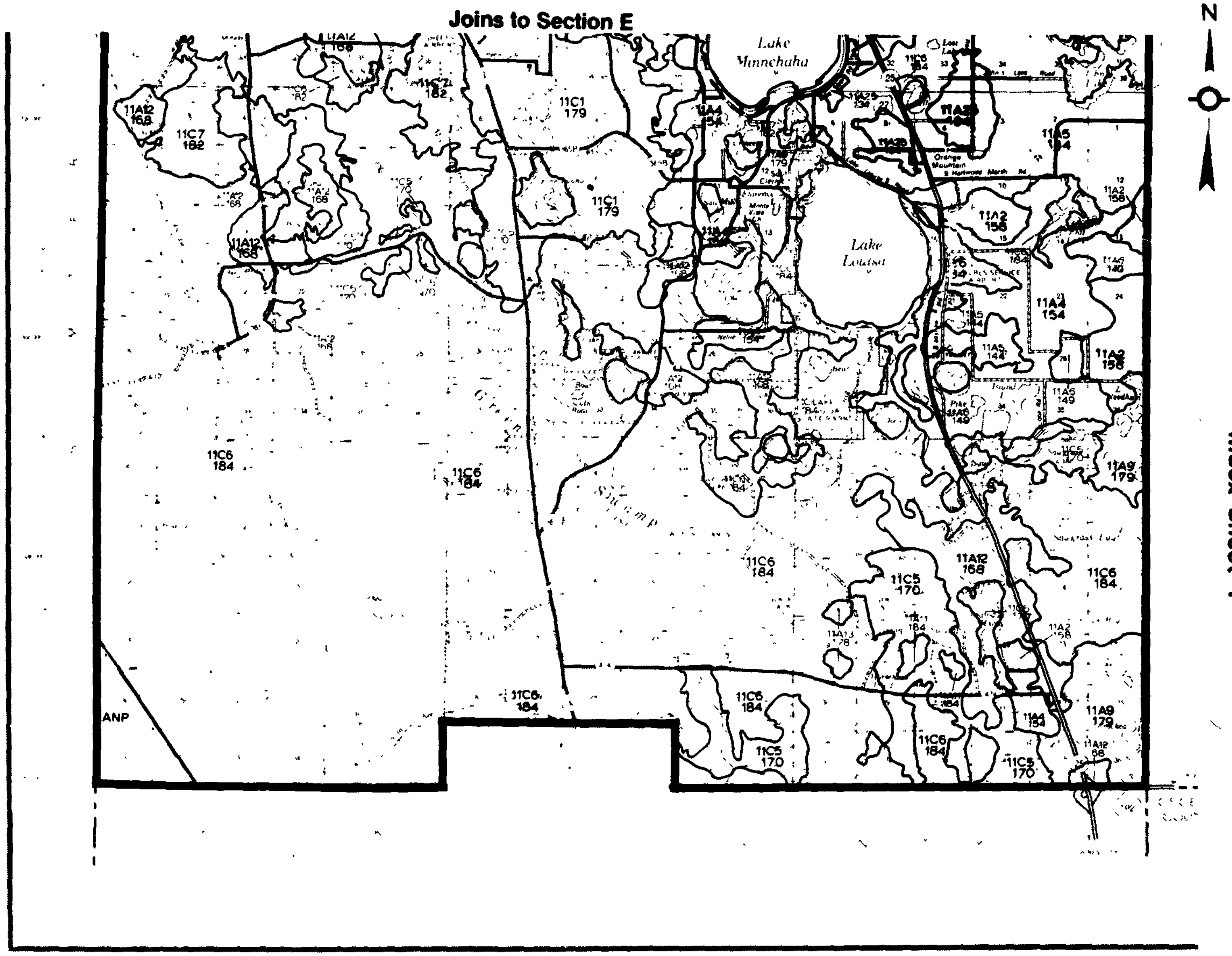
0 1 2 3 4

Index Sheet E



Index Sheet F

Joins to Section E



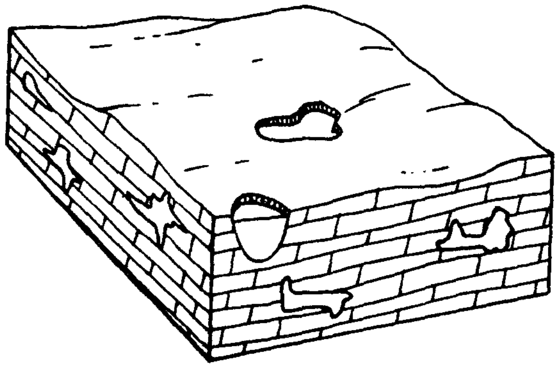
SCALE IN MILES

0 1 2 3 4

SOUTHEAST COASTAL PLAIN

(11A) Solution Limestone and Shallow Surficial Aquifers

This hydrogeologic setting is characterized by low to moderate topographic relief and deposits of limestone which have been partially dissolved to form a network of solution cavities and caves. Surficial deposits typically consist of sands which may serve as localized aquifers. The underlying limestone typically serves as the principal aquifer due to the high yields. The shallow surficial aquifer may not be present in all areas. Precipitation is abundant and recharge is high. Water levels are variable but are usually moderate in the limestone and shallow in the overlying surficial sands. These sands also serve as an important source of recharge for the limestones. Due to the presence of a shallow water table and direct recharge to the limestone these surficial sands are very vulnerable to pollution. Near the coast, these aquifers are very susceptible to salt water intrusion.



SETTING 11A1 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	169

SETTING 11A2 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	158

SETTING 11A3 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	159

SETTING 11A4 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	154

SETTING 11A5 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	144

SETTING 11A6 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	149

SETTING 11A7 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	148

SETTING 11A8 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	164

SETTING 11A9 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	179

SETTING 11A10 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sh and/or Agg Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	180

SETTING 11A11 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	184

SETTING 11A12 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	168

SETTING 11A13 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	178

SETTING 11A14 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	190

SETTING 11A15 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	185

SETTING 11A16 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	174

SETTING 11A17 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	150

SETTING 11A18 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	154

SETTING 11A19 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	160

SETTING 11A20 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sh and/or Agg Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	186

SETTING 11A21 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	184

SETTING 11A22 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	175

SETTING 11A23 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	170

SETTING 11A24 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	164

SETTING 11A25 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	134

SETTING 11A26 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	175

SETTING 11A27 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	164

SETTING 11A28 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	174

SETTING 11A29 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	186

SETTING 11A30 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	156

SETTING 11A31 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	154

SETTING 11A32 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	180

SETTING 11A33 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	160

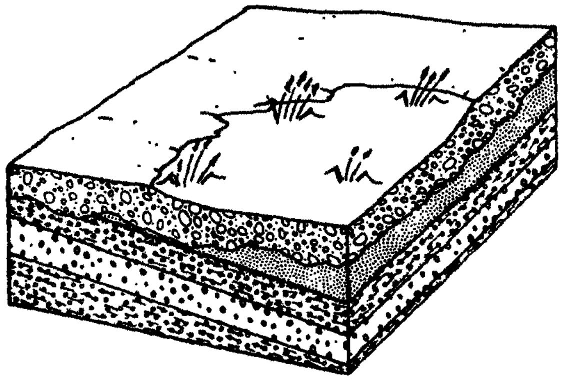
SETTING 11A34 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	180

SETTING 11A35 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	170

SOUTHEAST COASTAL PLAIN

(11C) Swamp

This hydrogeologic setting is characterized by flat topographic relief, very high water levels and deposits of limestone which have partially been dissolved to form a network of solution cavities and caves. Soils are typically sand and recharge may be high due to the abundant precipitation. The limestone typically serves as the major regional aquifer. These swamps also serve as discharge areas, but due to their environmental vulnerability, and possible gradient reversal, they should be regarded as areas of maximum (potential) recharge. Water levels are typically at or above the surface during the majority of the year.



SETTING 11C1 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	179

SETTING 11C2 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	190

SETTING 11C3 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Peat	2	8	16
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	188

SETTING 11C4 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Muck	2	2	4
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	176

SETTING 11C5 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Muck	2	2	4
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	170

SETTING 11C6 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	184

SETTING 11C7 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Peat	2	8	16
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	182

SETTING 11C8 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	180

SETTING 11C9 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sh and/or Agg Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	186

SETTING 11C10 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Muck	2	2	4
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	166

SETTING 11C11 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	186

SETTING 11C12 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Muck	2	2	4
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	172

SETTING 11C13 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sh and/or Agg Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	176

SETTING 11C14 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	175

SETTING 11C15 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	7-10	4	8	37
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Peat	2	8	16
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	178

SETTING 11C16 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	181

SETTING 11C17 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sh and/or Agg Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	182

LAKE COUNTY FLORIDA
(CONFINED AQUIFER)

Lake County, Florida, lies within the Southeast Coastal Plain ground-water region. The county is characterized by low to moderate relief with karst topography and numerous sinkholes, lakes and swampy areas. Water depths are typically shallow and soils are highly permeable. Ground-water resources within Lake County are derived from either a near-surface sand aquifer or an underlying carbonate rock aquifer, which is in hydraulic connection with the overlying sand deposits. The aquifers are separated by a confining bed comprised of an interbedded mixture of clayey sand and clay. This confining layer is extensive throughout the county, although variable in thickness and discontinuous in local sections. Yields from the surficial sand aquifer are usually sufficient for domestic purposes. Because of the highly permeable overlying soils and shallow water table, the surficial aquifer is vulnerable to pollution from the surface. The carbonate rock aquifer is referred to as the "Floridan" aquifer and is the major ground-water resource in the county. The susceptibility of this aquifer to pollution from the surface depends on the degree or confinement of the limestone aquifer and the amount of recharge received from the more vulnerable surficial sand aquifer. The DRASTIC Index numbers reflect evaluation of confined aquifers only. Computed DRASTIC indexes range from 93 to 214.

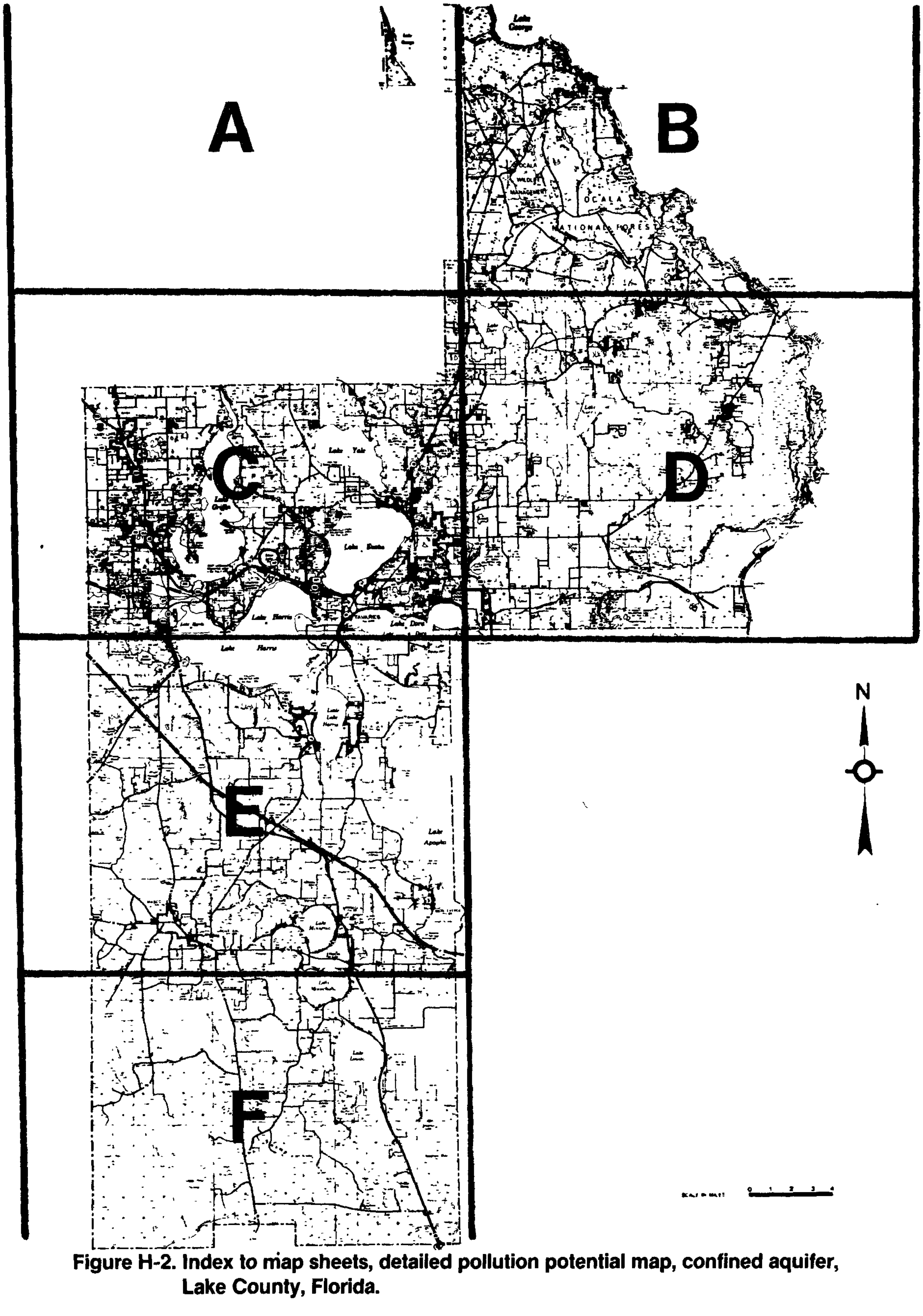
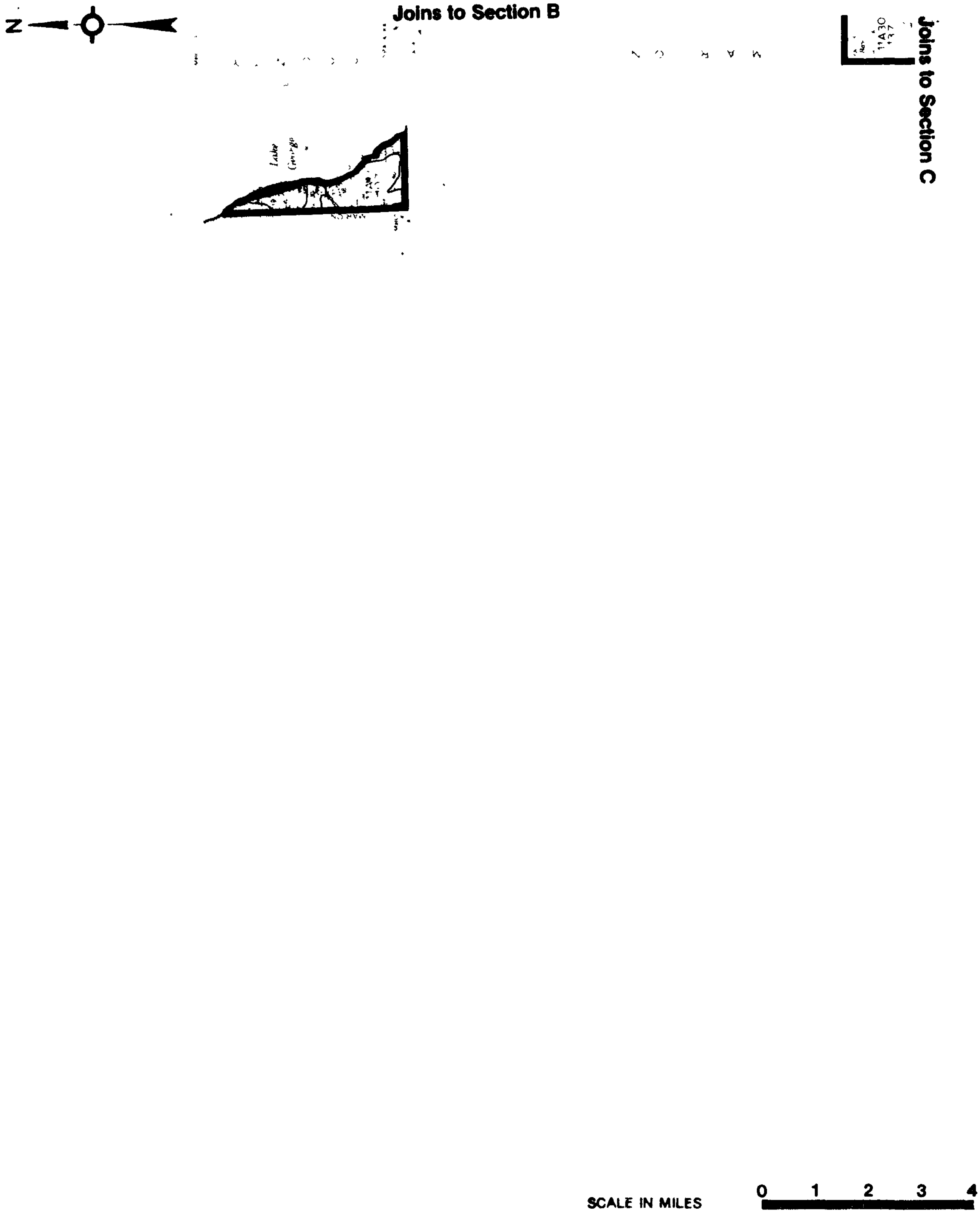
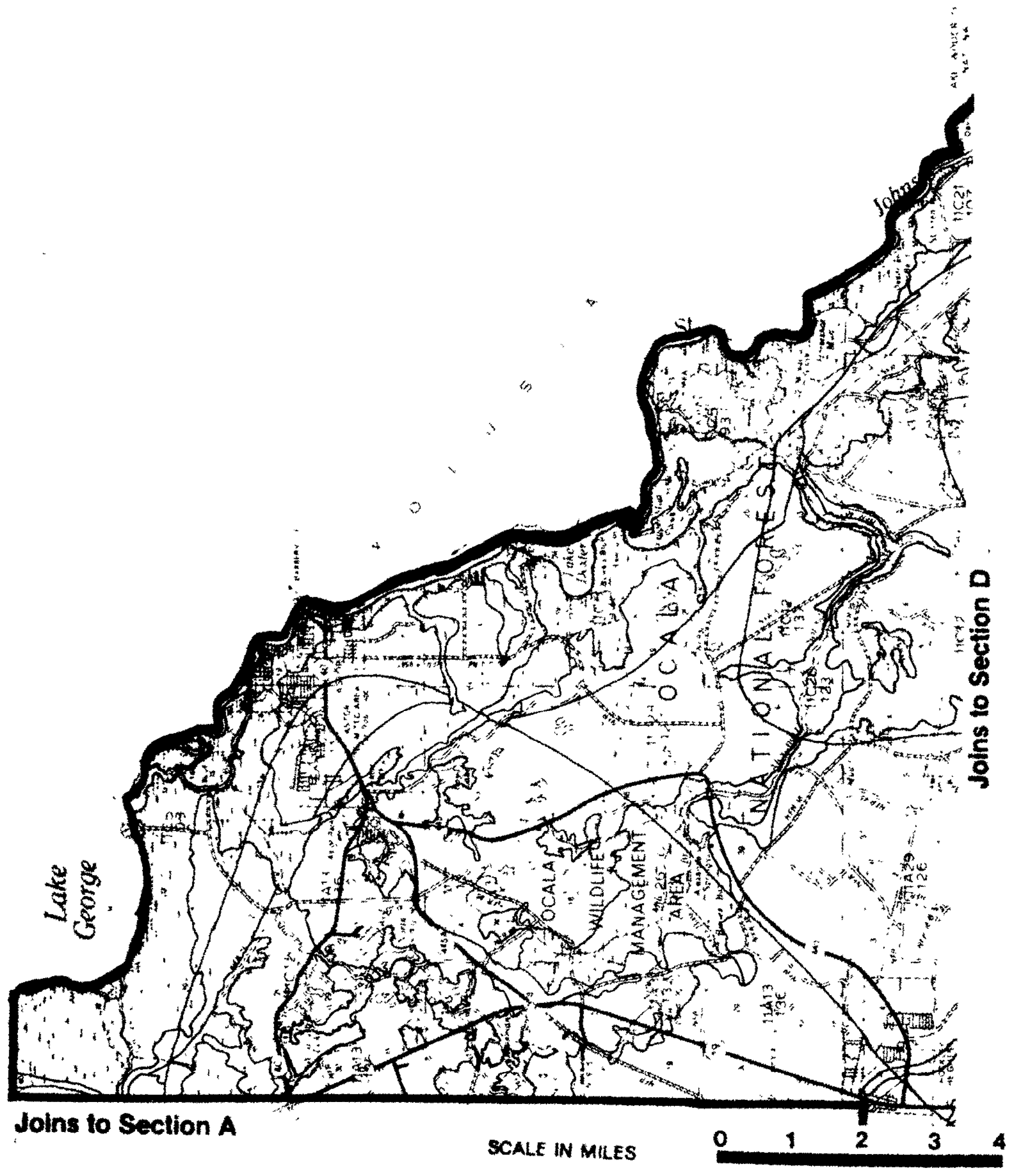


Figure H-2. Index to map sheets, detailed pollution potential map, confined aquifer, Lake County, Florida.

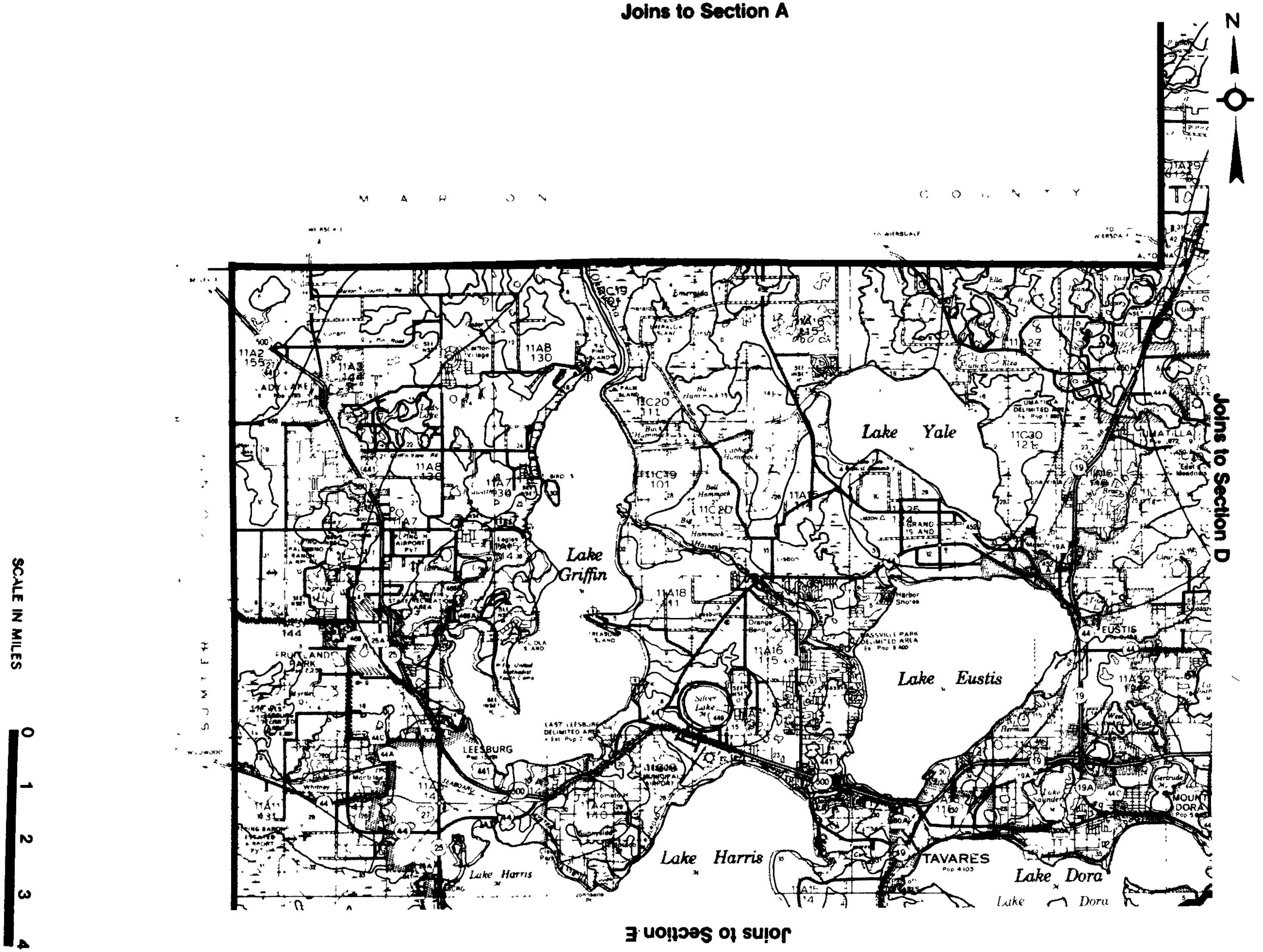


Index Sheet A

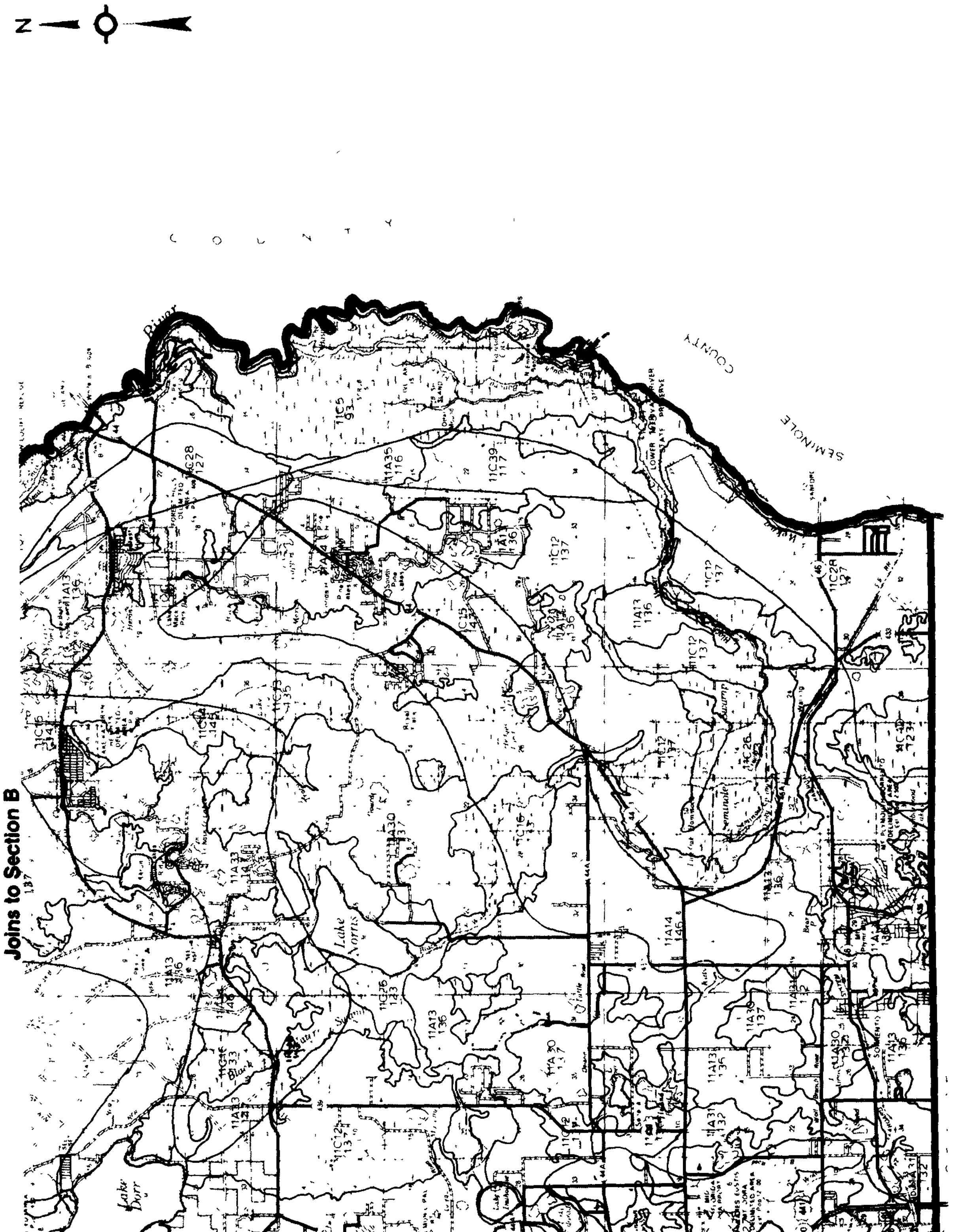
Index Sheet B



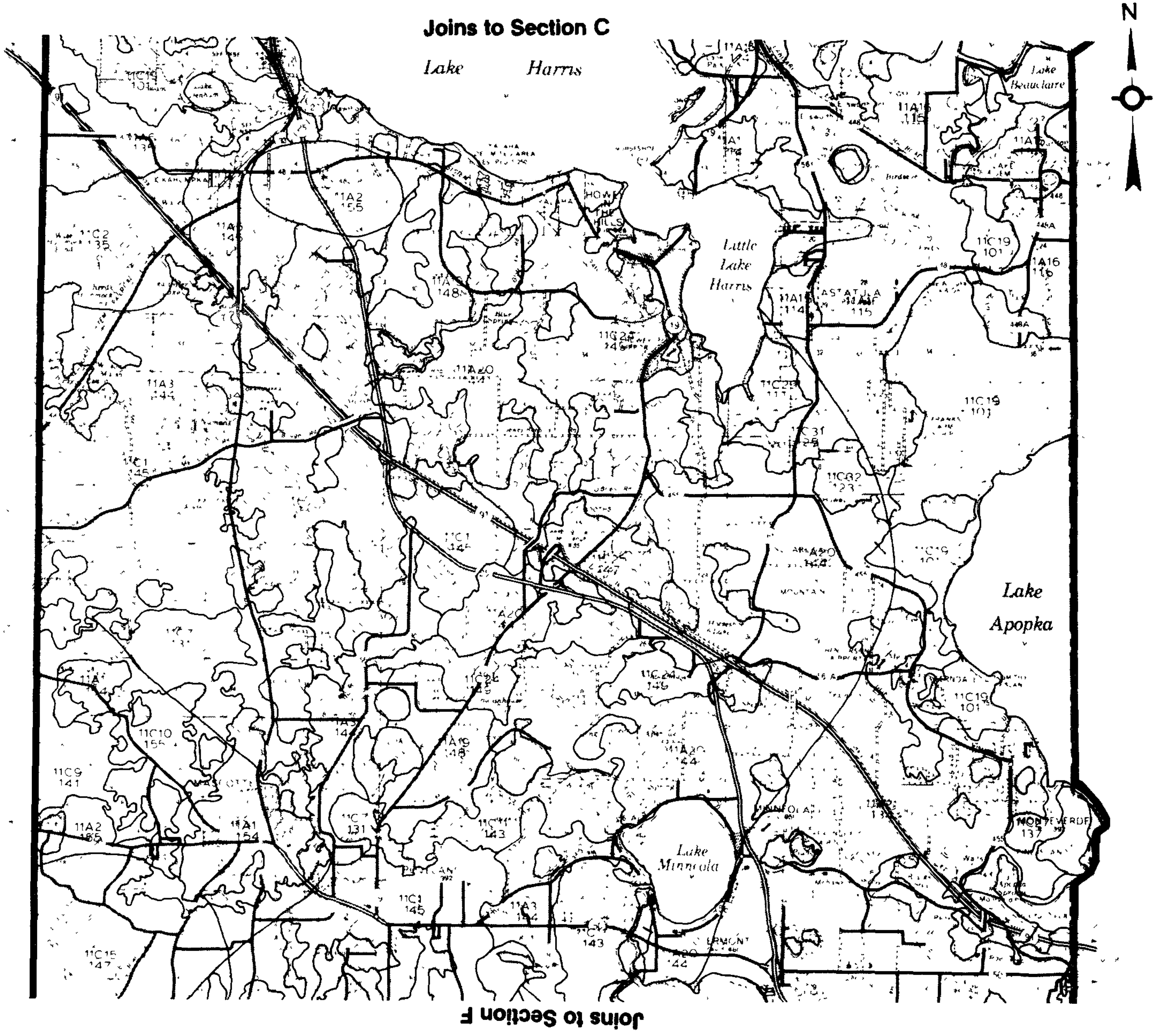
Index Sheet C



Index Sheet D



Index Sheet E



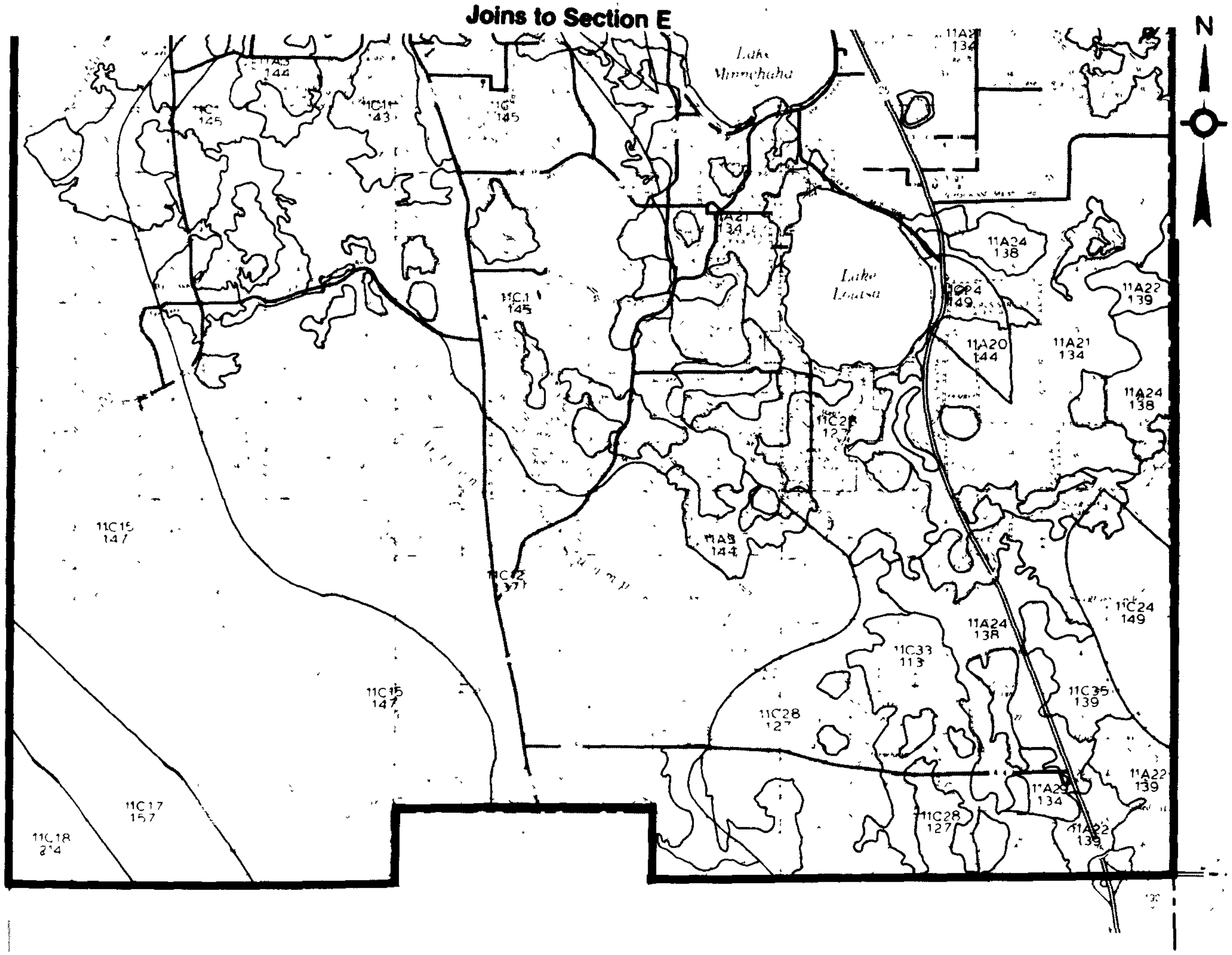
SCALE IN MILES

0 1 2 3 4

Index Sheet F

SCALE IN MILES

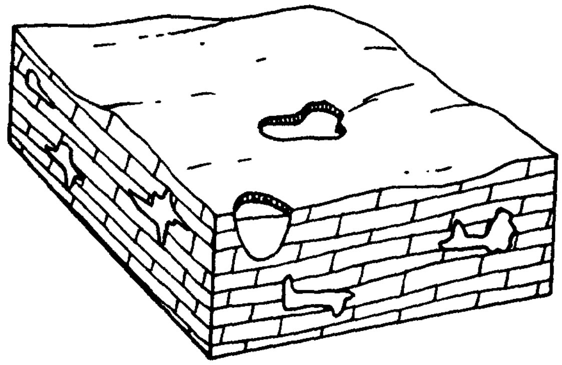
0 1 2 3 4



SOUTHEAST COASTAL PLAIN

(11A) Solution Limestone and Shallow Surficial Aquifers

This hydrogeologic setting is characterized by low to moderate topographic relief and deposits of limestone which have been partially dissolved to form a network of solution cavities and caves. Surficial deposits typically consist of sands which may serve as localized aquifers. The underlying limestone typically serves as the principal aquifer due to the high yields. The shallow surficial aquifer may not be present in all areas. Precipitation is abundant and recharge is high. Water levels are variable but are usually moderate in the limestone and shallow in the overlying surficial sands. These sands also serve as an important source of recharge for the limestones. Due to the presence of a shallow water table and direct recharge to the limestone these surficial sands are very vulnerable to pollution. Near the coast, these aquifers are very susceptible to salt water intrusion.



SETTING 11A1 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	7-10	4	8	32
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	154

SETTING 11A2 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	7-10	4	8	32
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	155

SETTING 11A3 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	7-10	4	8	32
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	144

SETTING 11A4 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	7-10	4	8	32
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	140

SETTING 11A5 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	7-10	4	8	32
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	145

SETTING 11A6 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	7-10	4	8	32
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	135

SETTING 11A7 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	7-10	4	8	32
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	134

SETTING 11A8 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	7-10	4	8	32
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	130

SETTING 11A9 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	106

SETTING 11A10 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	7-10	4	8	32
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sh and/or Agg Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	141

SETTING 11A11 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	7-10	4	8	32
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sh and/or Agg Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	131

SETTING 11A12 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	20
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	107

SETTING 11A13 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	136

SETTING 11A14 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	146

SETTING 11A15 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	2-4	4	3	12
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	114

SETTING 11A16 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	2-4	4	3	12
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	115

SETTING 11A17 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	2-4	4	3	12
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	110

SETTING 11A18 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	2-4	4	3	12
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sh and/or Agg Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	111

SETTING 11A19 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	148

SETTING 11A20 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	144

SETTING 11A21 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	134

SETTING 11A22 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	139

SETTING 11A23 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	149

SETTING 11A24 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	138

SETTING 11A25 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	2-4	4	3	12
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	124

SETTING 11A26 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	2-4	4	3	12
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	120

SETTING 11A27 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	2-4	4	3	12
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	125

SETTING 11A28 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	127

SETTING 11A29 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	126

SETTING 11A30 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	132

SETTING 11A31 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	137

SETTING 11A32 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	122

SETTING 11A33 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	147

SETTING 11A34 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	102

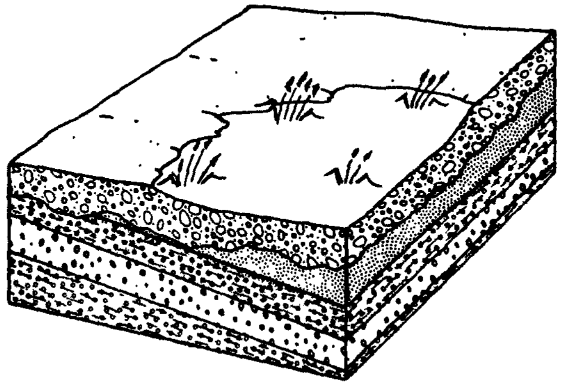
SETTING 11A35 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	116

SETTING 11A36 Solution Limestone		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	117

SOUTHEAST COASTAL PLAIN

(11C) Swamp

This hydrogeologic setting is characterized by flat topographic relief, very high water levels and deposits of limestone which have partially been dissolved to form a network of solution cavities and caves. Soils are typically sand and recharge may be high due to the abundant precipitation. The limestone typically serves as the major regional aquifer. These swamps also serve as discharge areas, but due to their environmental vulnerability, and possible gradient reversal, they should be regarded as areas of maximum (potential) recharge. Water levels are typically at or above the surface during the majority of the year.



SETTING 11C1 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	7-10	4	8	32
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	145

SETTING 11C2 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	7-10	4	8	32
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	135

SETTING 11C3 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	2-4	4	3	12
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Peat	2	8	16
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	113

SETTING 11C4 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	2-4	4	3	12
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	115

SETTING 11C5 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Muck	2	2	4
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	93

SETTING 11C6 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Muck	2	2	4
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	103

SETTING 11C7 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	7-10	4	8	32
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Muck	2	2	4
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	131

SETTING 11C8 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	7-10	4	8	32
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Muck	2	2	4
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	121

SETTING 11C9 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	7-10	4	8	32
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Muck	2	2	4
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	141

SETTING 11C10 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	7-10	4	8	32
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	155

SETTING 11C11 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	7-10	4	8	32
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Peat	2	8	16
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	143

SETTING 11C12 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	137

SETTING 11C13 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Peat	2	8	16
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	135

SETTING 11C14 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Peat	2	8	16
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	145

SETTING 11C15 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	147

SETTING 11C16 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Muck	2	2	4
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	133

SETTING 11C17 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	157

SETTING 11C18 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Thin or Absent	2	10	20
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	214

SETTING 11C19 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	2-4	4	3	12
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Muck	2	2	4
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	101

SETTING 11C20 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	2-4	4	3	12
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sh and/or Agg. Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	131

SETTING 11C21 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	107

SETTING 11C22 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	7-10	4	8	32
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Peat	2	8	16
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	133

SETTING 11C23 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Peat	2	8	16
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	105

SETTING 11C24 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	149

SETTING 11C25 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Peat	2	8	16
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	147

SETTING 11C26 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Muck	2	2	4
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	123

SETTING 11C27 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Peat	2	8	16
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	137

SETTING 11C28 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	127

SETTING 11C29 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	2-4	4	3	12
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Muck	2	2	4
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	111

SETTING 11C30 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	2-4	4	3	12
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sh and/or Agg. Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	121

SETTING 11C31 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	2-4	4	3	12
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	125

SETTING 11C32 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	2-4	4	3	12
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Peat	2	8	16
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	123

SETTING 11C33 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Muck	2	2	4
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	113

SETTING 11C34 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Muck	2	2	4
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	125

SETTING 11C35 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	139

SETTING 11C36 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	10+	4	9	36
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Muck	2	2	4
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	135

SETTING 11C37 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sh and/or Agg. Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	133

SETTING 11C38 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sh and/or Agg. Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	143

SETTING 11C39 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sand	2	9	18
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	117

SETTING 11C40 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	4-7	4	6	24
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sh and/or Agg. Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	123

SETTING 11C41 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sh and/or Agg. Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	103

SETTING 11C42 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	0-2	4	1	4
Aquifer Media	Karst Limestone	3	10	30
Soil Media	Sh and/or Agg. Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	113

APPENDIX I

MINIDOKA COUNTY, IDAHO

Minidoka County, Idaho, lies within the Columbia Lava Plateau ground-water region. The majority of the county is covered by thick deposits of basalt resulting from numerous sequences of individual lava flows. These igneous rocks are generally exposed throughout the northern part of the county and are overlain by loess and alluvial deposits in the central and southern sections of the county, respectively. The DRASTIC Index numbers reflect evaluation of unconfined aquifers only. Computed DRASTIC Index values range from 127 to 167.

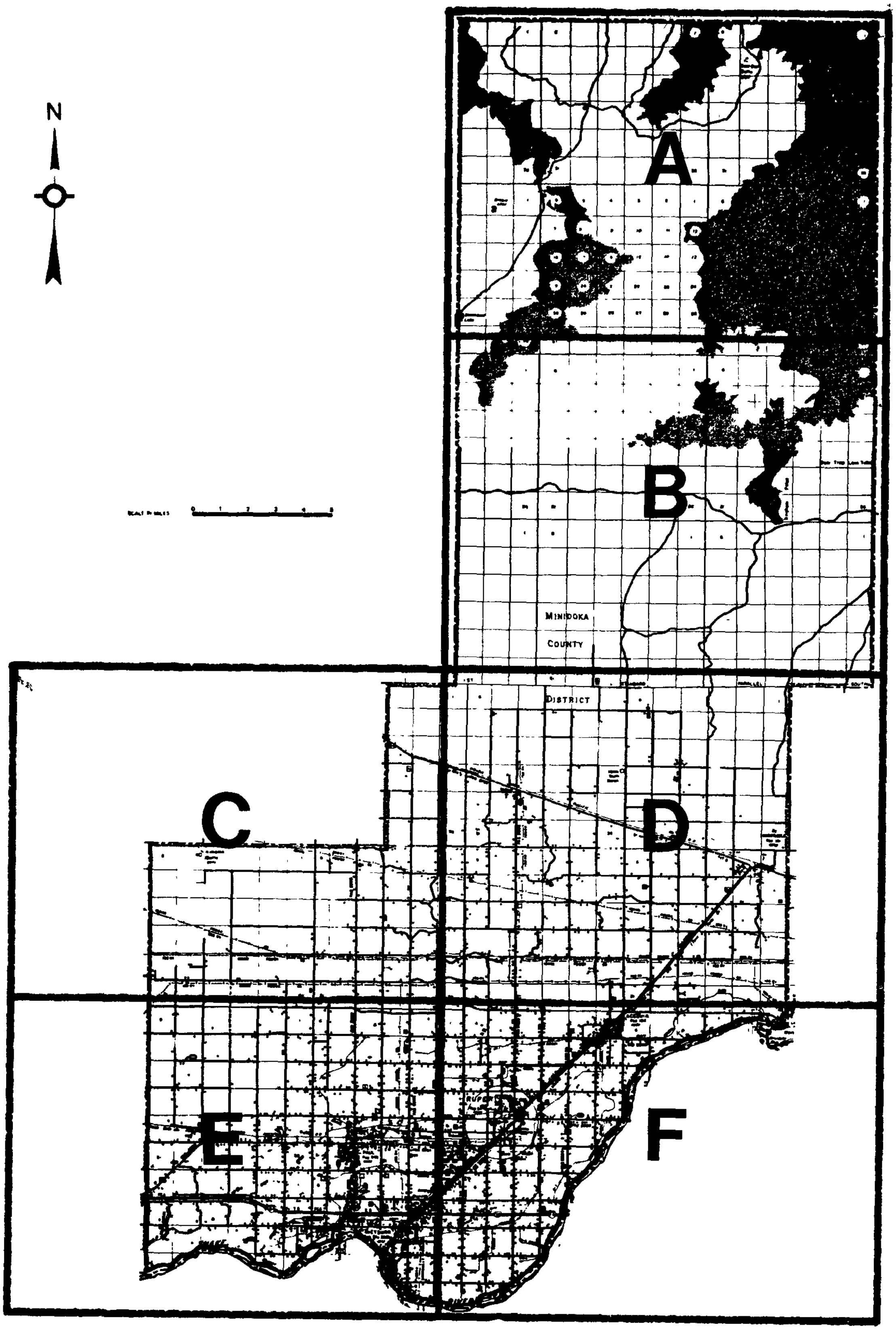
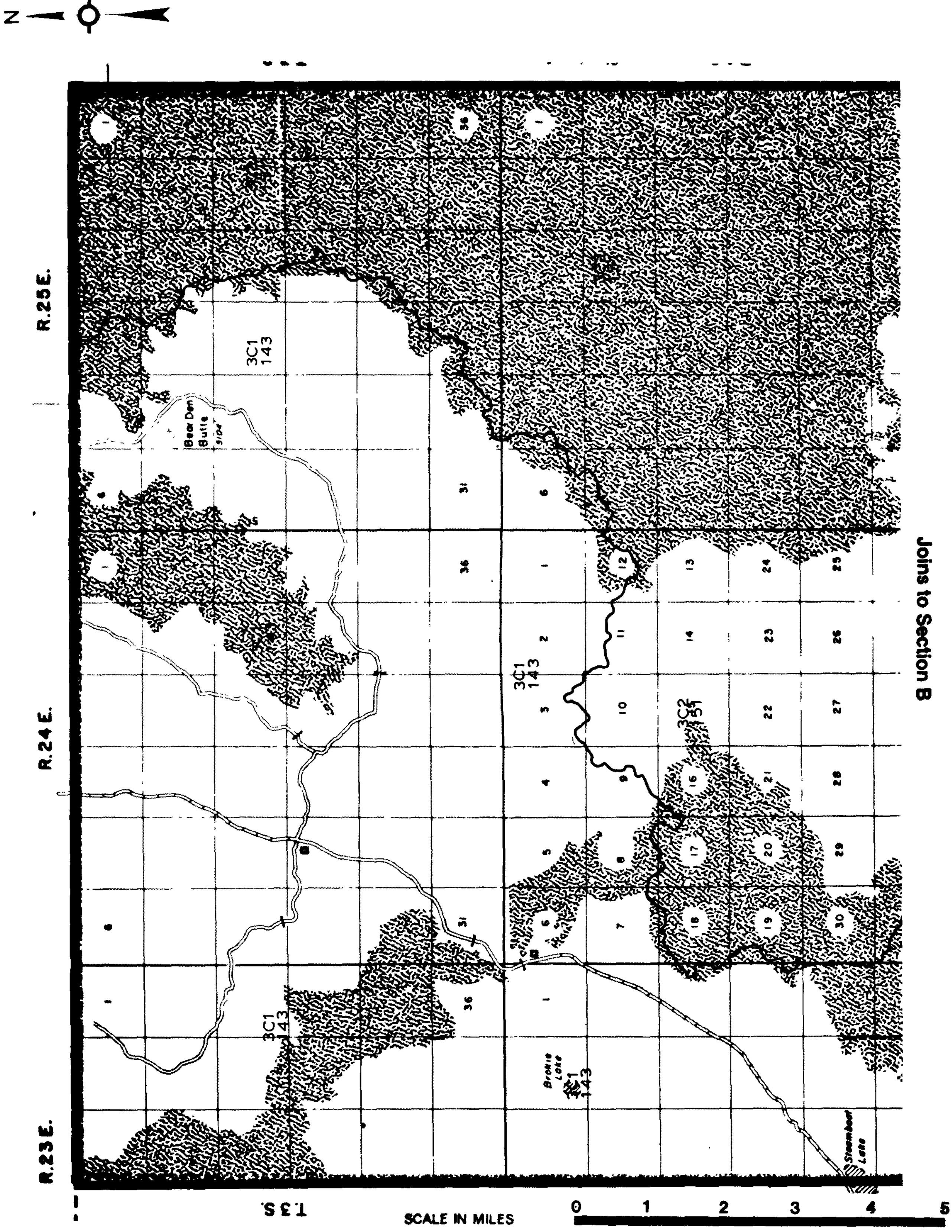
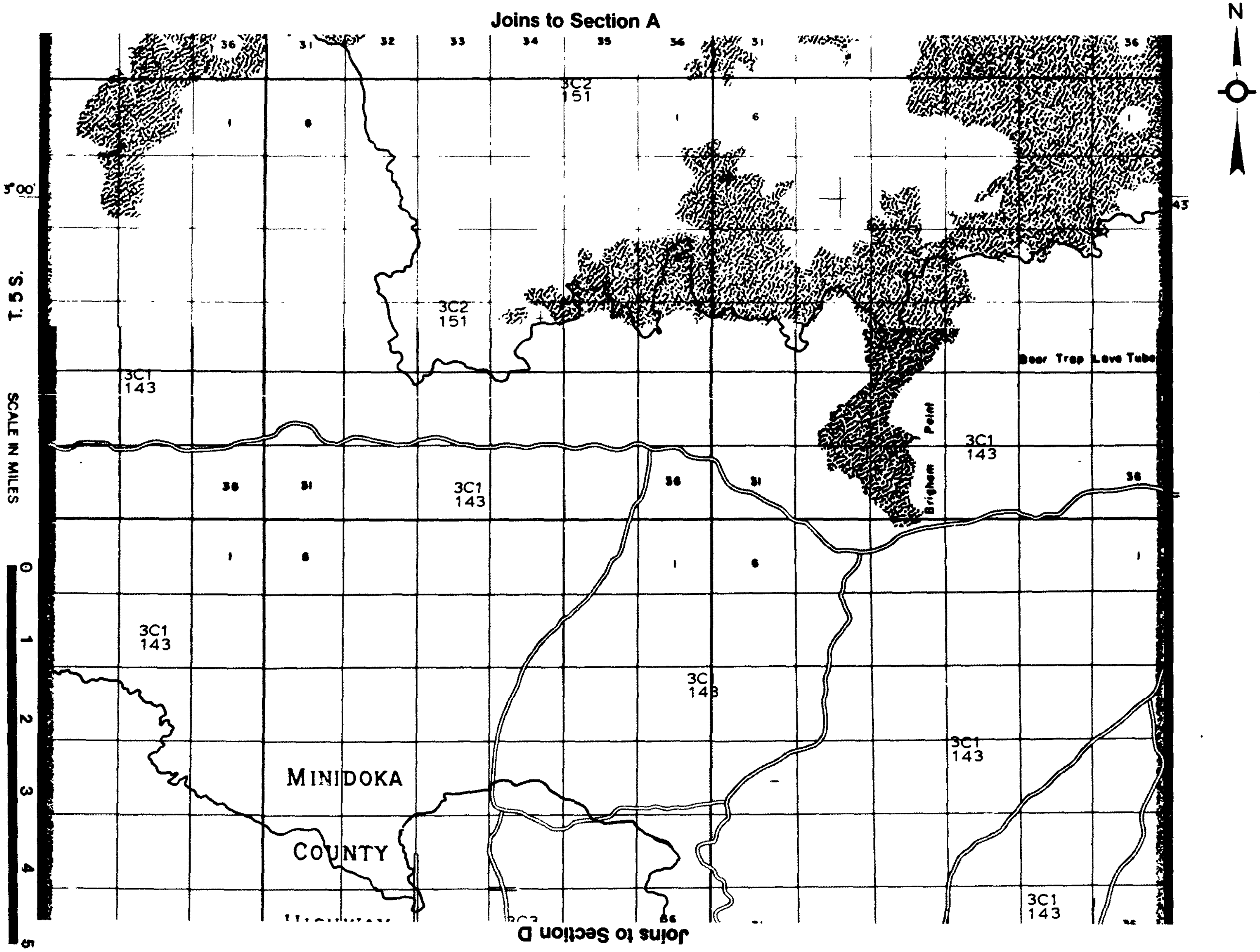


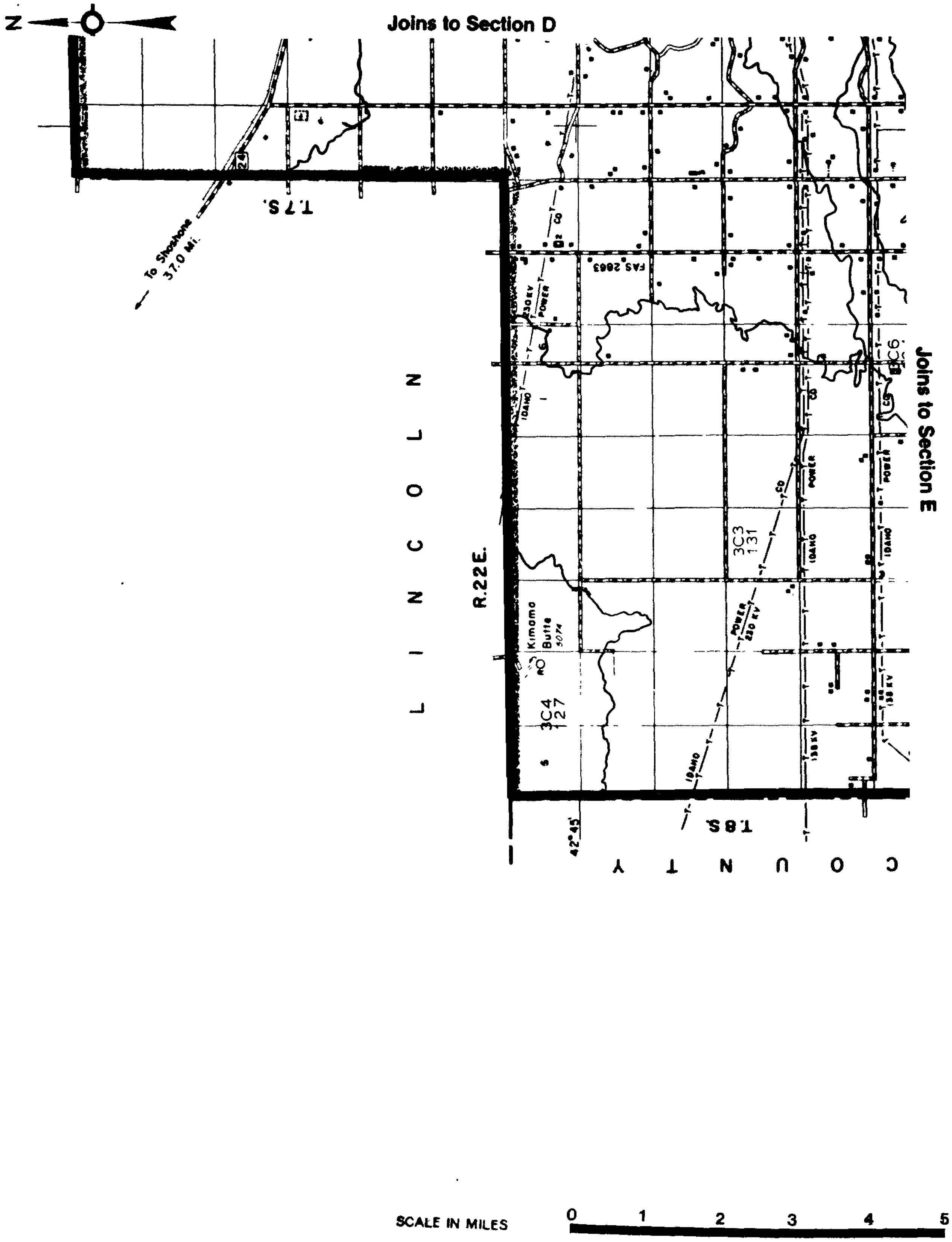
Figure I-1. Index to map sheets, detailed pollution potential map, Minidoka County, Idaho.

Index Sheet A



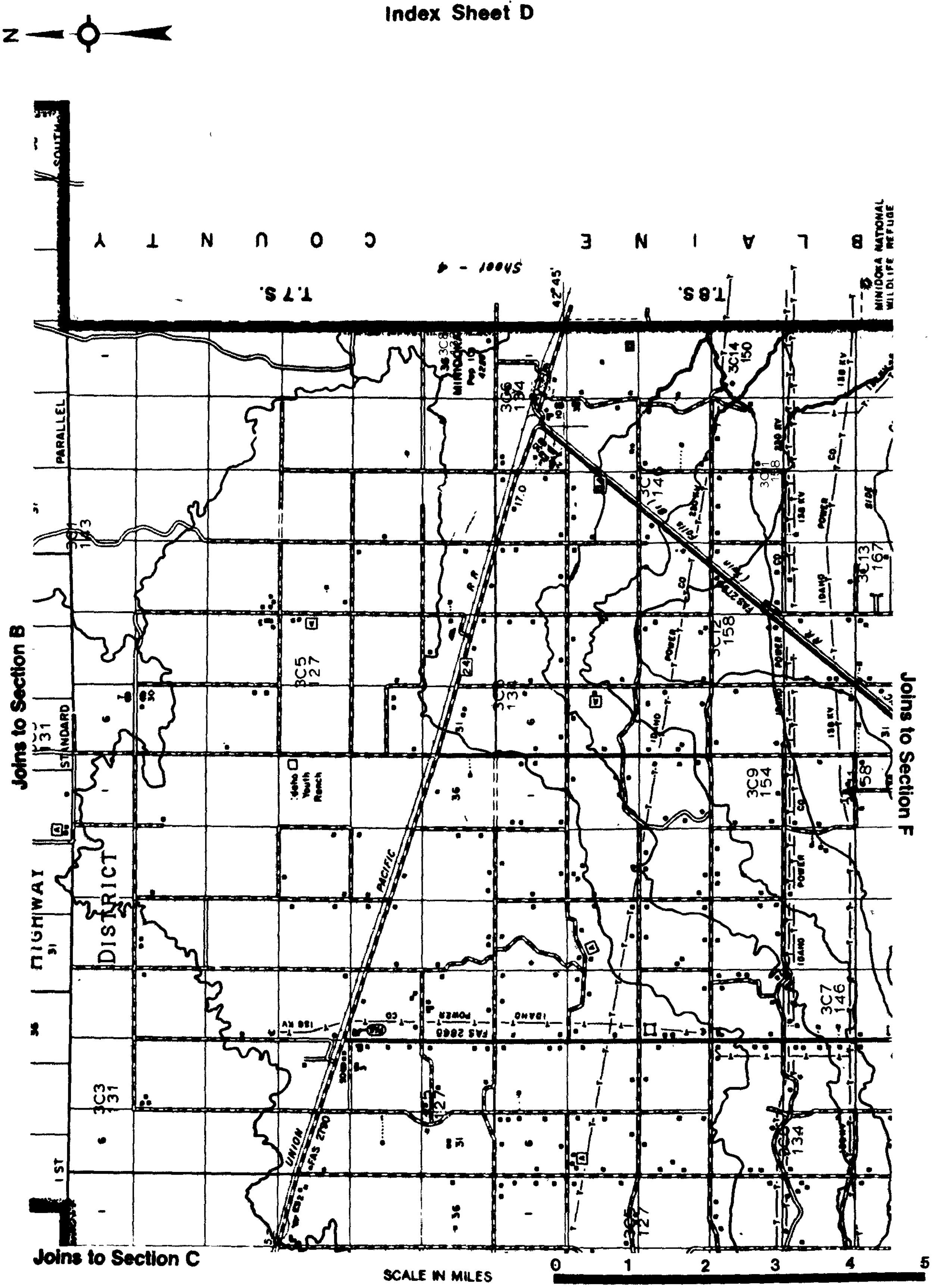
Index Sheet B

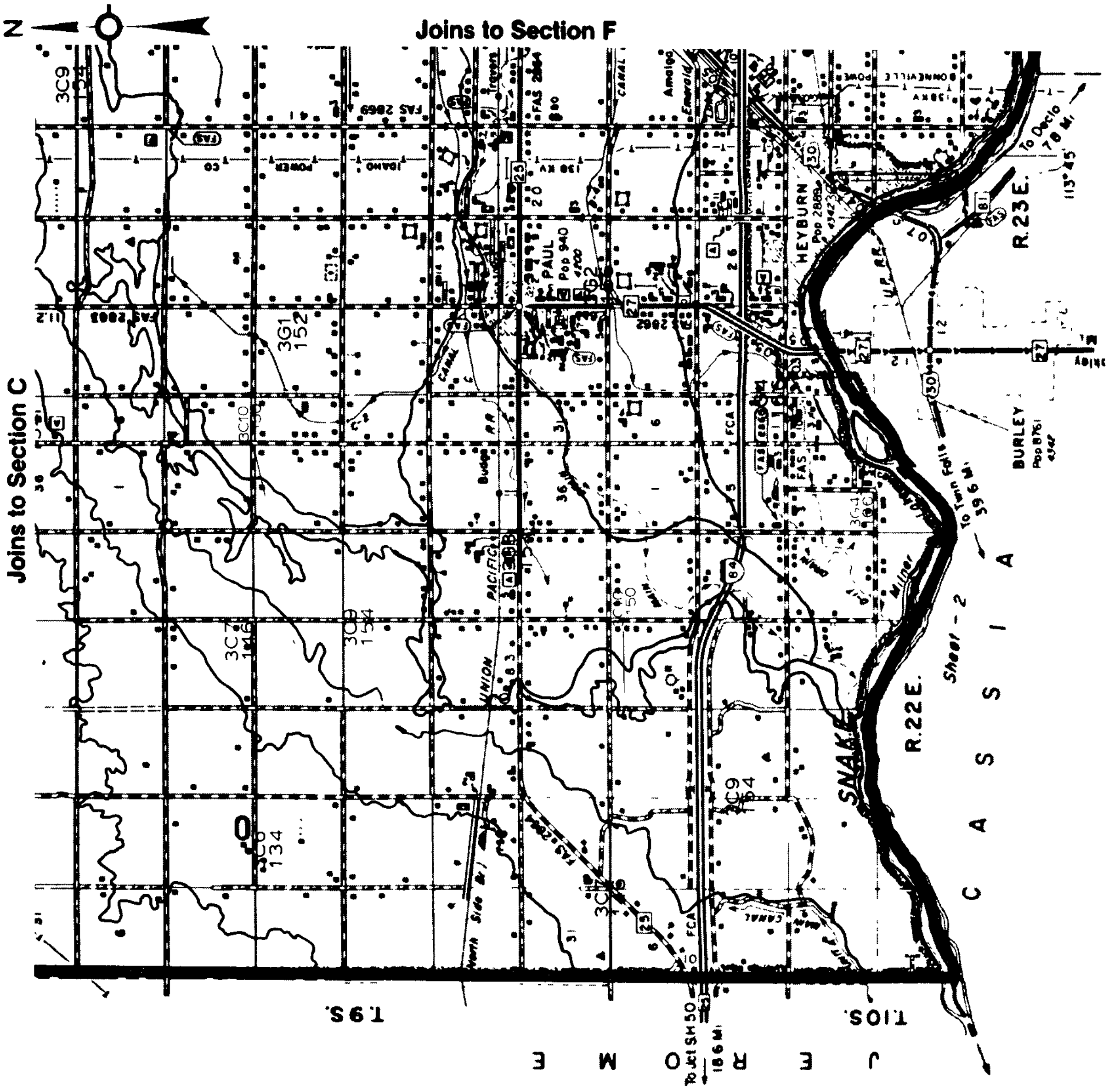




Index Sheet C

Index Sheet D

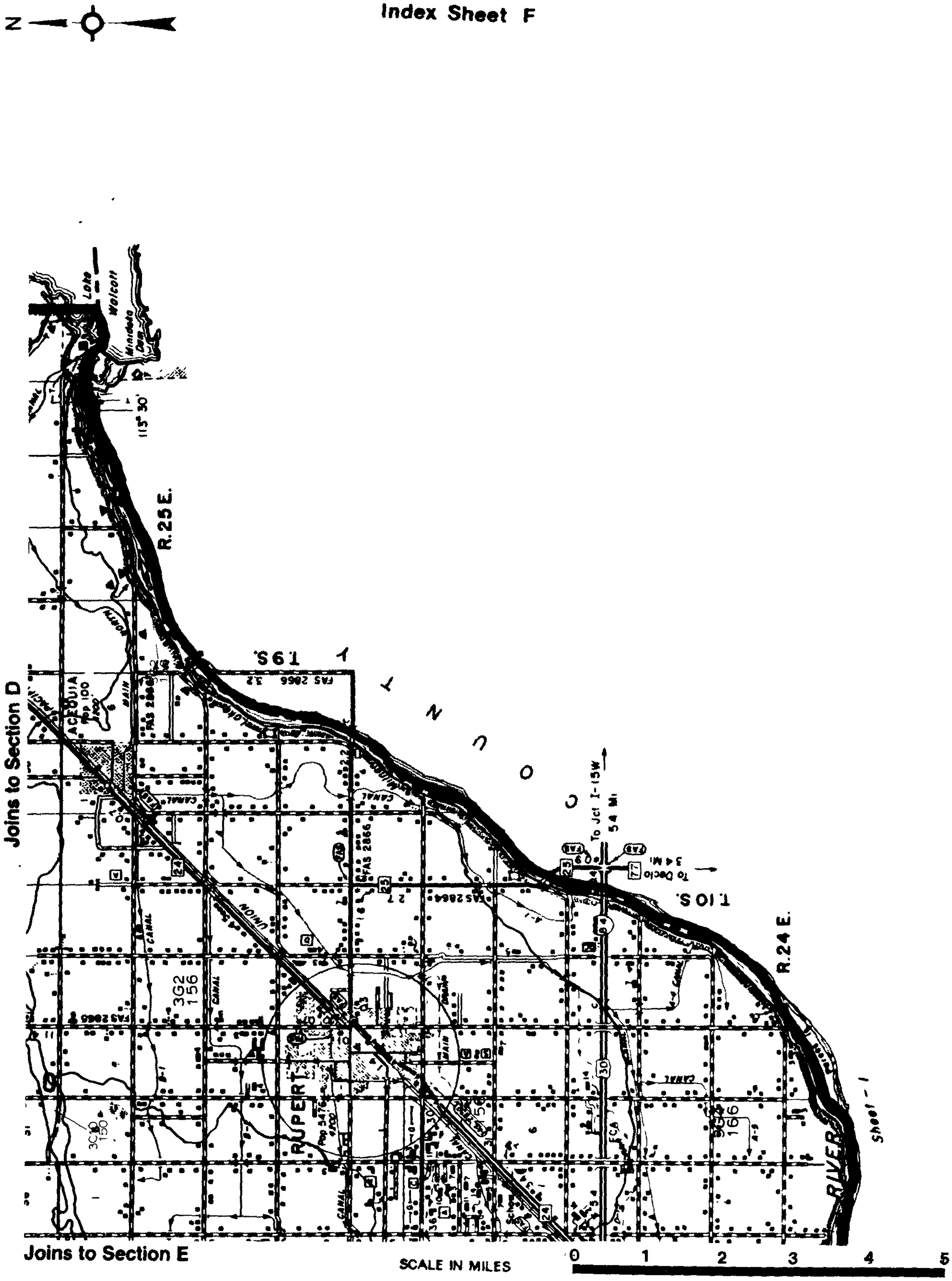




SCALE IN MILES 0 1 2 3 4 5

Index Sheet E

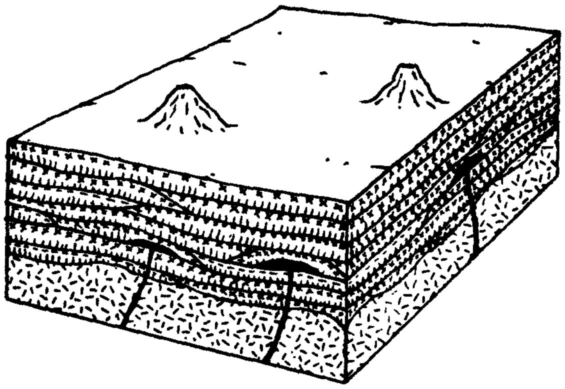
Index Sheet F



COLUMBIA LAVA PLATEAU

(3C) Hydraulically Connected Lava Flows

This hydrogeologic setting is characterized by low topographic relief, a thin sandy soil cover and a thick sequence of successive lava flows which is irregularly interbedded with thin unconsolidated deposits. The lava beds are underlain by poorly permeable bedrock of igneous, sedimentary or metamorphic origin. Ground water is obtained primarily from the interflow zones comprised of sequential, thin, lava flows and related sedimentary deposits, cooling fractures, lava tubes and minor structural features. Water levels are extremely variable but are typically deep. Well yields may vary from low to extremely high depending on the characteristics of the underlying lava flows at a particular site. Ground-water recharge may be appreciable because the layers of lava are interconnected hydraulically. This setting is characterized by the deposits that occur in southwestern Idaho (Snake River area), northern Nevada, southeastern Oregon and extreme northeastern California, which are of Pliocene to Holocene age.



SETTING 3 C1 Hydraulically Connected Lava Flows		GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Basalt	3	10	30
Soil Media	Thin or Absent	2	10	20
Topography	2-6%	1	9	9
Impact Vadose Zone	Basalt	5	9	45
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	143

SETTING 3 C2 Hydraulically Connected Lava Flows		GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	100+	5	1	5
Net Recharge	2-4	4	3	12
Aquifer Media	Basalt	3	10	30
Soil Media	Thin or Absent	2	10	20
Topography	2-6%	1	9	9
Impact Vadose Zone	Basalt	5	9	45
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	151

SETTING 3 C3 Hydraulically Connected Lava Flows		GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Basalt	3	10	30
Soil Media	Silty Loam	2	4	8
Topography	2-6%	1	9	9
Impact Vadose Zone	Basalt	5	9	45
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	131

SETTING 3 C4 Hydraulically Connected Lava Flows		GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Basalt	3	10	30
Soil Media	Silty Loam	2	4	8
Topography	6-12%	1	5	5
Impact Vadose Zone	Basalt	5	9	45
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	127

SETTING 3 C5 Hydraulically Connected Lava Flows		GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Basalt	3	10	30
Soil Media	Silty Loam	2	4	8
Topography	0-2%	1	10	10
Impact Vadose Zone	Basalt	5	8	40
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	127

SETTING 3 C6 Hydraulically Connected Lava Flows		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	2-4	4	3	12
Aquifer Media	Basalt	3	10	30
Soil Media	Silty Loam	2	4	8
Topography	2-6%	1	9	9
Impact Vadose Zone	Basalt	5	8	40
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	134

SETTING 3 C7 Hydraulically Connected Lava Flows		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	4-7	4	6	24
Aquifer Media	Basalt	3	10	30
Soil Media	Silty Loam	2	4	8
Topography	2-6%	1	9	9
Impact Vadose Zone	Basalt	5	8	40
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	146

SETTING 3 C8 Hydraulically Connected Lava Flows		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Basalt	3	10	30
Soil Media	Silty Loam	2	4	8
Topography	0-2%	1	10	10
Impact Vadose Zone	Basalt	5	9	45
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	132

SETTING 3 C9 Hydraulically Connected Lava Flows		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	7-10	4	8	32
Aquifer Media	Basalt	3	10	30
Soil Media	Silty Loam	2	4	8
Topography	2-6%	1	9	9
Impact Vadose Zone	Basalt	5	8	40
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	154

SETTING 3 C10 Hydraulically Connected Lava Flows		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	7-10	4	8	32
Aquifer Media	Basalt	3	10	30
Soil Media	Silty Loam	2	4	8
Topography	6-12%	1	5	5
Impact Vadose Zone	Basalt	5	8	40
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	150

SETTING 3 C11 Hydraulically Connected Lava Flows		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	7-10	4	8	32
Aquifer Media	Basalt	3	10	30
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	Basalt	5	8	40
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	158

SETTING 3 C12 Hydraulically Connected Lava Flows		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	10+	4	9	36
Aquifer Media	Basalt	3	10	30
Soil Media	Silty Loam	2	4	8
Topography	2-6%	1	9	9
Impact Vadose Zone	Basalt	5	8	40
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	158

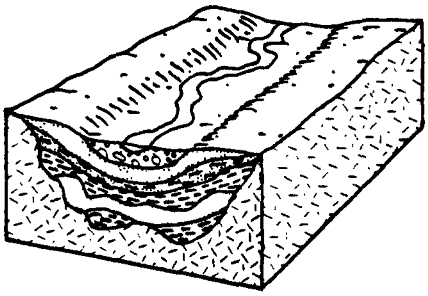
SETTING 3 C13 Hydraulically Connected Lava Flows		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	10+	4	9	36
Aquifer Media	Basalt	3	10	30
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	Basalt	5	8	40
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	167

SETTING 3 C14 Hydraulically Connected Lava Flows		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	4-7	4	6	24
Aquifer Media	Basalt	3	10	30
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	Basalt	5	8	40
Hydraulic Conductivity	2000+	3	10	30
		Drastic Index		150

COLUMBIA LAVA PLATEAU

(3G) River Alluvium

This hydrogeologic setting is characterized by low topography and deposits of alluvium along parts of valley streams. The alluvium yields small to moderate supplies of ground water. Water is obtained from sand and gravel layers which are interbedded with finer-grained alluvial deposits; these are usually in direct hydraulic contact with the stream. Water levels are extremely variable but are commonly moderately shallow. Although precipitation is low, recharge is significant due to the low topography and sandy loam soil cover. The alluvium is underlain by sedimentary or igneous bedrock which may or may not be in direct hydraulic connection with the overlying alluvial deposits.



SETTING 3 G1 River Alluvium		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Silty Loam	2	4	8
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
		Drastic Index		152

SETTING 3 G2 River Alluvium		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
		Drastic Index		156

SETTING 3 G3 River Alluvium		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Loam	2	5	10
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
		Drastic Index		154

SETTING 3 G4 River Alluvium		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	7	21
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
		Drastic Index		166

APPENDIX J

NEW CASTLE COUNTY, DELAWARE

New Castle County, Delaware, lies within the boundaries of two ground-water regions which are separated by the Fall Line; the northern area is within the Piedmont and Blue Ridge, while the remainder of the county lies within the Atlantic and Gulf Coastal Plain. Ground-water resources in the Piedmont and Blue Ridge region of the county are derived primarily from igneous and metamorphic rocks covered by variable thicknesses of saprolite. Unconfined ground water accumulates in the saprolite overlying the parent rock and often serves as a recharge source for these aquifers. Although the saprolite is an easily developed ground-water source, low yields and seasonal fluctuations typically limit the development of this resource. Ground water in the underlying igneous/metamorphic aquifer system provides small to moderate yields from fractures and faults. Wells in the Hockessin-Yorklyn and Pleasant Hill Valleys underlain by a white marble formation have much higher yields. The DRASTIC Index numbers reflect evaluation of unconfined aquifers only. Computed DRASTIC Index values range from 114 to 194.

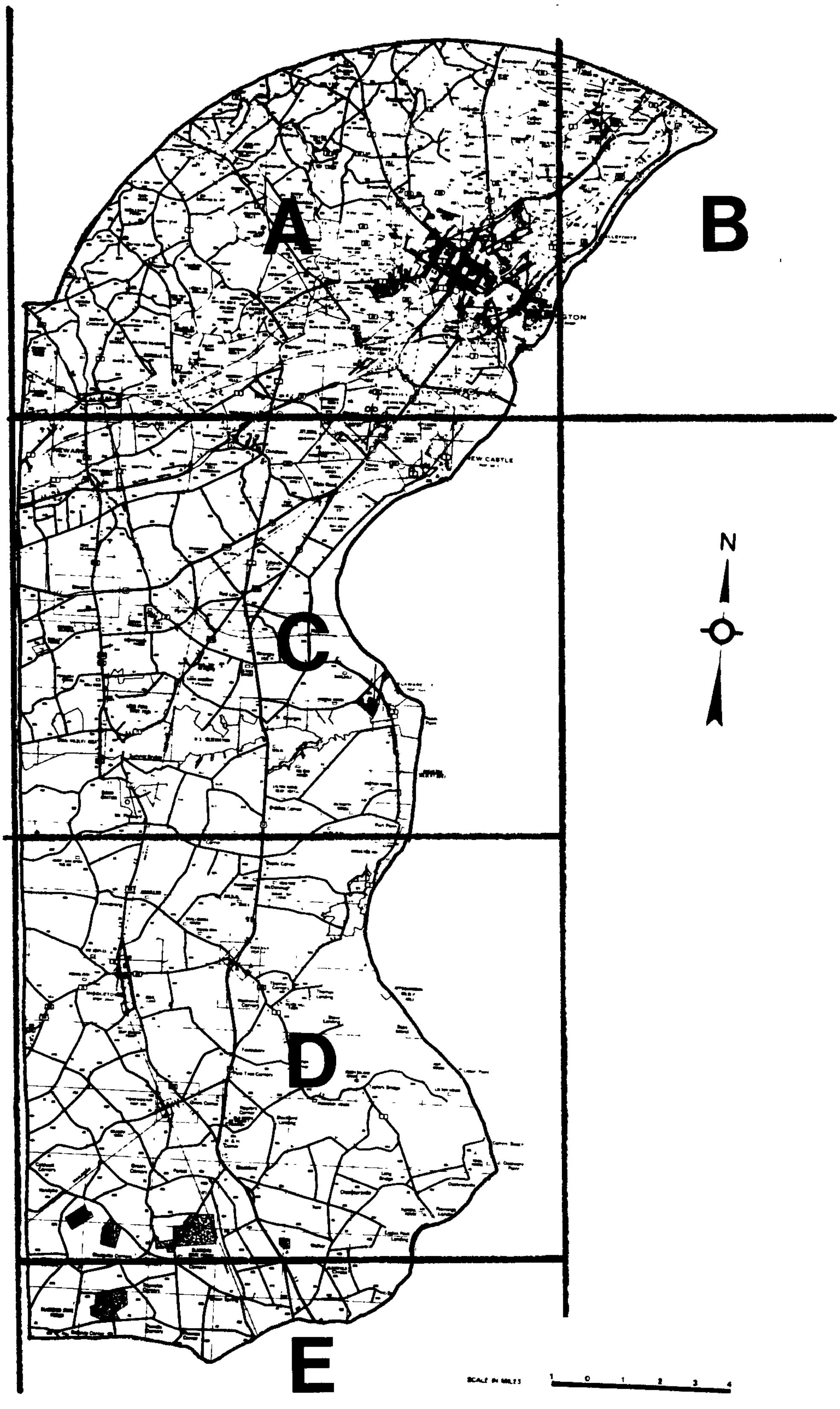


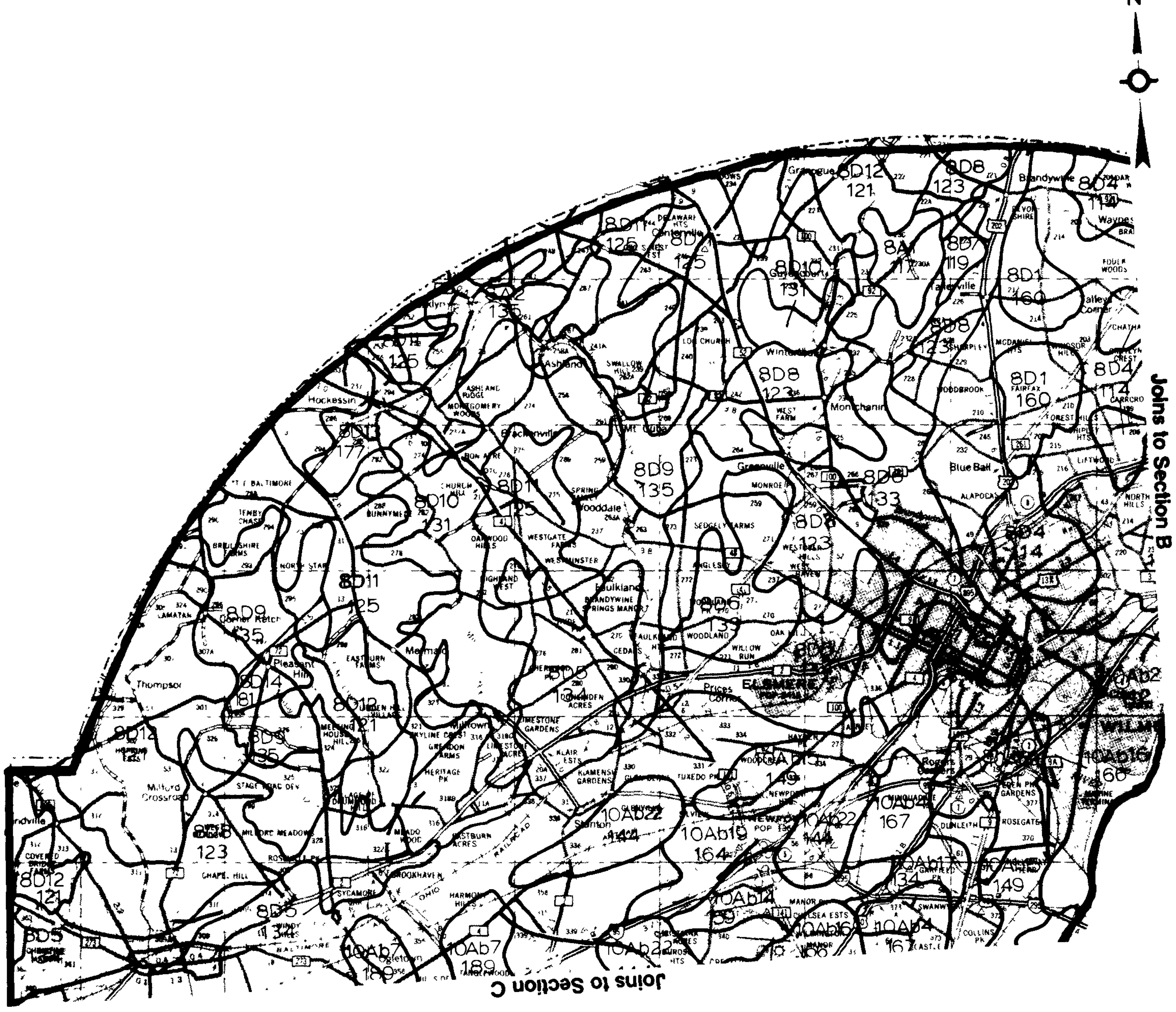
Figure J-1. Index to map sheets, detailed pollution potential map, New Castle County, Delaware.

Index Sheet A

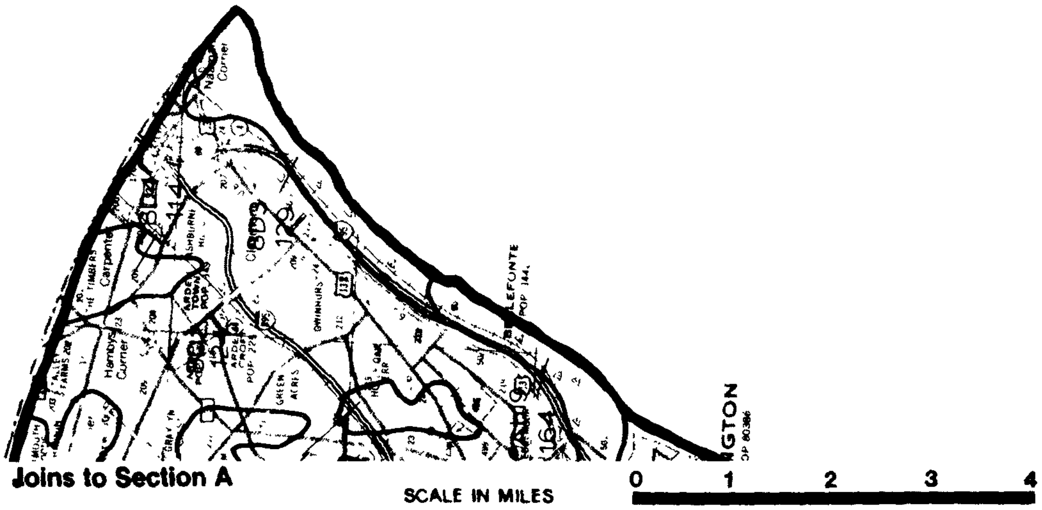
567

SCALE IN MILES

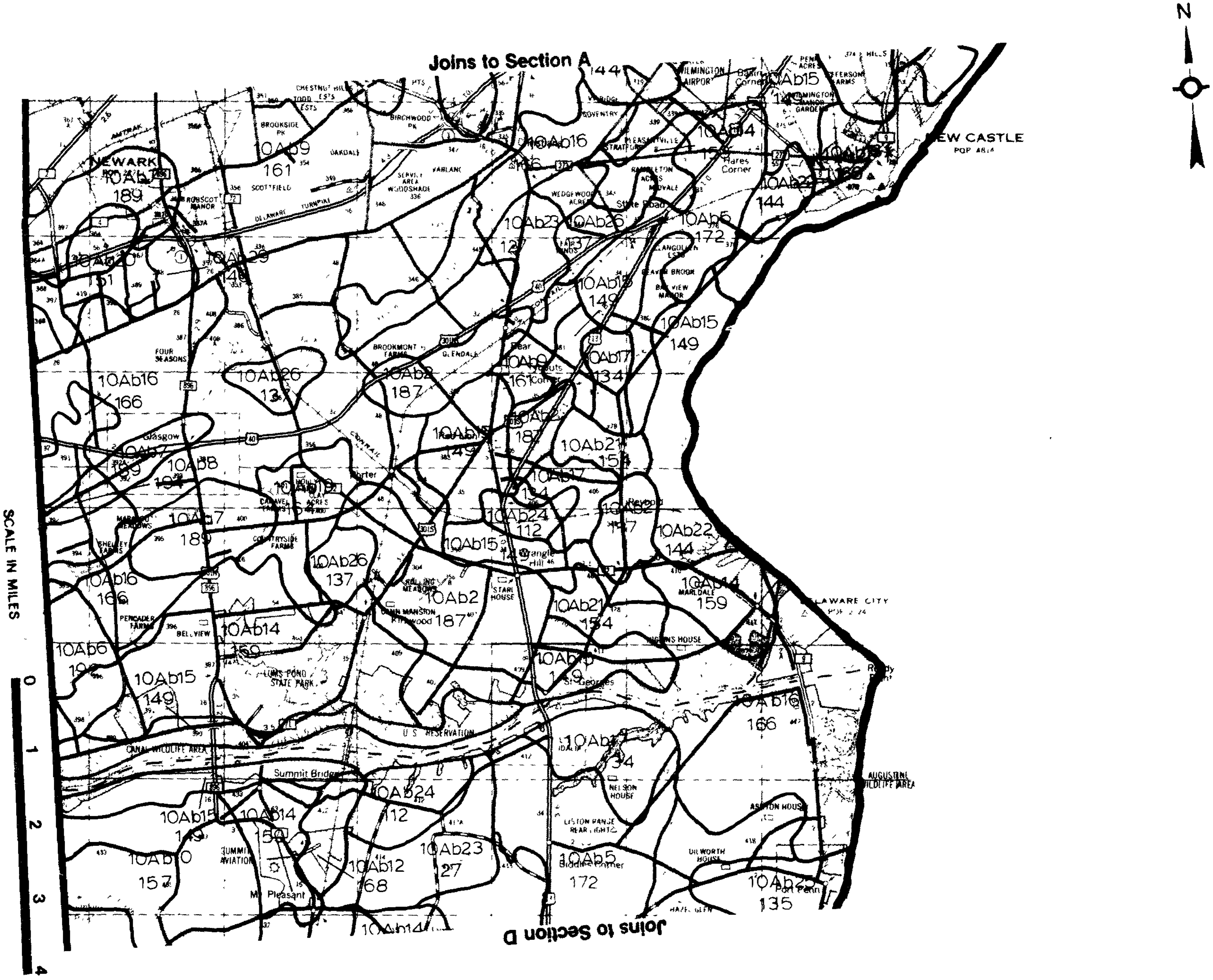
0 1 2 3 4



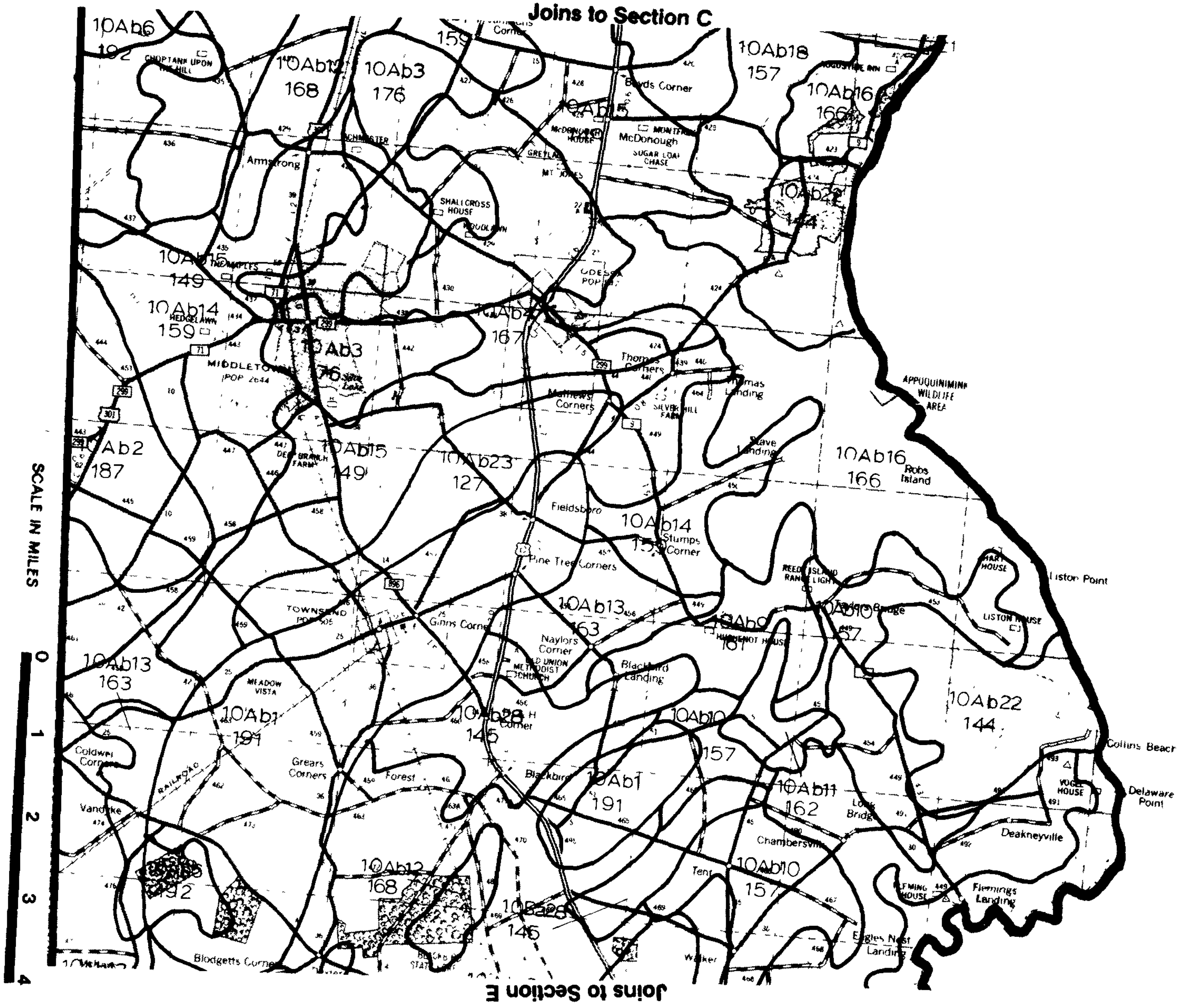
Index Sheet B



Index Sheet C

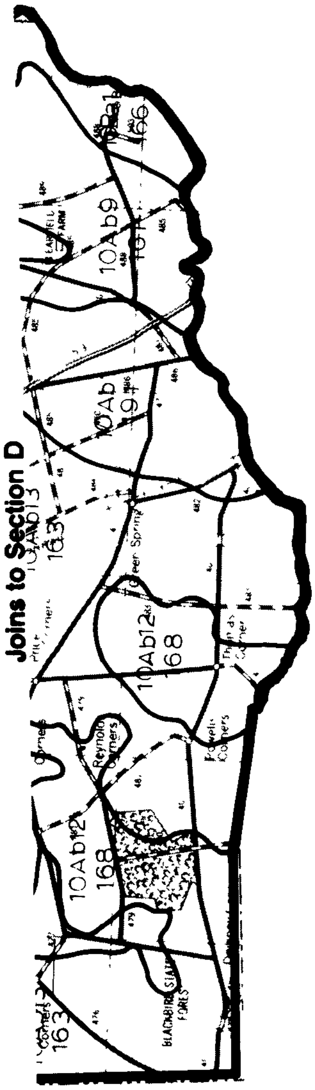


Index Sheet D



Index Sheet E

N

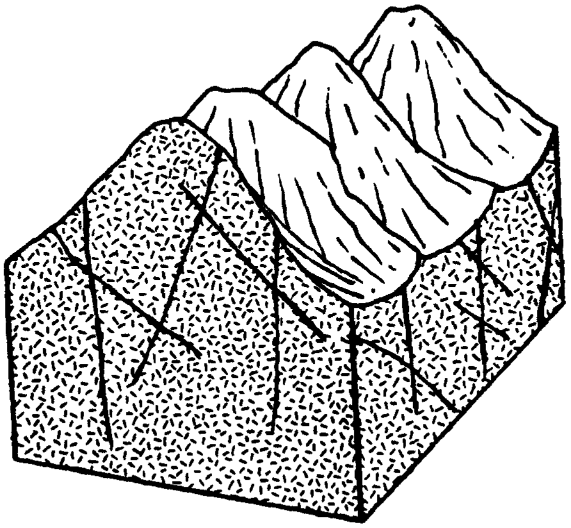


SCALE IN MILES 0 1 2 3 4

PIEDMONT AND BLUE RIDGE

(8A) Mountain Slopes

This hydrogeologic setting is characterized by steep slopes on the side of mountains, a thin soil cover and fractured bedrock. Ground water is obtained primarily from the fractures in the bedrock which may be of sedimentary, metamorphic or igneous origin, but which is commonly metamorphic or igneous. The fractures provide localized sources of ground water and well yields are typically limited. Although precipitation is abundant, due to the steep slopes, thin soil cover and small storage capacity of the fractures, runoff is significant and ground-water recharge is only moderate. Water levels are extremely variable but are commonly deep.



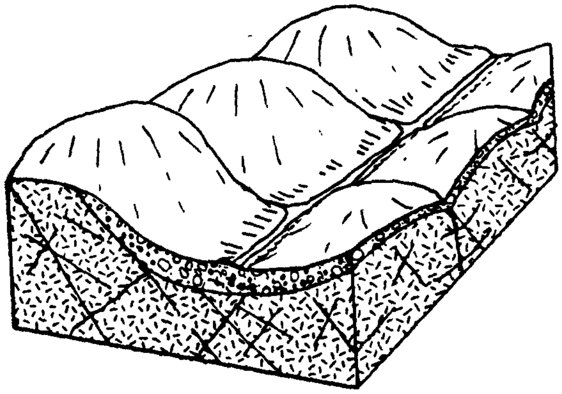
SETTING 8 A1 Mountain Slopes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Silty Loam	2	4	8
Topography	12-18	1	3	3
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	117

SETTING 8 A2 Mountain Slopes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Loam	2	5	10
Topography	12-18	1	3	3
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	100-300	3	4	12
			Drastic Index	135

PIEDMONT AND BLUE RIDGE

(8D) Regolith

This hydrogeologic setting is characterized by moderate to low slopes covered by regolith and underlain by fractured bedrock of igneous, sedimentary or metamorphic origin. The regolith is typically clay-rich but may also serve as a source of ground water for low-yield wells. The regolith functions as a reservoir for ground-water recharge to the bedrock which is in direct hydraulic connection with the overlying regolith. The bedrock typically yields larger amounts of ground water than the regolith when the well intersects fractures in the bedrock.



SETTING 8 D1 Regolith		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Silty Loam	2	4	8
Topography	0-2	1	10	10
Impact Vadose Zone	S&G w/sig. Silt & Clay	5	5	25
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	160

SETTING 8 D2 Regolith		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Silty Loam	2	4	8
Topography	0-2	1	10	10
Impact Vadose Zone	Metamorphic/Igneous	5	2	10
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	124

SETTING 8 D3 Regolith		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Silty Loam	2	4	8
Topography	0-2	1	10	10
Impact Vadose Zone	Metamorphic/Igneous	5	2	10
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	129

SETTING 8 D4 Regolith		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Silty Loam	2	4	8
Topography	0-2	1	10	10
Impact Vadose Zone	Metamorphic/Igneous	5	2	10
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	114

SETTING 8 D5 Regolith		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Silty Loam	2	4	8
Topography	0-2	1	10	10
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	134

SETTING 8 D6 Regolith		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Silty Loam	2	4	8
Topography	2-6	1	9	9
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	133

SETTING 8 D7 Regolith		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Silty Loam	2	4	8
Topography	6-12	1	5	5
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	119

SETTING 8 D8 Regolith		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Silty Loam	2	4	8
Topography	2-6	1	9	9
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	123

SETTING 8 D9 Regolith		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Loam	2	5	10
Topography	2-6	1	9	9
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	135

SETTING 8 D10 Regolith		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Loam	2	5	10
Topography	6-12	1	5	5
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	131

SETTING 8 D11 Regolith		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Loam	2	5	10
Topography	2-6	1	9	9
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	125

SETTING 8 D12 Regolith		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Loam	2	5	10
Topography	6-12	1	5	5
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	121

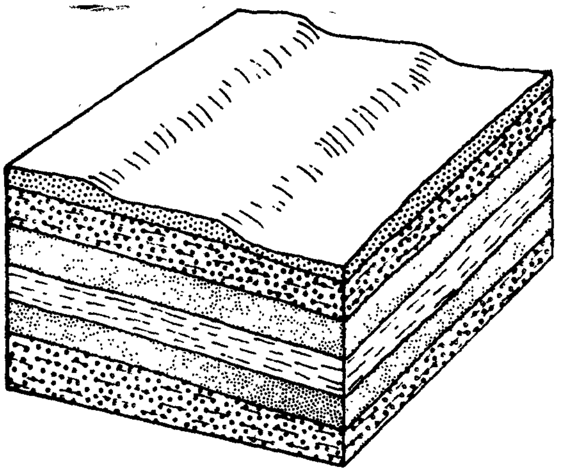
SETTING 8 D13 Regolith		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Metamorphic/Igneous	3	5	15
Soil Media	Loam	2	6	12
Topography	6-12	1	5	5
Impact Vadose Zone	Metamorphic/Igneous	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	177

SETTING 8 D14 Regolith		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Metamorphic/Igneous	3	5	15
Soil Media	Loam	2	6	12
Topography	2-6	1	9	9
Impact Vadose Zone	Metamorphic/Igneous	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	181

ATLANTIC AND GULF COASTAL PLAIN

(10Ab) Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer

This setting is very similar to (10Aa) Confined Regional Aquifers except that the principal aquifer is the shallow surficial deposits which serve as a local source of water and typically provide recharge for the regional aquifer. Water is obtained from the surficial sand and gravel which may be separated from the underlying regional aquifer by a confining layer. This confining layer typically "leaks" providing recharge to the deeper zones. Surficial deposits are sandy loams. Water levels tend to be quite shallow, especially near the coast. Precipitation is abundant and recharge to the ground water is high. These deposits are very vulnerable to ground-water pollution due to their permeable nature.



SETTING 10 Ab1 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	191

SETTING 10 Ab2 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	2	4	8
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	187

SETTING	10 Ab3 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer	GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	2	4	8
Topography	2-6	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	176

SETTING	10 Ab4 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer	GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	30-50	5	5	25
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	2	4	8
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	167

SETTING	10 Ab5 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer	GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	2	4	8
Topography	6-12	1	5	5
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	172

SETTING	10 Ab6 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer	GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	2	4	8
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	192

SETTING	10 Ab7 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer	GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Loam	2	5	10
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	189

SETTING	10 Ab8 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer	GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Loam	2	5	10
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	194

SETTING	10 Ab9 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer	GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Loam	2	5	10
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	161

SETTING	10 Ab10 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer	GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Clay Loam	2	3	6
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	157

SETTING 10 Ab11 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Clay Loam	2	3	6
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	162

SETTING 10 Ab15 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Silty Loam	2	4	8
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	149

SETTING 10 Ab12 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sandy Loam	2	6	12
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	168

SETTING 10 Ab16 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Loam	2	5	10
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	166

SETTING 10 Ab13 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Sandy Loam	2	6	12
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	163

SETTING 10 Ab17 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Silty Loam	2	4	8
Topography	6-12	1	5	5
Impact Vadose Zone	Sand and Gravel	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	134

SETTING 10 Ab14 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Silty Loam	2	4	8
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	159

SETTING 10 Ab18 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Clay Loam	2	3	6
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	157

SETTING 10 Ab19 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Silty Loam	2	4	8
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	164

SETTING 10 Ab20 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Loam	2	5	10
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	151

SETTING 10 Ab21 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Silty Loam	2	4	8
Topography	6-12	1	5	5
Impact Vadose Zone	Sand and Gravel	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	154

SETTING 10 Ab22 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	5	15
Soil Media	Loam	2	5	10
Topography	0-2	1	10	10
Impact Vadose Zone	S&G w/sig. Silt & Clay	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	144

SETTING 10 Ab23 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	5	15
Soil Media	Silty Loam	2	4	8
Topography	0-2	1	10	10
Impact Vadose Zone	S&G w/sig. Silt & Clay	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	127

SETTING 10 Ab24 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	5	15
Soil Media	Silty Loam	2	4	8
Topography	6-12	1	5	5
Impact Vadose Zone	S&G w/sig. Silt & Clay	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	112

SETTING 10 Ab25 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	5	15
Soil Media	Clay Loam	2	3	6
Topography	0-2	1	10	10
Impact Vadose Zone	S&G w/sig. Silt & Clay	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	135

SETTING 10 Ab26 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	5	15
Soil Media	Silty Loam	2	4	8
Topography	0-2	1	10	10
Impact Vadose Zone	S&G w/sig. Silt & Clay	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	137

SETTING 10 Ab27 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	5	15
Soil Media	Silty Loam	2	4	8
Topography	0-2	1	10	10
Impact Vadose Zone	S&G w/sig. Silt & Clay	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	142

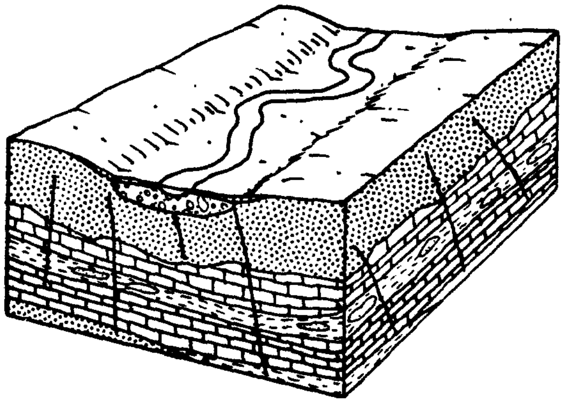
SETTING 10 Ab28 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	5	15
Soil Media	Sandy Loam	2	6	12
Topography	2-6	1	9	9
Impact Vadose Zone	S&G w/sig. Silt & Clay	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	145

SETTING 10 Ab29 Unconsolidated & Semi-Consolidated Shallow Surficial Aquifer		GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Loam	2	5	10
Topography	6-12	1	5	5
Impact Vadose Zone	Sand and Gravel	5	6	30
Hydraulic Conductivity	300-700	3	4	20
			Drastic Index	146

ATLANTIC AND GULF COASTAL PLAIN

(10Ba) River Alluvium with Overbank Deposits

This hydrogeologic setting is characterized by low topography and thin to moderately thick deposits of alluvium along parts of river valleys. The alluvium is underlain by consolidated and semi-consolidated sedimentary rocks. Water is obtained from sand and gravel layers which are interbedded with finer-grained alluvial deposits. The floodplain is covered by varying thicknesses of fine-grained, silty deposits called overbank deposits. The overbank thickness is usually greater along major streams (as much as 40 feet) and thinner along minor streams. Precipitation in the region is abundant, but recharge is somewhat reduced because of the silty overbank deposits and subsequent silty soils which typically cover the surface. Water levels are typically moderately shallow. The alluvium may serve as a significant source of water and may be in direct hydraulic connection with the underlying sedimentary rocks. The alluvium may also serve as a source of recharge to the underlying bedrock.



SETTING 10 Ba1 River Alluvium with Overbank		GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	0-5	5	10	50
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	6	18
Soil Media	Loam	2	5	10
Topography	0-2	1	10	10
Impact Vadose Zone	S&G w/sig. Silt & Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	166

APPENDIX K

PIERCE COUNTY, WASHINGTON

Pierce County, Washington, lies within the boundaries of two ground-water regions; the western two-thirds is within the Alluvial Basins, and the eastern one-third lies within the Western Mountain Ranges. The western portion of the county is within the Puget Lowland, which is filled with very thick sequences of interbedded glacial sands, gravels and silts. The shallow aquifer consists of medium- to coarse-grained sands and gravels exhibiting shallow water-table conditions. These deposits are very permeable and provide significant quantities of water to domestic and municipal wells. The shallow aquifer provides recharge to deeper sand and gravel aquifers and is often in direct hydraulic connection with the deeper aquifers. Ground-water resources constitute over seventy-five percent of the drinking water used in this area. The volcanic mudflows and igneous/metamorphic rocks of the Cascade Range which occur in the eastern portion of the county provide low yields to wells. Most ground-water supplies are derived from alluvium adjacent to river valleys. The DRASTIC Index numbers reflect evaluation of unconfined aquifers only. Computed DRASTIC Index values range from 77 to 200.

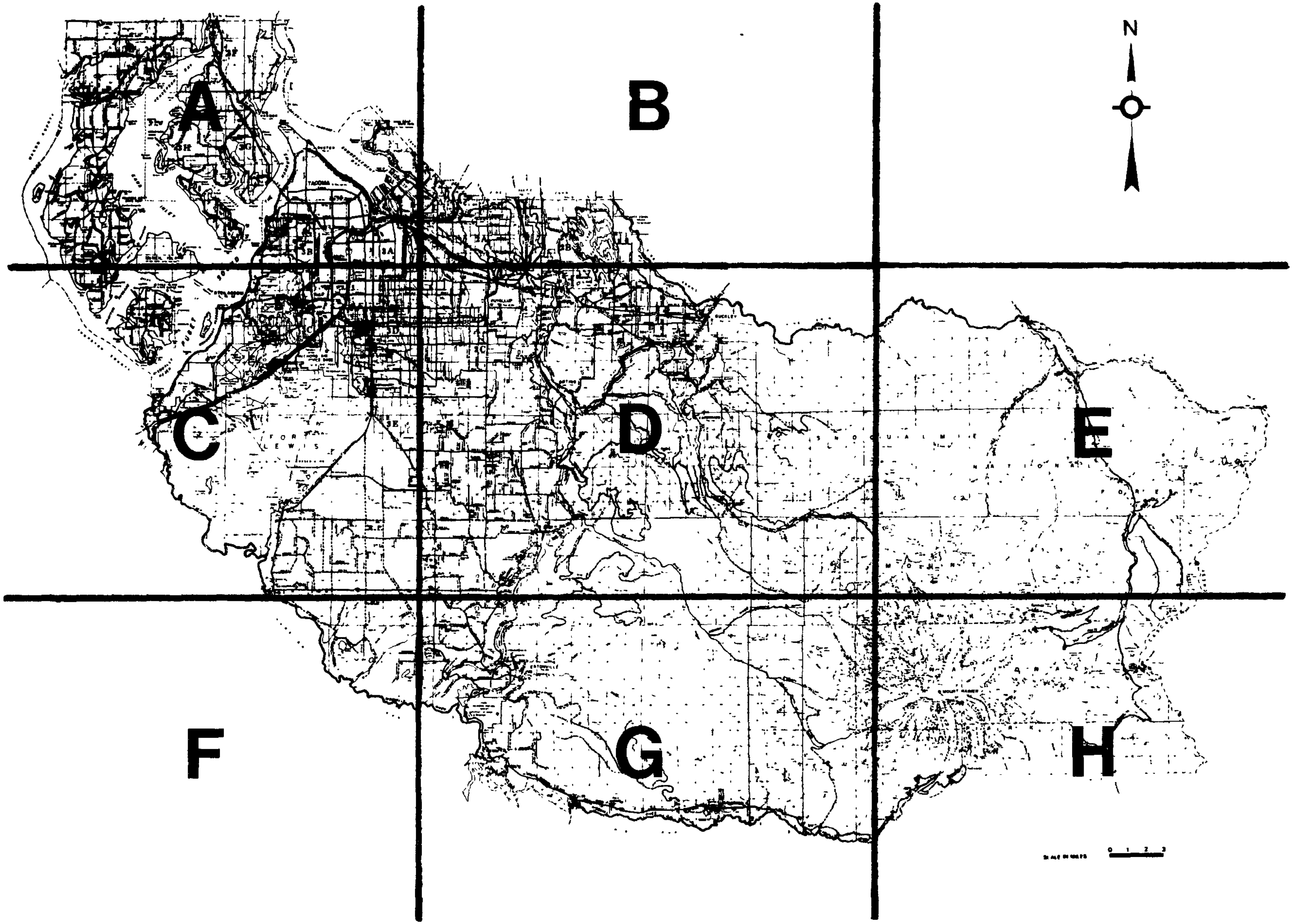
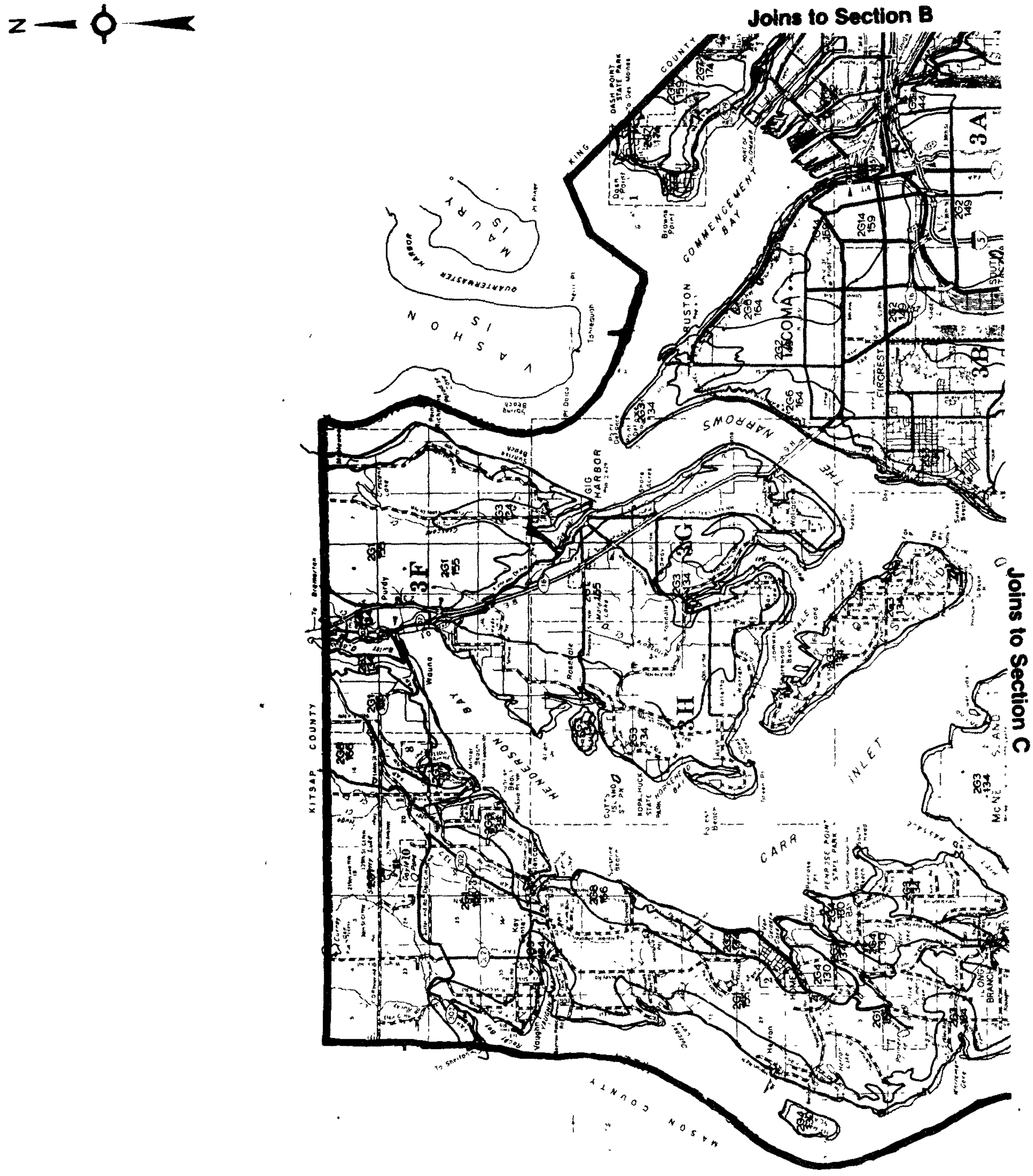


Figure K-1. Index to map sheets, detailed pollution potential map, Pierce County, Washington.

Joins to Section B

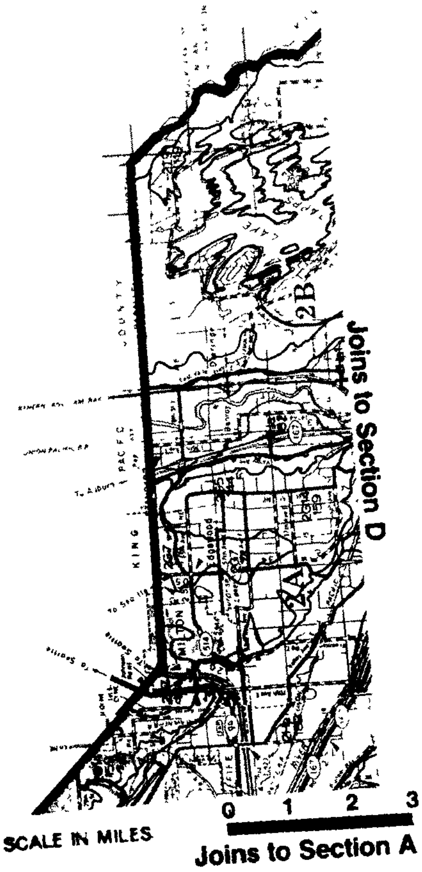


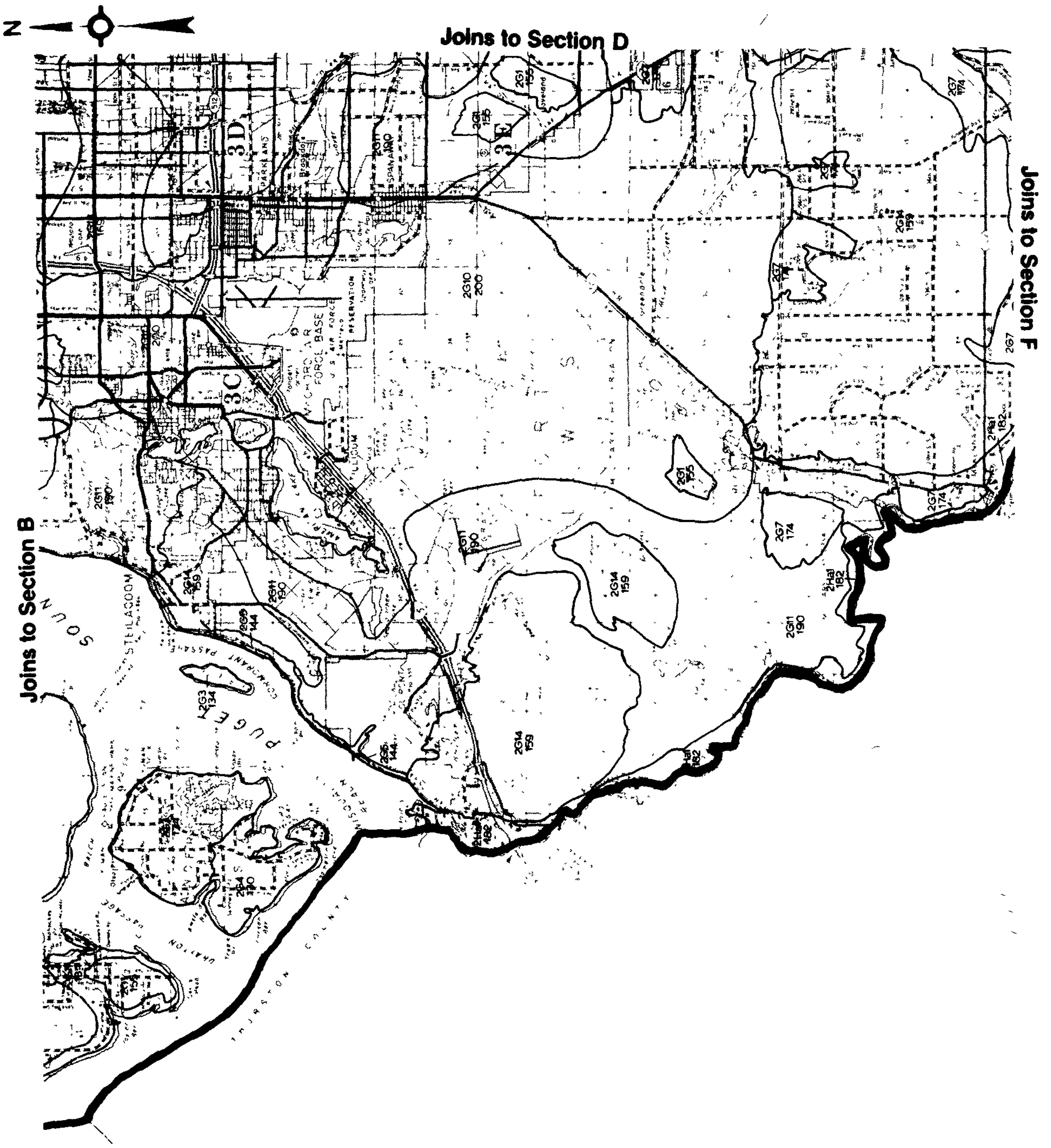
Joins to Section C

SCALE IN MILES 0 1 2 3

Index Sheet A

Index Sheet B

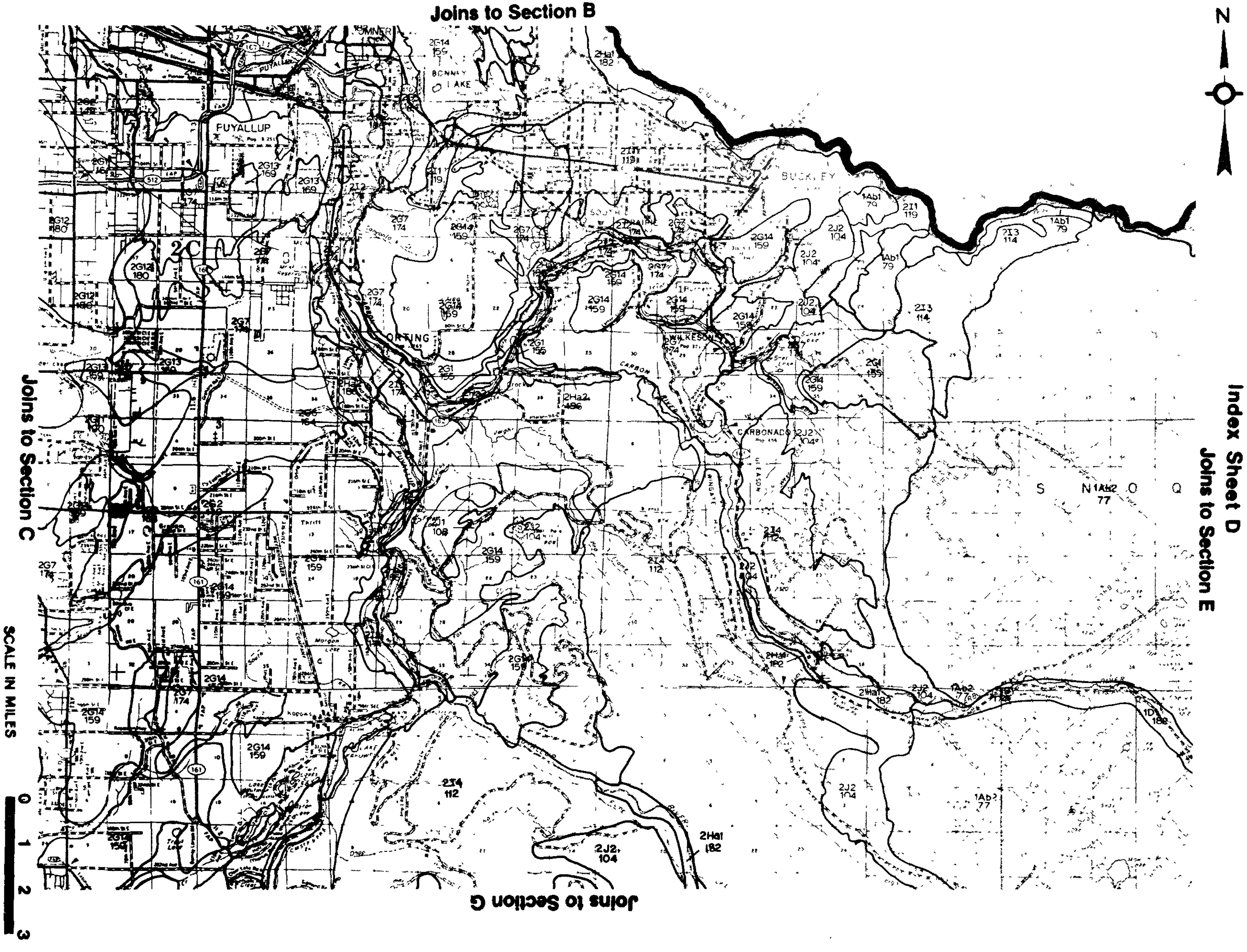




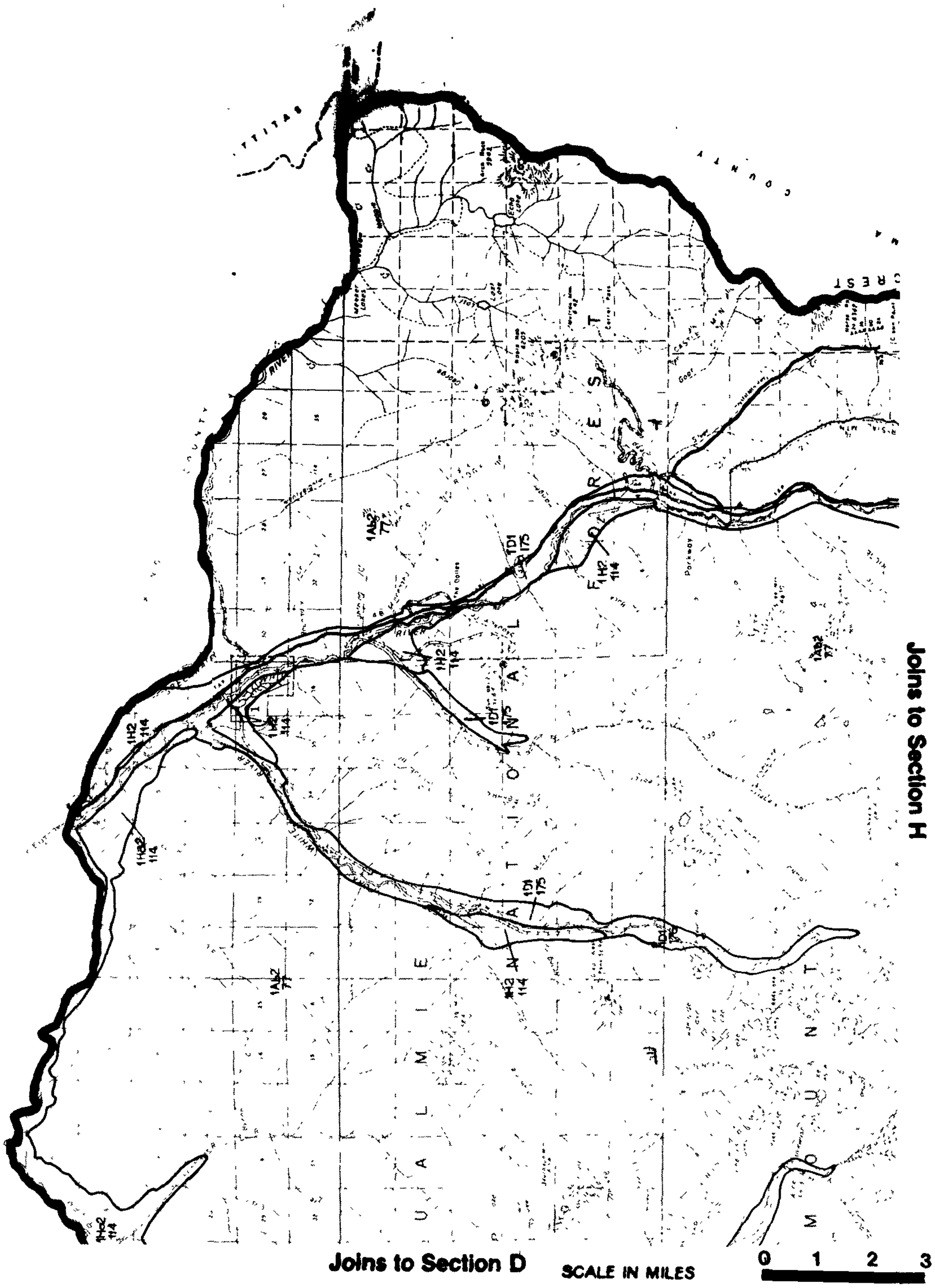
Index Sheet C

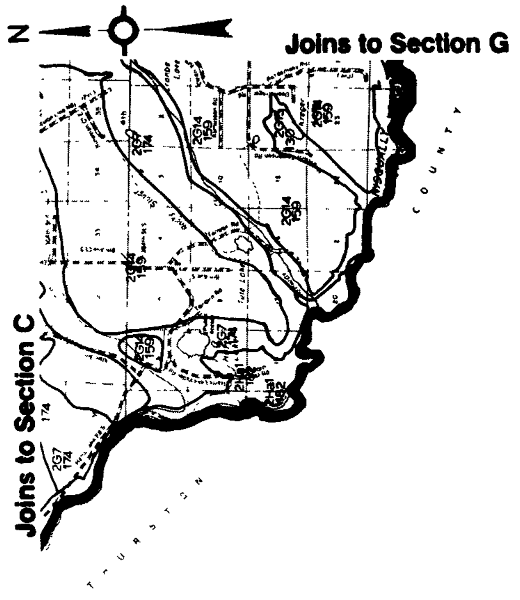
SCALE IN MILES 0 1 2 3

Index Sheet D



Index Sheet E

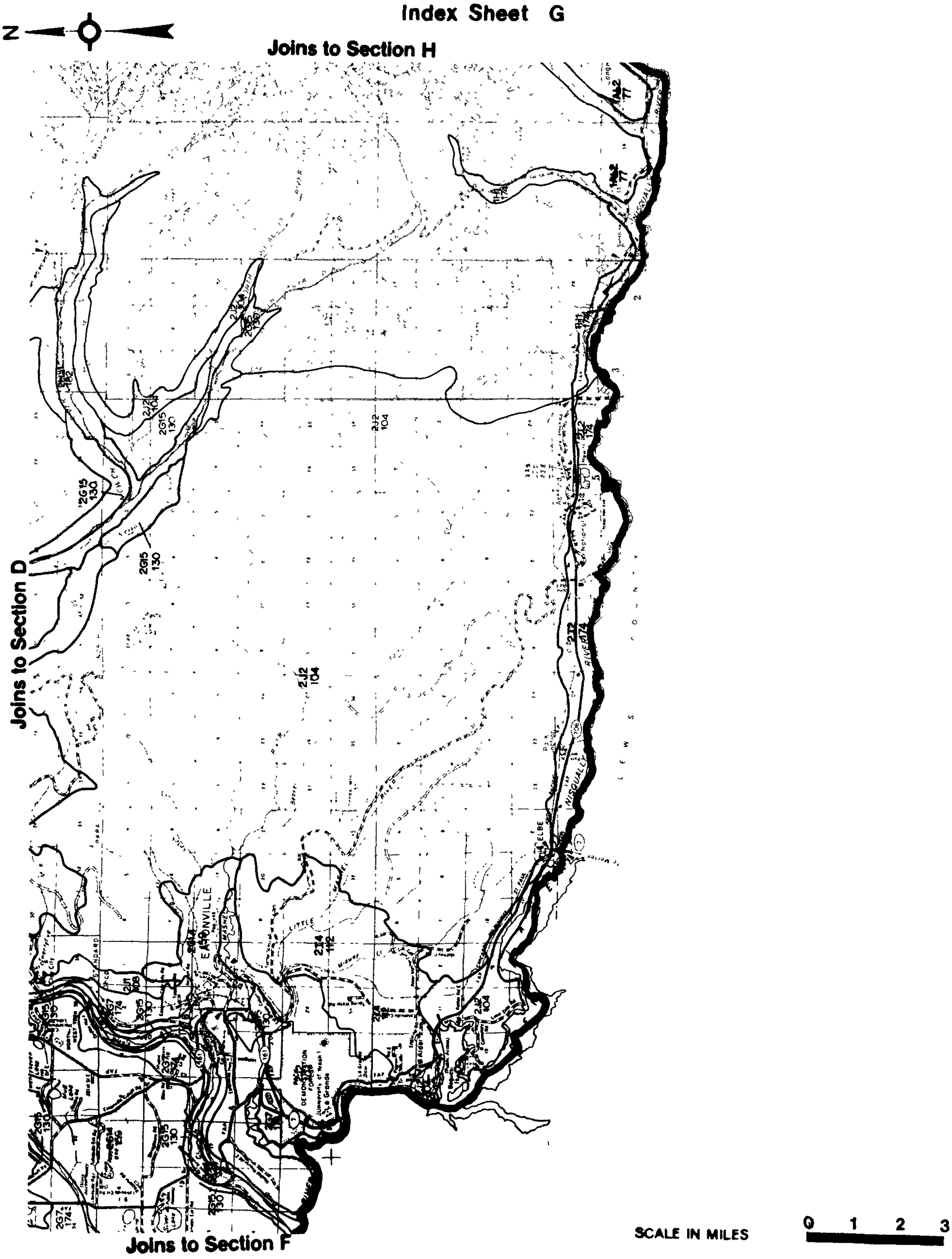




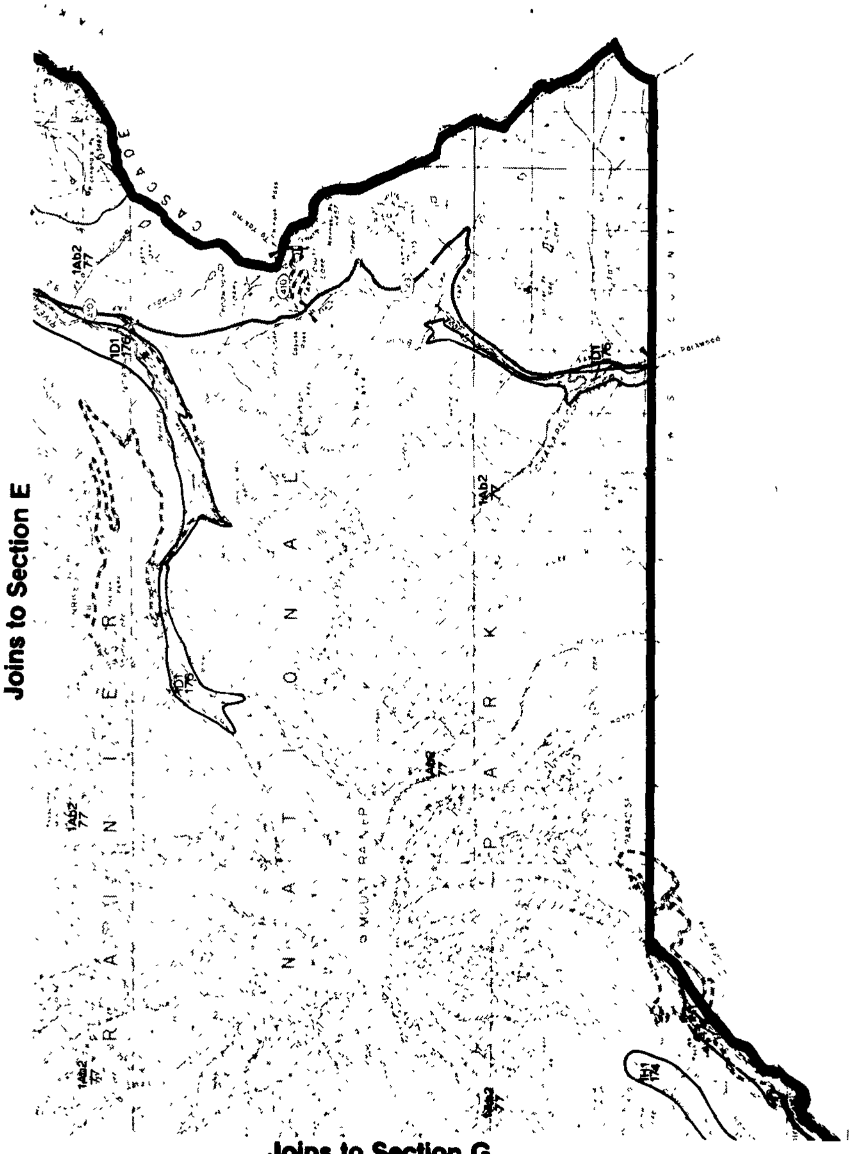
Index Sheet F

SCALE IN MILES 0 1 2 3

Index Sheet G



Index Sheet H



Joins to Section E

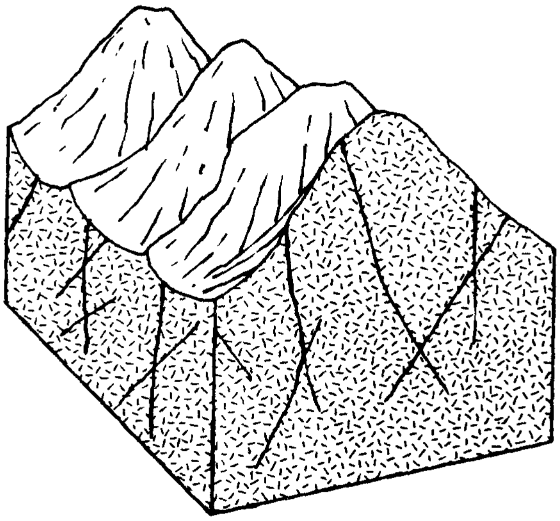
Joins to Section G

SCALE IN MILES 0 1 2 3

WESTERN MOUNTAIN RANGES

(1Ab) Mountain Slopes - West

This setting is similar to (1Aa) Mountain Slopes-East except that ground water levels are typically more shallow and precipitation greatly exceeds the amount which falls on the eastern slopes. Even though rainfall is more abundant, recharge is still low due to the steepness of the slopes and density of the underlying bedrock and may only exceed 2 inches/year in places where precipitation is very high and soil cover is unusually favorable. Due to increased precipitation, pollutants may tend to migrate to the water table more rapidly, but be more diluted, than on the comparable eastern slopes.



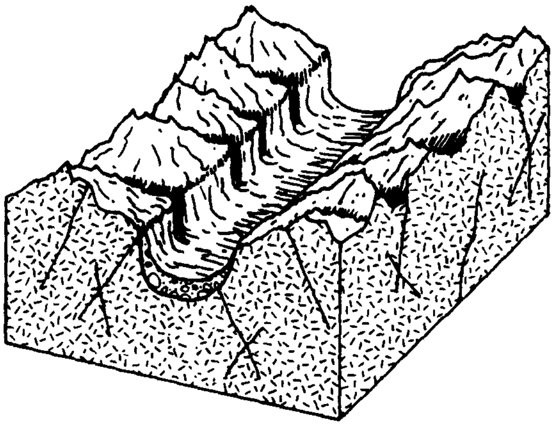
SETTING 1 Ab1 Mountain Slopes - West		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	4-7	4	6	24
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Loam	2	5	10
Topography	12-18%	1	3	3
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	79

SETTING 1 Ab2 Mountain Slopes - West		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	4-7	4	6	24
Aquifer Media	Metamorphic/Igneous	3	3	9
Soil Media	Loam	2	5	10
Topography	18+%	1	1	1
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	77

WESTERN MOUNTAIN RANGES

(1D) Glaciated Mountain Valleys

This hydrogeologic setting is characterized by moderate topographic relief, and very coarse-grained deposits associated with the near mountain glacial features, such as cirques and paternoster lakes. These deposits may serve as localized sources of water. Water tables are typically shallow with coarse-grained deposits present at the surface. Mountain glaciers may be present in some areas. Although precipitation may not be great, recharge is relatively high when compared to other settings in the region because of the large volumes of water produced from the glaciers during the summer melting cycle. These recent glacial deposits are underlain by fractured bedrock of igneous or metamorphic origin all of which are in direct hydraulic connection with the overlying deposits. The fractured bedrock may also serve as a local source of ground water.

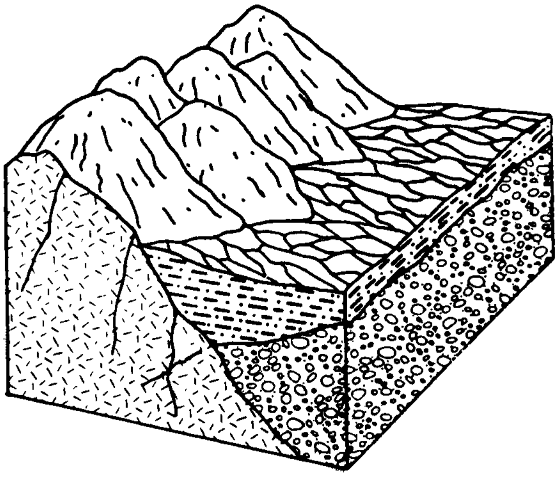


SETTING 1 D1 Glacial Mountain Valleys		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	175

WESTERN MOUNTAIN RANGES REGION

(1H) Mud Flows

This hydrogeologic setting is characterized by low to moderate topography and variable thicknesses of unsorted mixtures of boulders and pebbles in a fine-grained matrix. The deposits originated from the adjacent mountain slopes and tend to be thicker toward the mountains and thinner in the valleys with no well-developed drainage pattern. The mud flows are typically underlain by glacial and alluvial deposits which serve as the major aquifer. Recharge is moderate to low because the mud flows restrict infiltration and may even serve to confine the underlying aquifer.



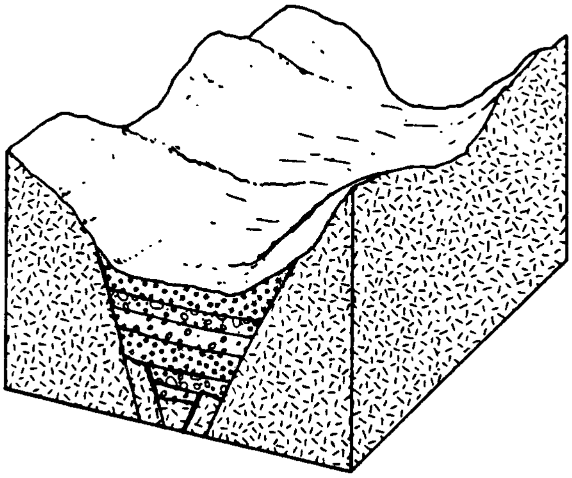
SETTING 1 H1 Mud Flows		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Loam	2	5	10
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	174

SETTING 1 H2 Mud Flows		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Loam	2	5	10
Topography	6-12%	1	5	5
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	114

ALLUVIAL BASINS

(2G) Coastal Lowlands

This hydrogeologic setting is characterized by thick and very permeable deposits of gravel and sand laid down by streams of glacial meltwater from the Pleistocene glaciers. The gravel and sand are interbedded with clay in parts of the area. Floodplain deposits and interbedded volcanics are also included in some areas. The area is characterized by the Willamette Valley - Puget Sound trough. Recharge is high and water levels are shallow to moderate. The sand and gravels and interbedded volcanics both may serve as prolific aquifers.



SETTING 2 G1 Coastal Lowlands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	6-12%	1	5	5
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	155

SETTING 2 G2 Coastal Lowlands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	149

SETTING 2 G3 Coastal Lowlands		GENERAL		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	75-100	5	2	10
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	6-12%	1	5	5
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	134

SETTING 2 G4 Coastal Lowlands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	2	4	8
Topography	6-12%	1	5	5
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	130

SETTING 2 G5 Coastal Lowlands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	6-12%	1	5	5
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	144

SETTING 2 G6 Coastal Lowlands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	164

SETTING 2 G7 Coastal Lowlands		**GENERAL**		
FEATURE	**RANGE**	**WEIGHT**	**RATING**	**NUMBER**
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	174

SETTING 2 G8 Coastal Lowlands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	6-12%	1	5	5
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	166

SETTING 2 G9 Coastal Lowlands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	144

SETTING 2 G10 Coastal Lowlands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	9	27
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	200

SETTING 2 G11 Coastal Lowlands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	9	27
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	190

SETTING 2 G12 Coastal Lowlands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	180

SETTING 2 G13 Coastal Lowlands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	169

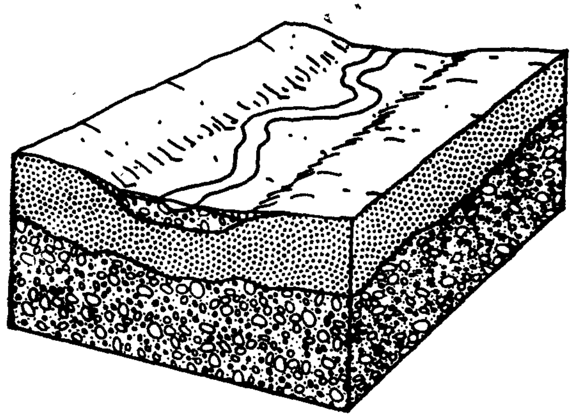
SETTING 2 G14 Coastal Lowlands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	159

SETTING 2 G15 Coastal Lowlands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	2	4	8
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	130

ALLUVIAL BASINS

(2Ha) River Alluvium With Overbank Deposits

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



SETTING 2 Ha1 River Alluvium With Overbank		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	2	4	8
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	182

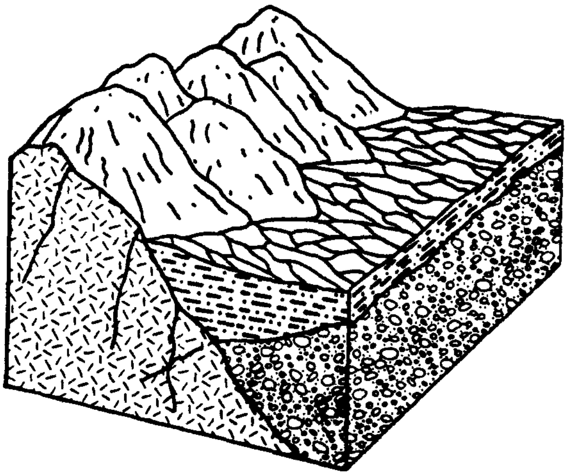
SETTING 2 Ha2 River Alluvium With Overbank		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	186

SETTING 2 Ha3 River Alluvium With Overbank		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	7	35
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	176

ALLUVIAL BASINS

(21) Mud Flows

This hydrogeologic setting is characterized by low topography and variable thicknesses of unsorted mixtures of boulders and pebbles in a fine-grained matrix. The deposits originated from the adjacent mountains and tend to be thicker toward the mountains and thinner in the valleys with no well developed drainage pattern. The mud flows are underlain by glacial and alluvial deposits which serve as the major aquifer. Recharge is moderate to low because the mud flows restrict infiltration and may even serve to confine the underlying aquifer.



SETTING 2 I1 Mud Flows		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Loam	2	5	10
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt & Clay	5	5	25
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	119

SETTING 2 I2 Mud Flows		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Loam	2	5	10
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt & Clay	5	5	25
Hydraulic Conductivity	1000-2000	3	8	24
			Drastic Index	174

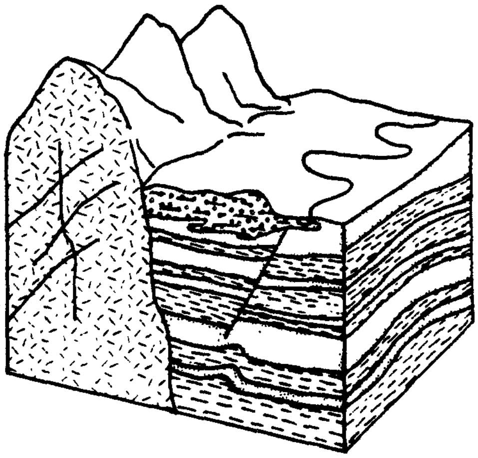
SETTING 2 I3 Mud Flows		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Loam	2	5	10
Topography	6-12%	1	5	5
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	114

SETTING 2 I4 Mud Flows		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Loam	2	5	10
Topography	12-18%	1	3	3
Impact Vadose Zone	S&G w/sig Silt & Clay	5	6	30
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	112

ALLUVIAL BASINS

(2J) Alternating Sandstone and Shale Sequences

This hydrogeologic setting is characterized by moderate topographic relief and loamy soils underlain by fractured and folded alternating layers of sedimentary rocks with a typically high percentage of volcanic fragments. The bedrock may be overlain by interbedded unconsolidated deposits comprised of volcanic mud flows, alluvium, ash, sands and silts. The recharge is typically high in areas of the region where precipitation is high. Water levels are extremely variable but are typically deep. The bedrock aquifer yields only small amounts of water from the interconnected fractures.



SETTING 2 J1 Alternating SS, SH Sequences		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	7-10	4	8	32
Aquifer Media	Thin Bedded SS, LS, SH	3	6	18
Soil Media	Loam	2	5	10
Topography	6-12%	1	5	5
Impact Vadose Zone	Bedded SS, LS, SH	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	108

SETTING 2 J2 Alternating SS, SH Sequences		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	75-100	5	2	10
Net Recharge	7-10	4	8	32
Aquifer Media	Thin Bedded SS, LS, SH	3	6	18
Soil Media	Loam	2	5	10
Topography	18+%	1	1	1
Impact Vadose Zone	Bedded SS, LS, SH	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	104

APPENDIX L

PORTAGE COUNTY, WISCONSIN

Portage County, Wisconsin, is situated within two ground-water regions; the northwestern part of the county is located in the Northeast and Superior Uplands and the remainder of the county is within the Glaciated Central Region. The water resources of the northwestern part of the county are derived primarily from metamorphic and igneous rocks which are in hydraulic connection with overlying thin glacial till. This aquifer yields supplies sufficient for domestic use only. The majority of the county is covered by thick sequences of glacial outwash sand and gravel which constitutes the major ground-water resource. These areas are characterized by highly permeable soils and shallow water depths. The DRASTIC Index numbers reflect evaluation of unconfined aquifers only. Computed DRASTIC Index values range from 99 to 200.

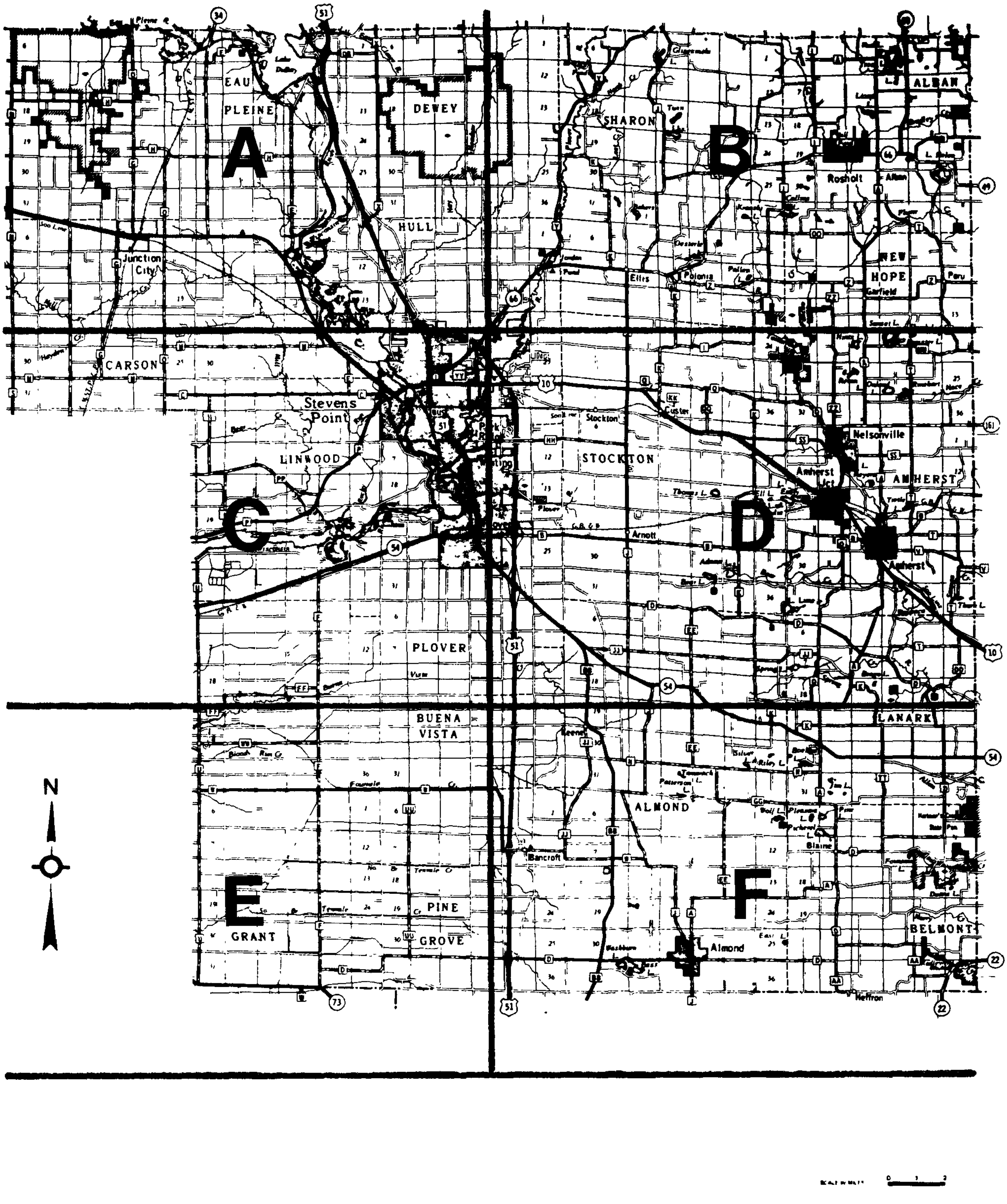
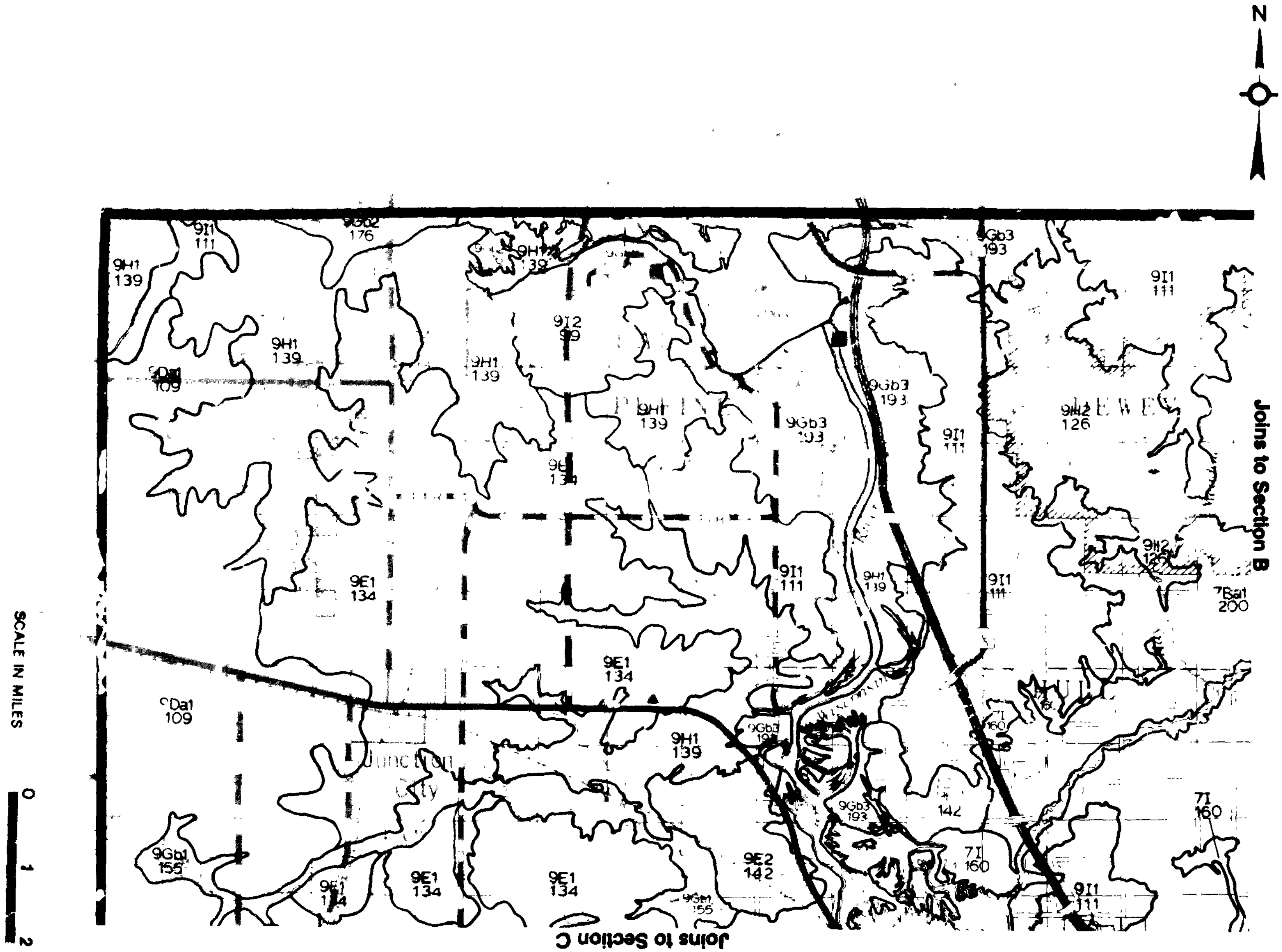
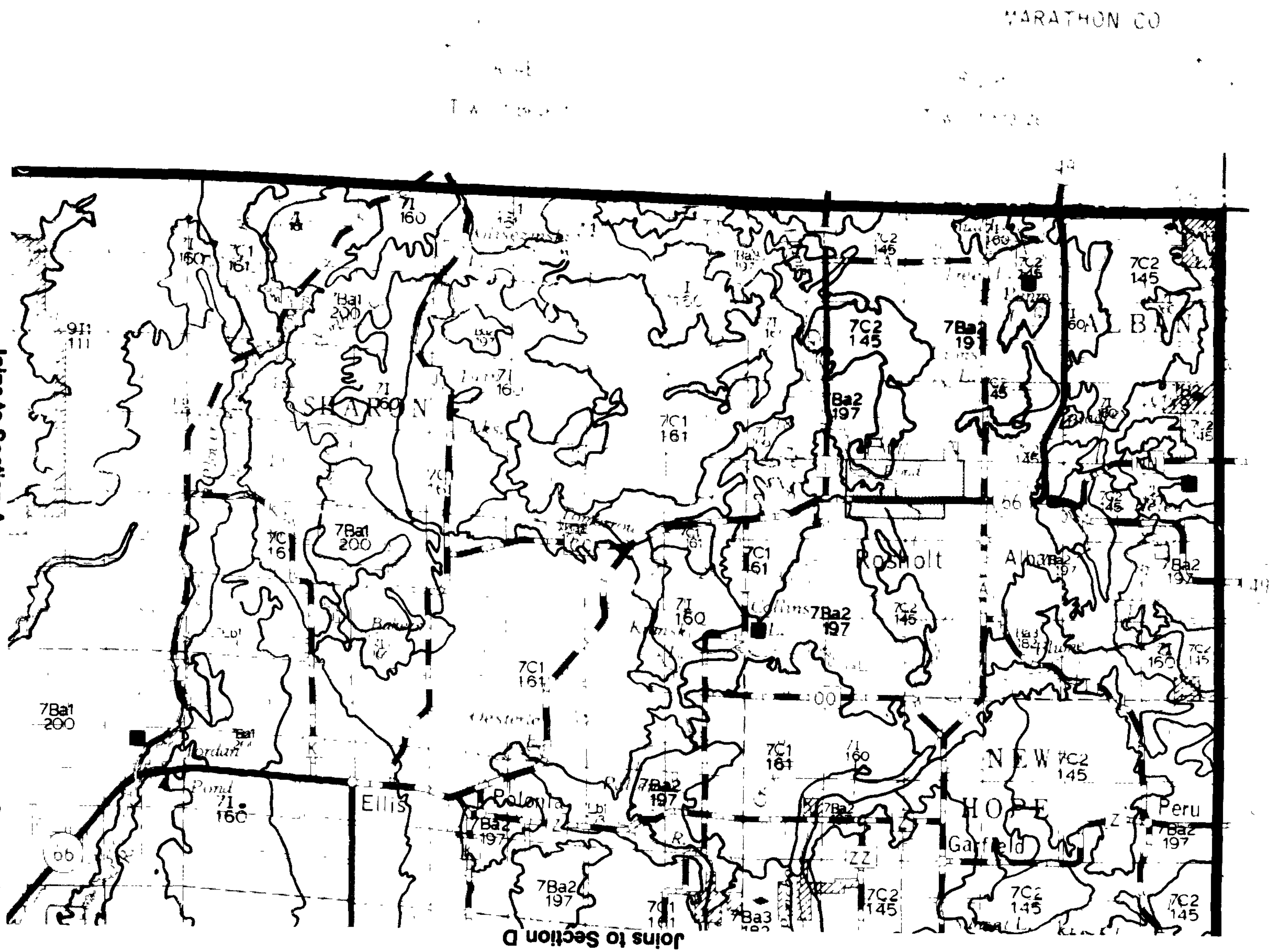


Figure L-1. Index to map sheets, detailed pollution potential map, Portage County, Wisconsin.



Index Sheet A

Index Sheet B



N

Joins to Section A

Joins to Section D

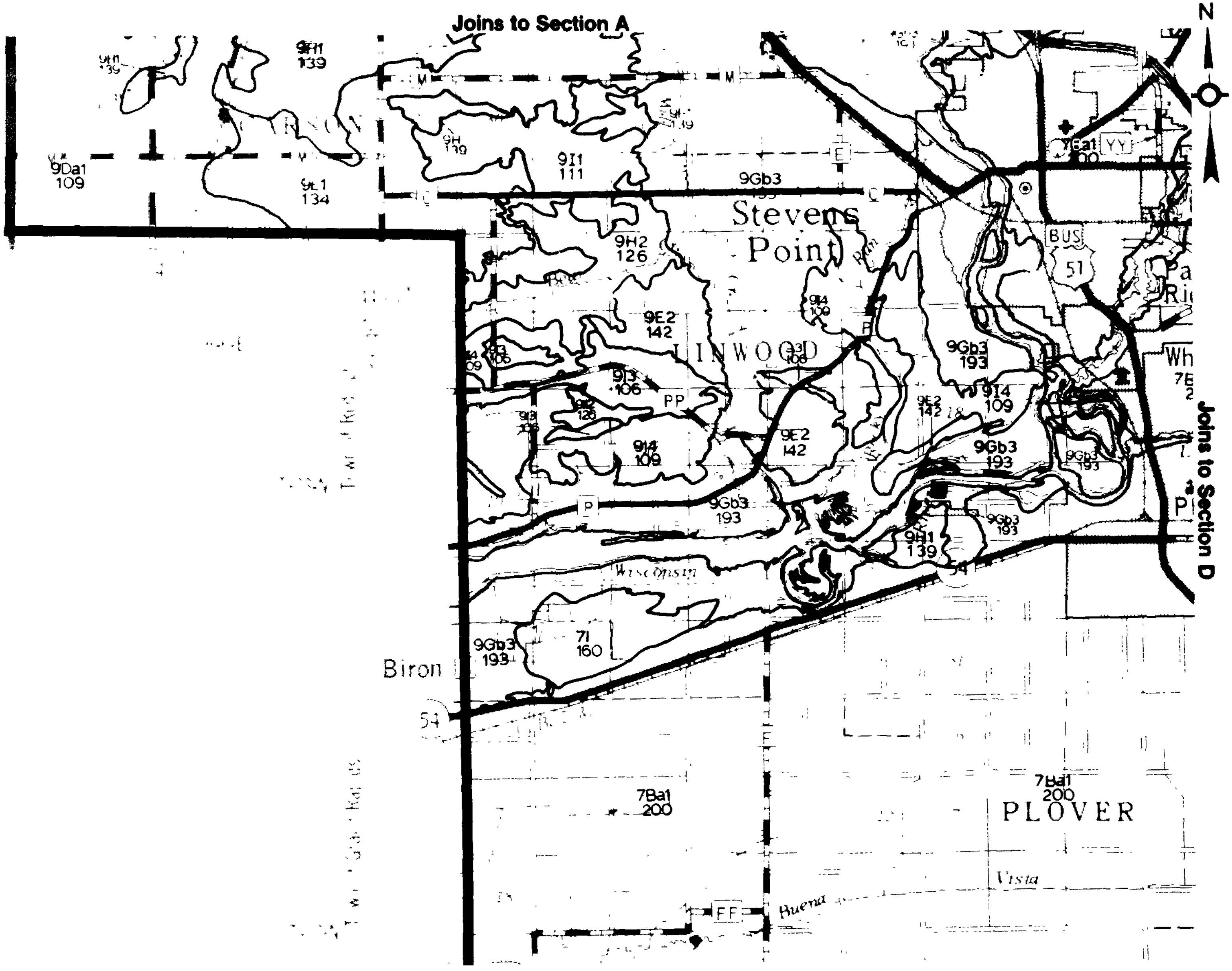
SCALE IN MILES

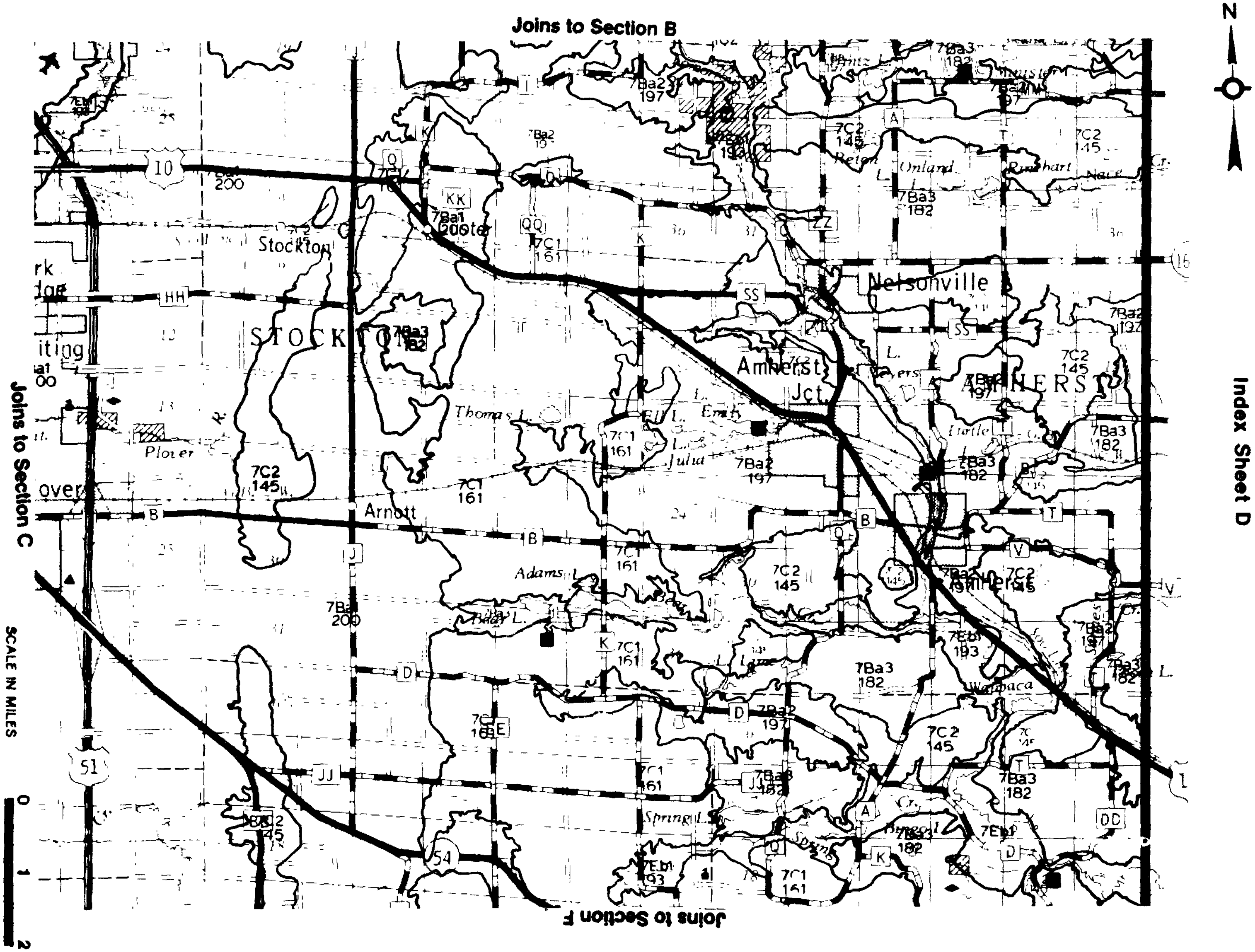
0 1 2

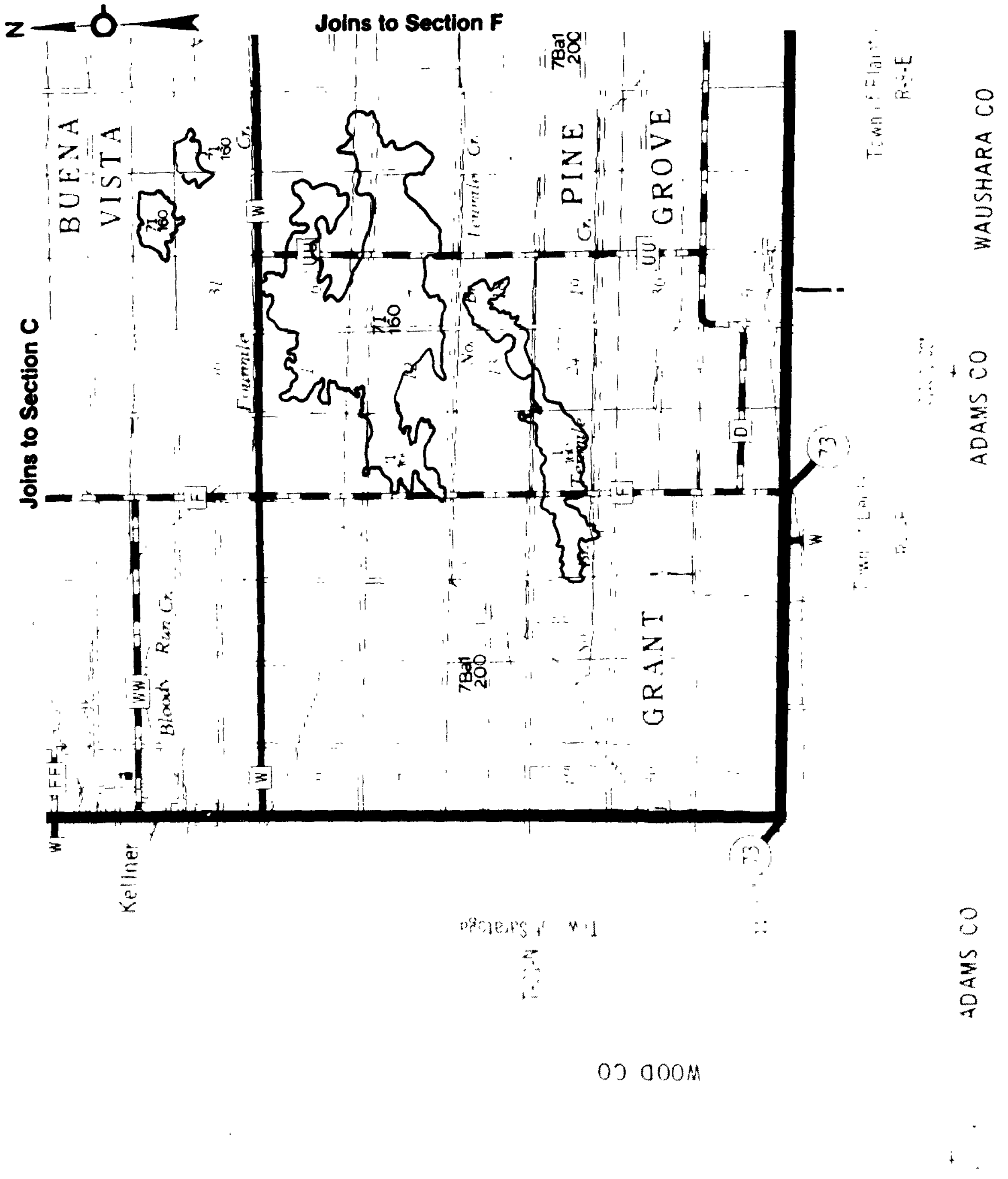
Index Sheet C

SCALE IN MILES

0 1 2

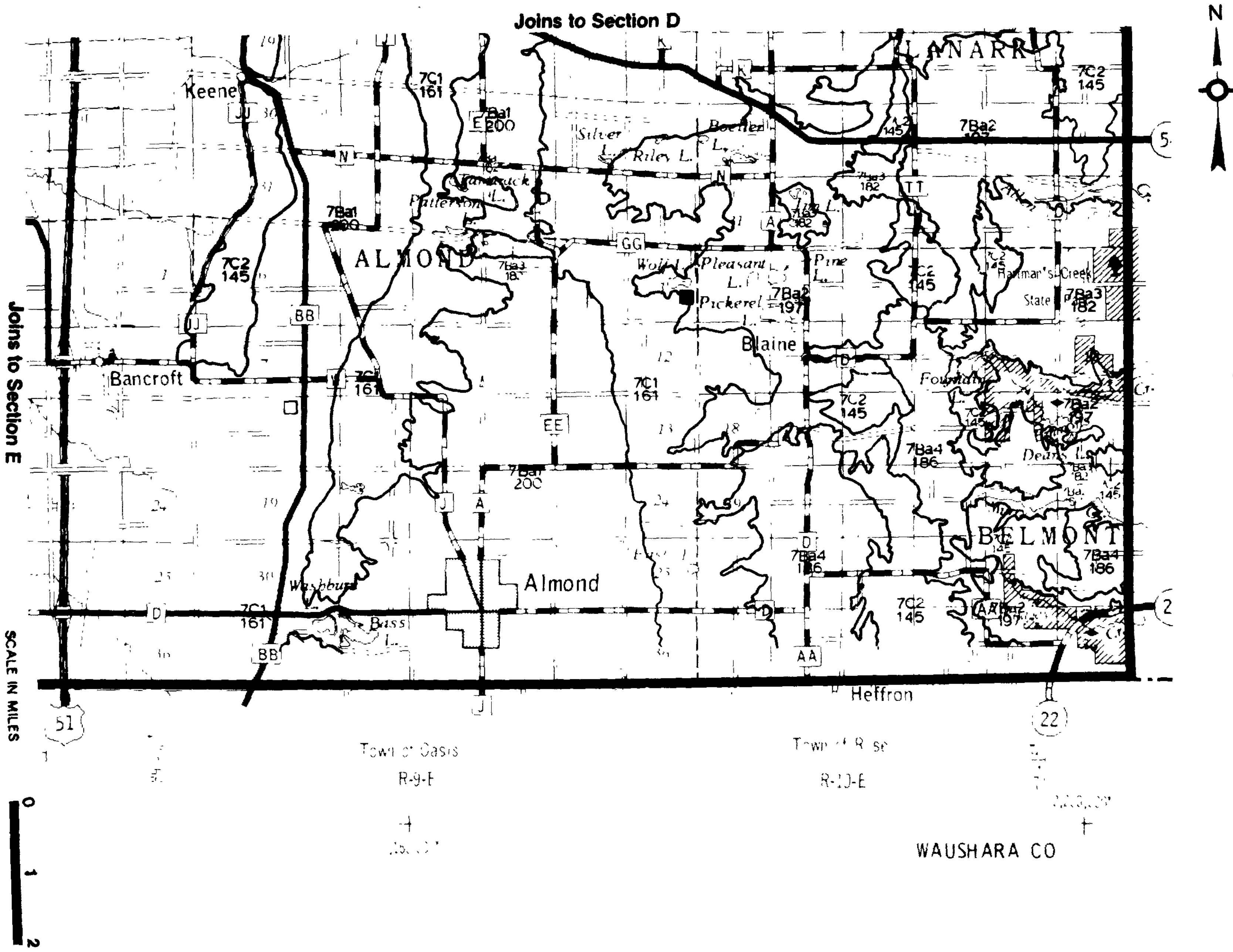



Joins to Section B
Joins to Section C
Joins to Section F
Index Sheet D
N
SCALE IN MILES
0
1
2
Stockton
STOCKTON
Nelsonville
Amherst Jct.
AMHERST
Arnott
Plover
Custer
Thomas L.
Adams L.
Bear L.
Emily L.
Ell L.
Julia L.
Lime L.
Spring L.
Onland L.
Peters L.
Waupaca
Little L.
10
51
54
HH
KK
QQ
SS
ZZ
JJ
DD
7Ba1 200
7Ba2 197
7Ba3 182
7C1 161
7C2 145
7Eb1 193



Index Sheet E

SCALE IN MILES 0 1 2

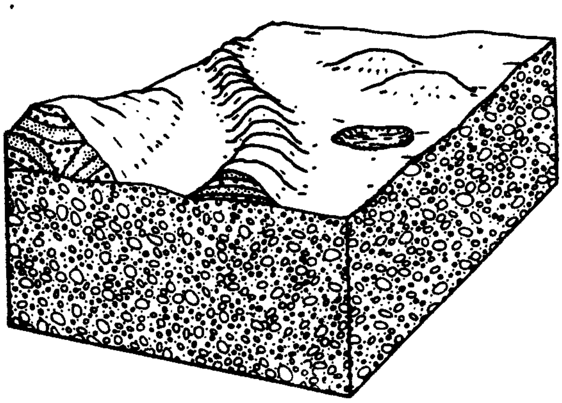


Index Sheet F

GLACIATED CENTRAL

(7Ba) Outwash

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



SETTING 7Ba1 Outwash		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	9	27
Soil Media	Sandy Loam	2	6	12
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	200

SETTING 7Ba2 Outwash		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel w/sig. Silt/Clay	5	8	40
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	197

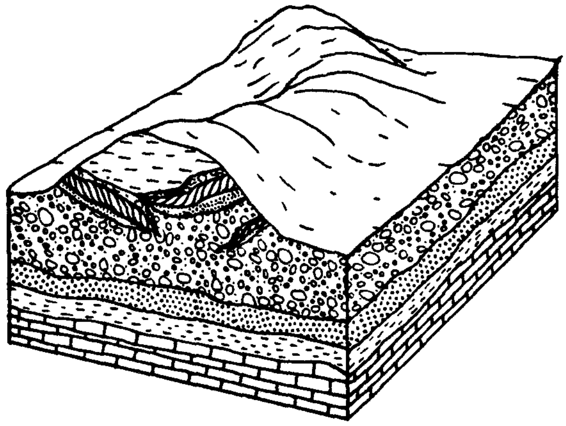
SETTING 7Ba3 Outwash		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	6-12	1	5	5
Impact Vadose Zone	Sand and Gravel w/sig. Silt/Clay	5	8	40
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	182

SETTING 7Ba4 Outwash		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	2-6	1	9	9
Impact Vadose Zone	Sand and Gravel w/sig. Silt/Clay	5	8	40
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	186

GLACIATED CENTRAL

(7C) Moraine

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



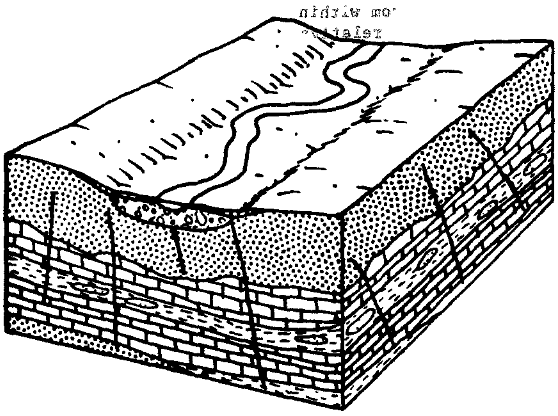
SETTING 7C1 Moraine		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	6-12	1	5	5
Impact Vadose Zone	Sand and Gravel w/sig. Silt/Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	161

SETTING 7C2 Moraine		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	6-12	1	5	5
Impact Vadose Zone	Sand and Gravel w/sig. Silt/Clay	5	5	25
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	145

GLACIATED CENTRAL

(7Eb) River Alluvium Without Overbank Deposits

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

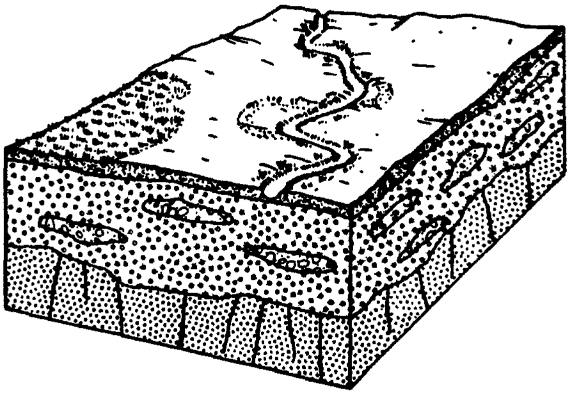


SETTING 7Eb1 River Alluvium w/o Overbank		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	193

GLACIATED CENTRAL

(7I) Swamp/Marsh

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

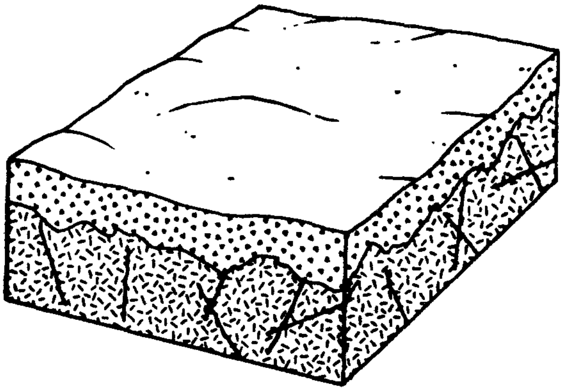


SETTING 7I Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water Table	0-5	5	10	50
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Muck	2	2	4
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel w/sig. Silt/Clay	5	6	30
Hydraulic Conductivity	700-1000	3	6	10
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

NORTHEAST AND SUPERIOR UPLANDS

(9Da) Glacial Till Over Crystalline Bedrock

This hydrogeologic setting is characterized by moderately low topographic relief and varying thicknesses of glacial till overlying severely fractured, folded and faulted bedrock of igneous and metamorphic origin with minor occurrences of bedded sedimentary rocks. The till is principally unsorted deposits which may be interbedded with localized deposits of sand and gravel. Although ground water occurs in both the glacial deposits and fractured bedrock, the bedrock is typically the principal aquifer. The glacial till serves as a recharge source. Although precipitation is abundant, recharge is only moderately high because of the low permeability of the glacial till and the surficial deposits which typically weather to loam. Depth to water is extremely variable depending in part on the thickness of the glacial till, but is typically moderately shallow.

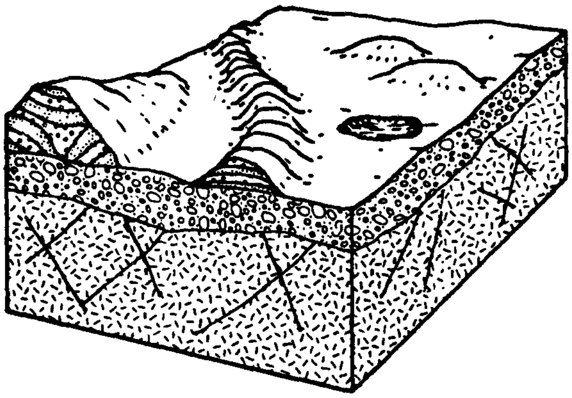


SETTING 9Da1 Glacial Till Over Crystalline Bedrock		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	4	12
Soil Media	Silty Loam	2	4	8
Topography	2-6	1	9	9
Impact Vadose Zone	Sand and Gravel w/Sig. Silt/Clay	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	109

NORTHEAST AND SUPERIOR UPLANDS

(9E) Outwash

This hydrogeologic setting is characterized by moderate topographic relief and varying thickness of outwash which overlie fractured bedrock of sedimentary, metamorphic or igneous origin. The outwash consists of water- washed deposits of sand and gravel which often serve as the principal aquifers in the area, and which typically have a sandy loam surficial layer. The outwash also serves as a source of recharge to the underlying bedrock. Recharge is abundant and ground-water recharge is high. Water levels are extremely variable, but are relatively shallow.



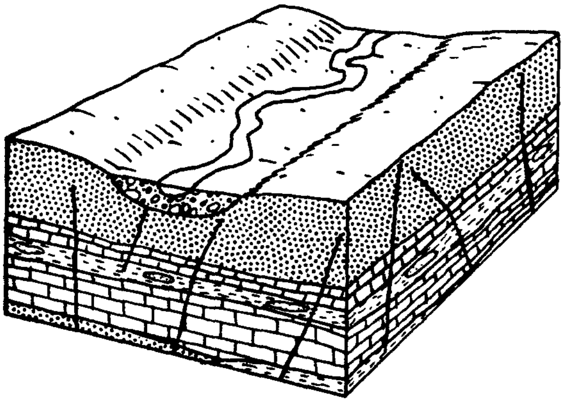
SETTING 9E1 Outwash		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	5	15
Soil Media	Loam	2	5	10
Topography	2-6	1	9	9
Impact Vadose Zone	Sand and Gravel w/sig. Silt/Clay	5	7	35
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	134

SETTING 9E2 Outwash		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	5	15
Soil Media	Sandy Loam	2	6	12
Topography	2-6	1	9	9
Impact Vadose Zone	Sand and Gravel w/sig. Silt/Clay	5	7	35
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	142

NORTHEAST AND SUPERIOR UPLANDS

(9Gb) River Alluvium Without Overbank Deposits

This hydrogeologic setting is identical to (9Ga) River Alluvium With Overbank Deposits except that no significant fine-grained floodplain deposits occupy the stream valley. This results in significantly higher recharge where precipitation is adequate and sandy soils occur at the surface. Water levels are moderate to shallow in depth. Hydraulic contact with the surface stream is usually excellent, with alternating recharge/discharge relationships varying with stream stage. These deposits serve as a good source of recharge to the underlying fractured bedrock.



SETTING 9Gb1 River Alluvium w/o Overbank		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel w/sig. Silt/Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	155

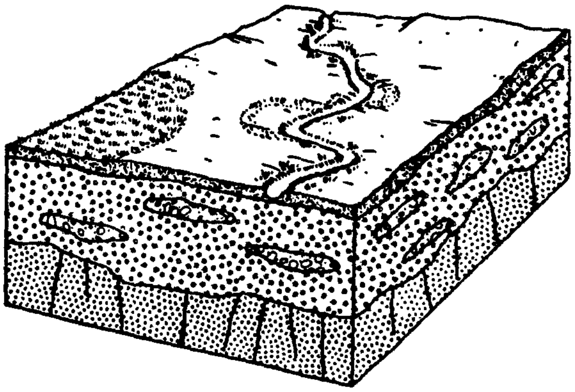
SETTING 9Gb2 River Alluvium w/o Overbank		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel w/sig. Silt/Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	176

SETTING 9Gb3 River Alluvium w/o Overbank		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sandy Loam	2	6	12
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	193

NORTHEAST AND SUPERIOR UPLANDS

(9H) Swamp/Marsh

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



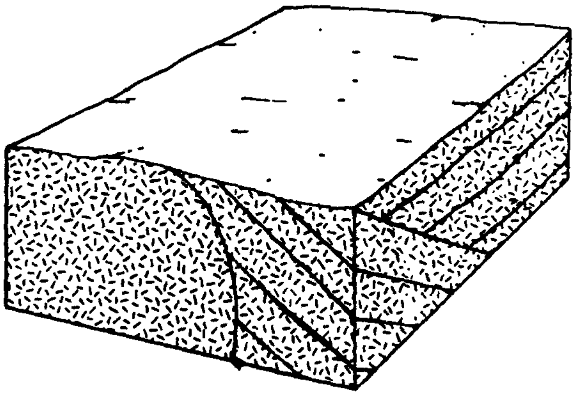
SETTING 9H1 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	5	15
Soil Media	Muck	2	2	4
Topography	0-2	1	10	10
Impact Vadose Zone	Sand and Gravel w/sig. Silt/Clay	5	6	30
Hydraulic Conductivity	100-300	3	2	6
			Drastic Index	139

SETTING 9H2 Swamp		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	0-5	5	10	50
Net Recharge	4-7	4	6	24
Aquifer Media	Weathered Metamorphic/Igneous	3	5	15
Soil Media	Muck	2	2	4
Topography	0-2	1	10	10
Impact Vadose Zone	Metamorphic/Igneous	5	4	20
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	126

NORTHEAST AND SUPERIOR UPLANDS

(9I) Bedrock Uplands

This hydrogeologic setting is characterized by moderately low topographic relief and exposed fractured, folded and faulted bedrock of igneous and low-grade metamorphic origin with minor occurrences of bedded sedimentary rocks. Recharge is primarily controlled by precipitation but is limited by the hydraulic conductivity of the rock. Where present, soils are commonly sandy. These areas typically serve as limited aquifers.



SETTING 9I1 Bedrock Uplands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	2-4	4	3	12
Aquifer Media	Weathered Metamorphic/Igneous	3	5	15
Soil Media	Sandy Loam	2	6	12
Topography	2-6	1	9	9
Impact Vadose Zone	Metamorphic/Igneous	5	5	25
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	111

SETTING 9I2 Bedrock Uplands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	2-4	4	3	12
Aquifer Media	Weathered Metamorphic/ Igneous	3	5	15
Soil Media	Loam	2	5	10
Topography	2-6%	1	9	9
Impact Vadose Zone	Metamorphic/Igneous	5	5	25
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	99

SETTING 9I3 Bedrock Uplands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	2-4	4	3	12
Aquifer Media	Sandstone	3	7	21
Soil Media	Loam	2	5	10
Topography	6-12	1	5	5
Impact Vadose Zone	Sandstone	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	106

SETTING 9I4 Bedrock Uplands		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	2-4	4	3	12
Aquifer Media	Weathered Metamorphic/ Igneous	3	5	15
Soil Media	Loam	2	5	10
Topography	2-6	1	9	9
Impact Vadose Zone	Metamorphic/Igneous	5	5	25
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	109

APPENDIX M

YOLO COUNTY, CALIFORNIA

Yolo County, California, lies within the Alluvial Basins ground-water region. From west to east, the hydrogeologic settings exemplify a typical cross section through an alluvial basin sequence. In the western portion of the county, marine sandstones and shales yield only small quantities of remnant saline water. Older continental deposits, alluvial fans and river alluvium comprised of sands, silts and clays provide the majority of the ground-water resources for the county. Conductivities are variable but typically provide significant well yields. These aquifers are usually unconfined and where they overlap, are hydraulically connected. Agricultural irrigation water provides significant recharge to these aquifers. The DRASTIC Index numbers reflect evaluation of unconfined aquifers only. Computed DRASTIC Index values range from 67 to 192.

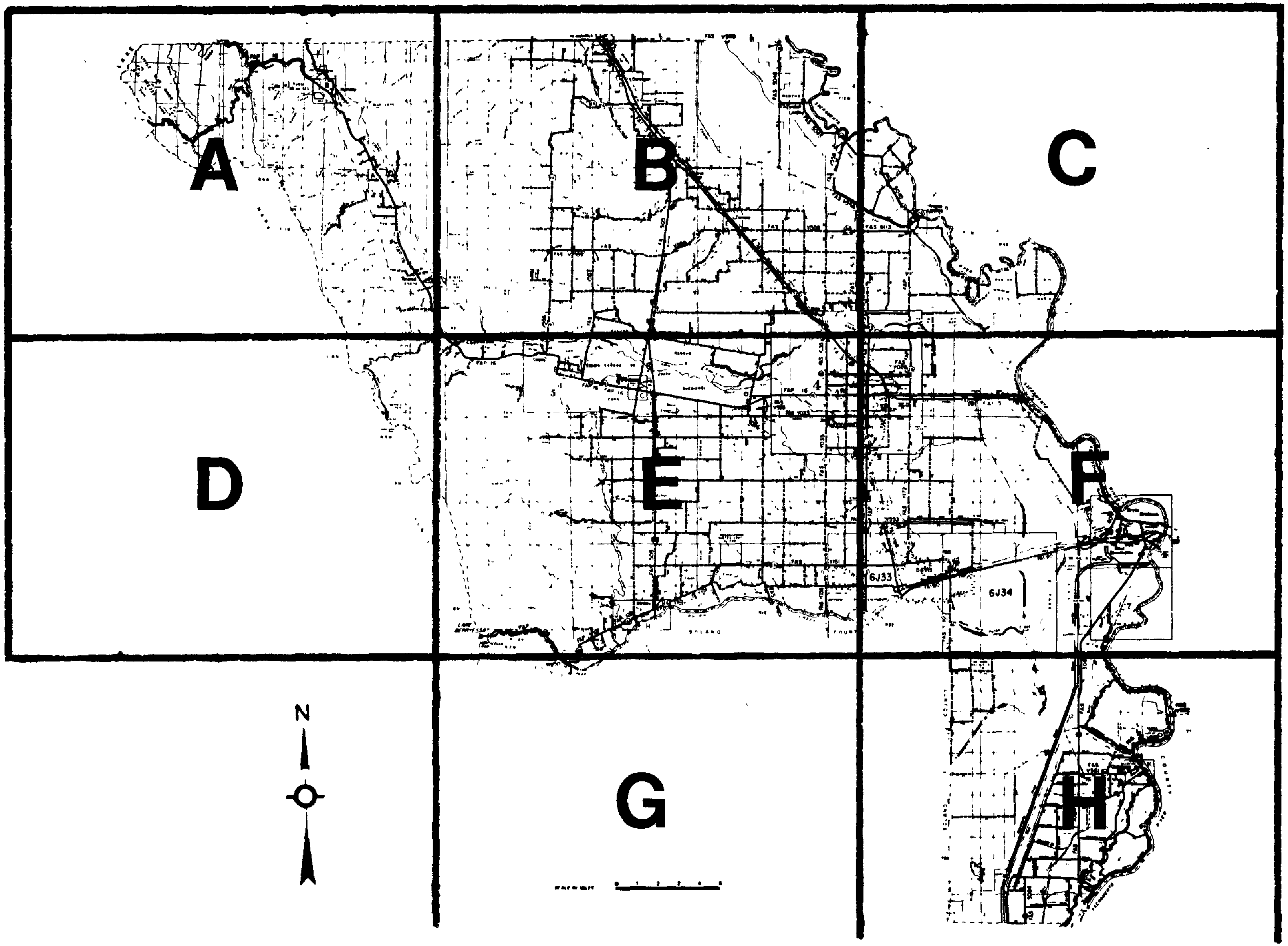
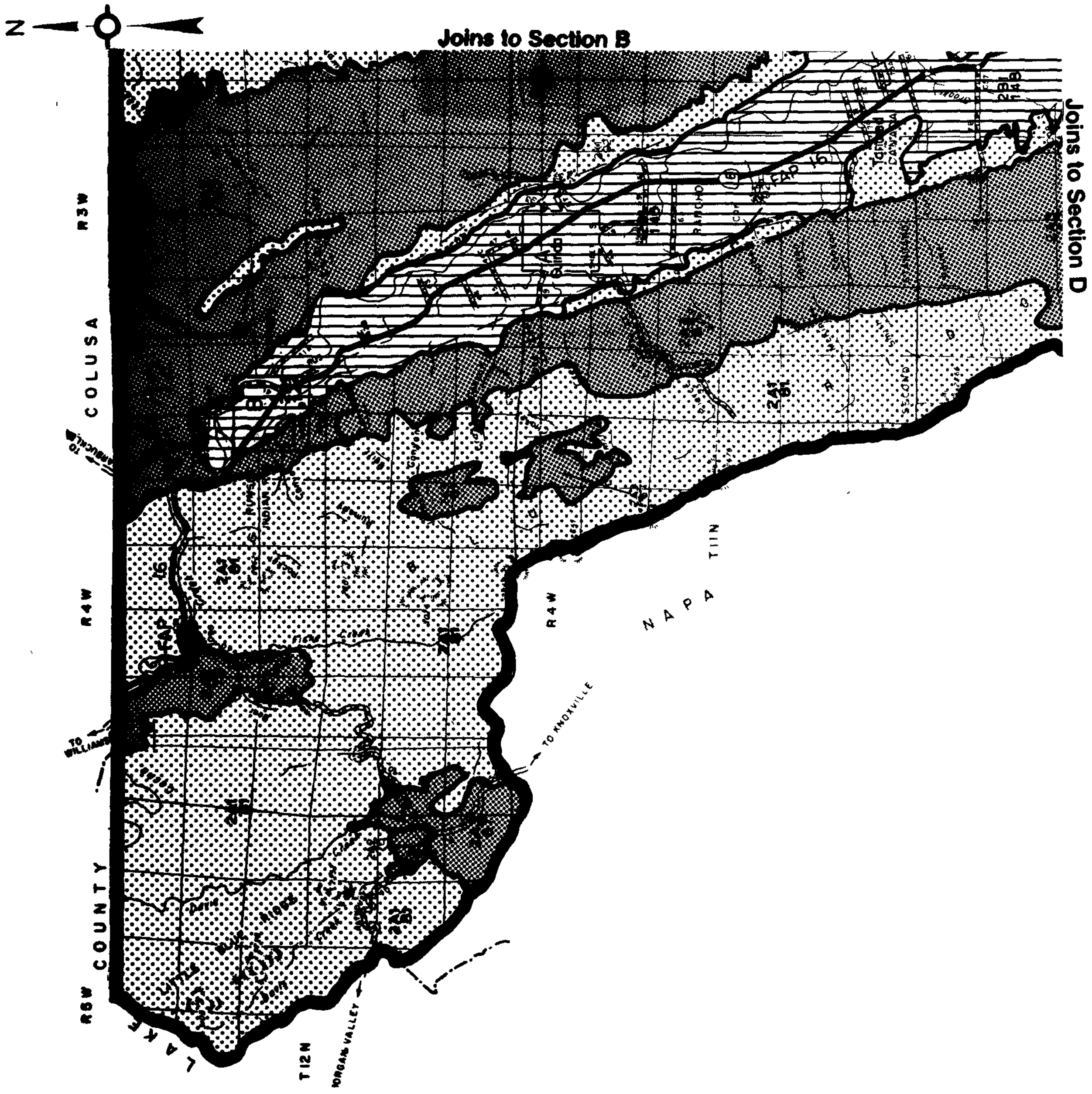


Figure M-1. Index to map sheets, detailed pollution potential map, Yolo County, California.

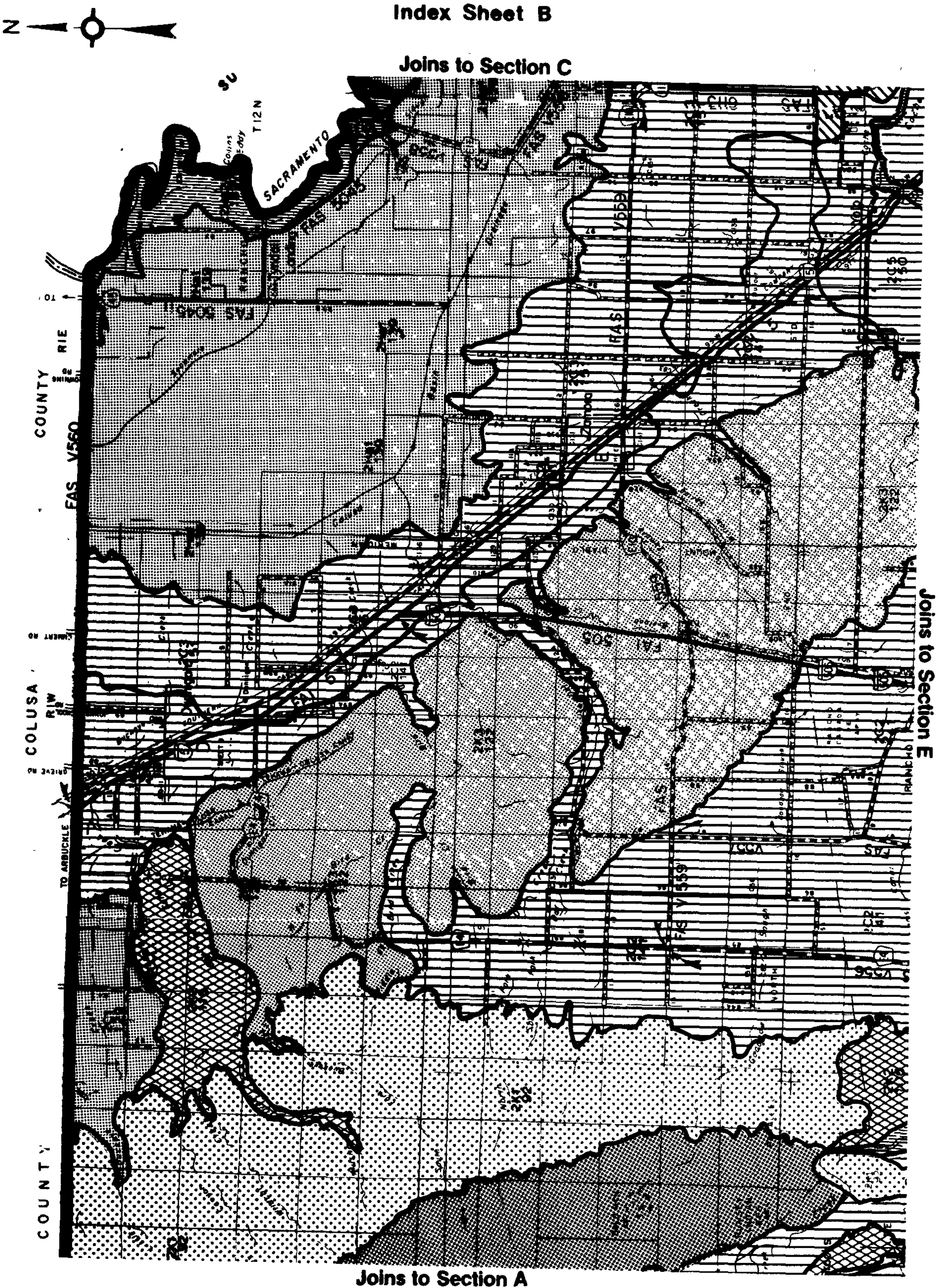


SCALE IN MILES 0 1 2 3 4 5

Index Sheet A

Index Sheet B

Joins to Section C

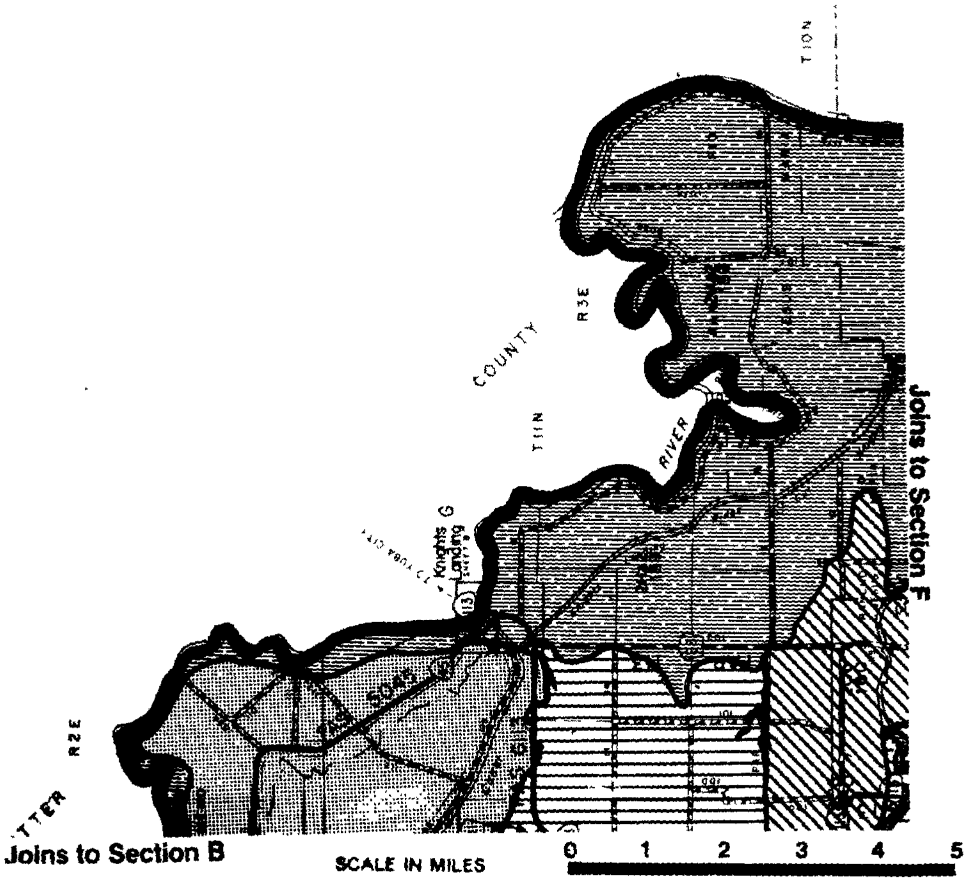


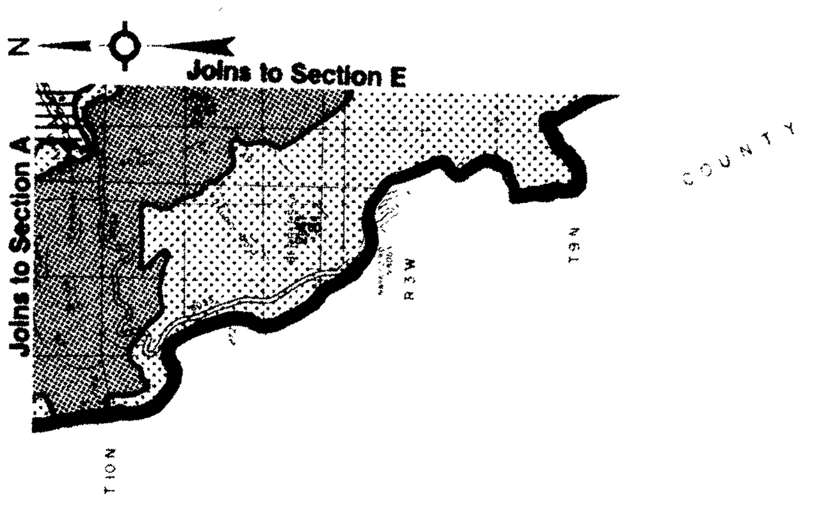
Joins to Section E

Joins to Section A

SCALE IN MILES 0 1 2 3 4 5

Index Sheet C

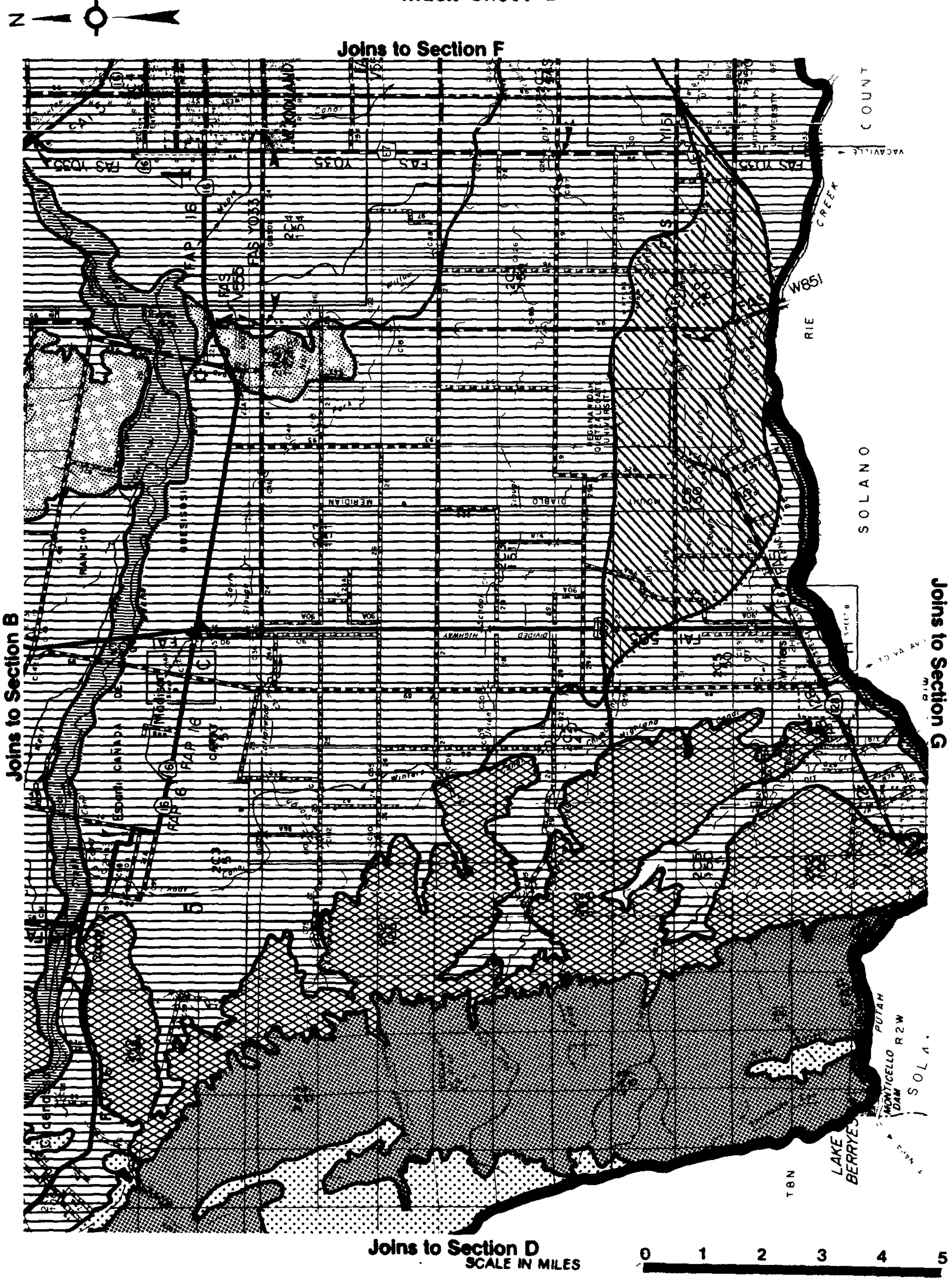




SCALE IN MILES 0 1 2 3 4 5

Index Sheet D

Index Sheet E



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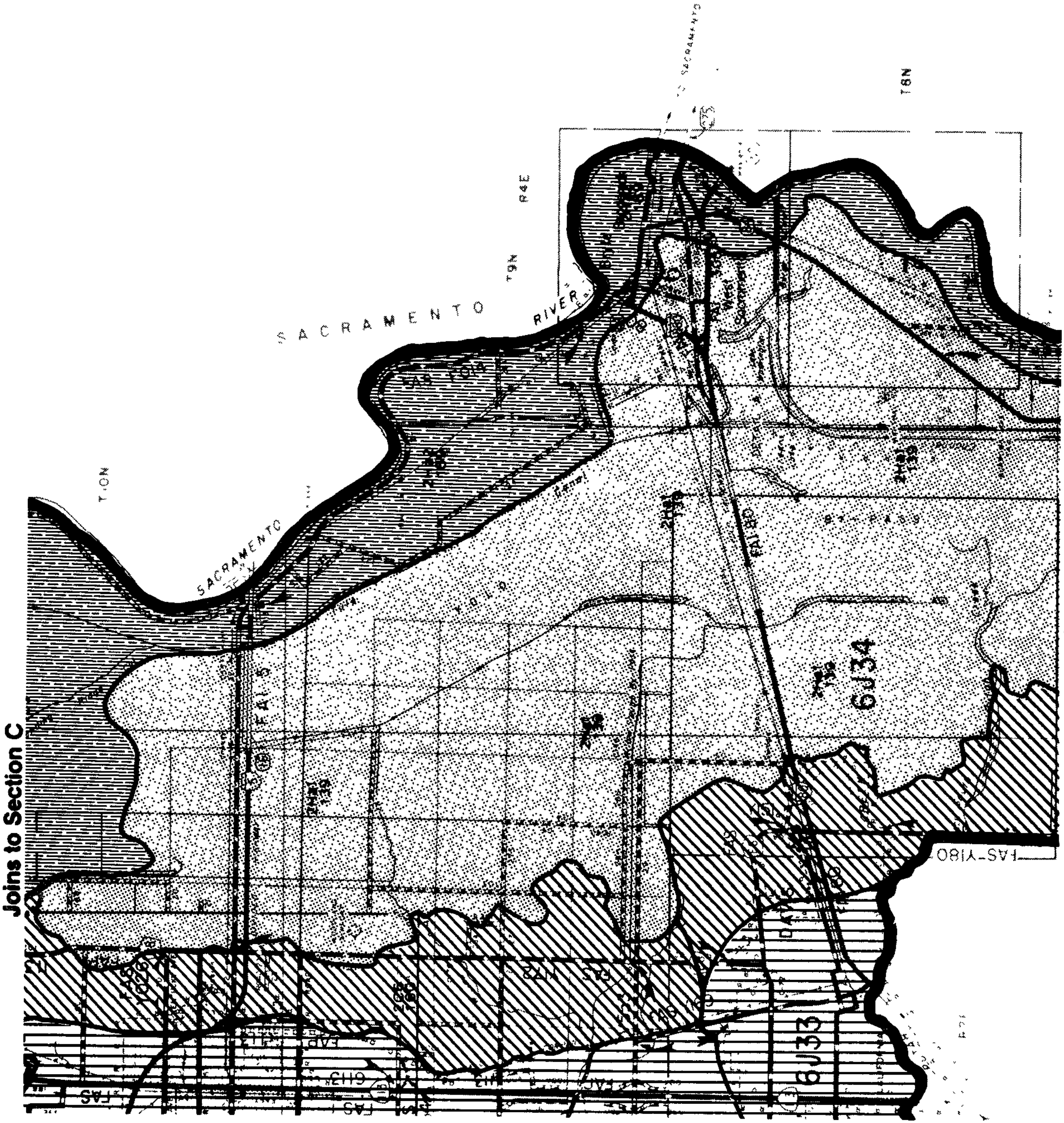


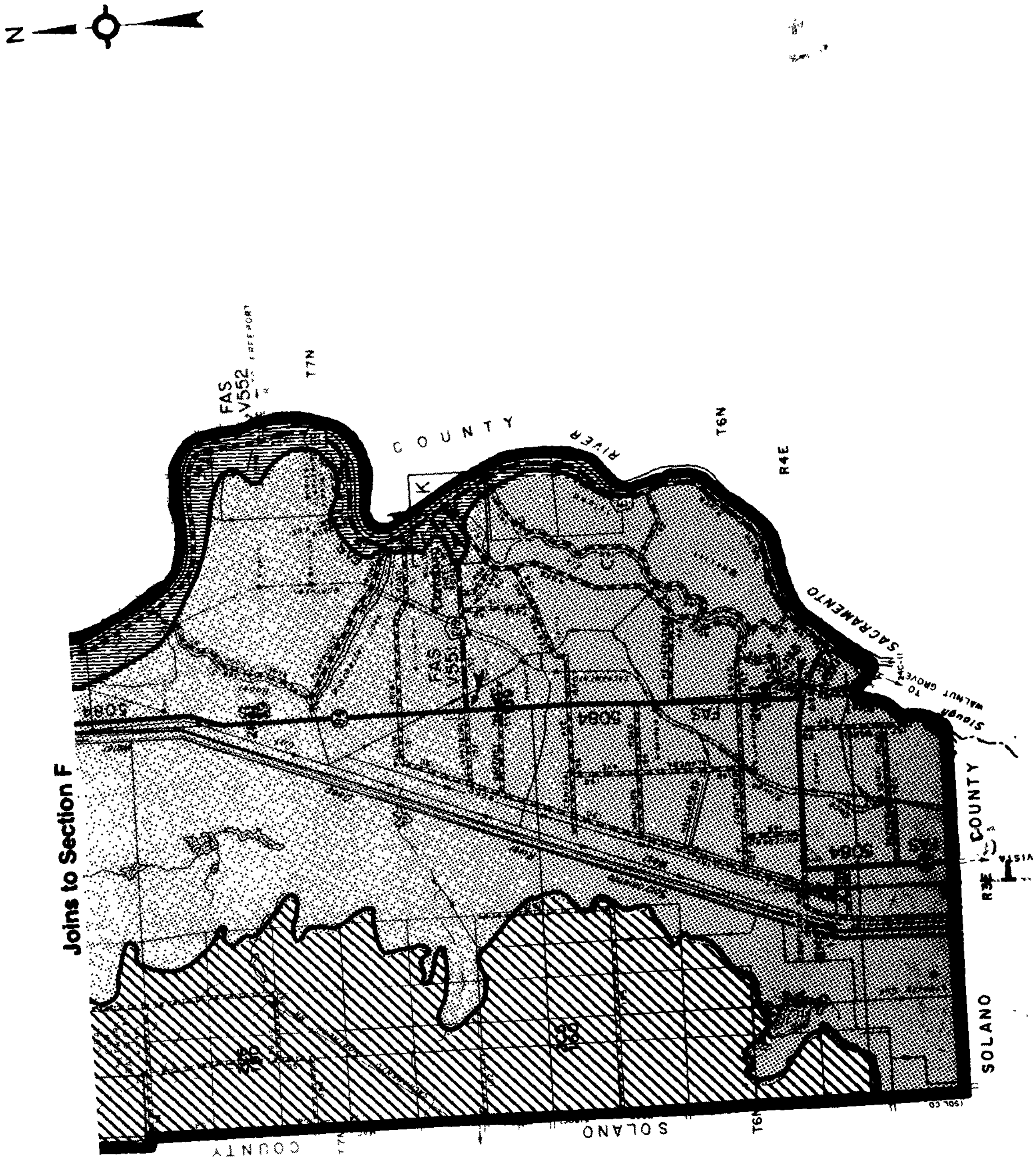
Joins to Section H

Joins to Section E

SCALE IN MILES

Index Sheet G

Index Sheet H



Joins to Section G

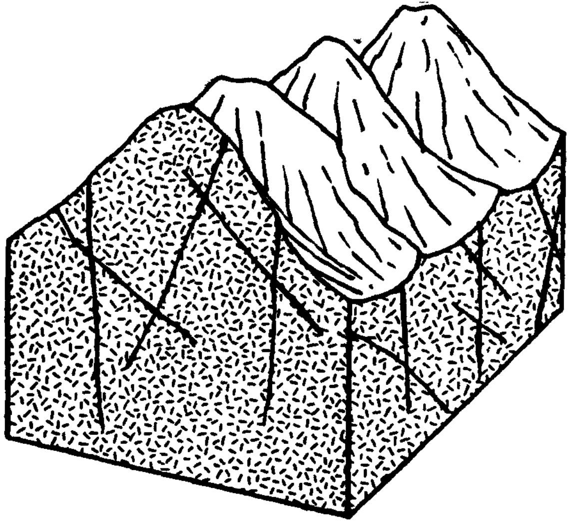
SCALE IN MILES

0 1 2 3 4 5

ALLUVIAL BASINS

(2A) Mountain Slopes

This hydrogeologic setting is characterized by steep slopes on the side of mountains, a thin soil cover and highly fractured bedrock. Ground water is obtained primarily from the fractures in the bedrock which may be of sedimentary, metamorphic or igneous origin. The fractures provide only localized sources of ground water and well yields are typically limited even though the hydraulic conductivity may be high because of the fractures. Due to the steep slopes, thin soil cover and small storage capacity of the fractures, runoff is significant and ground-water recharge is minimal. Ground-water levels are extremely variable, but are typically deep.



SETTING 2 A1 Mountain Slopes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Thin Bedded SS-LS-SH	3	6	18
Soil Media	Thin/Absent	2	10	20
Topography	18+	1	1	1
Impact Vadose Zone	Bedded SS-LS-SH	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	81

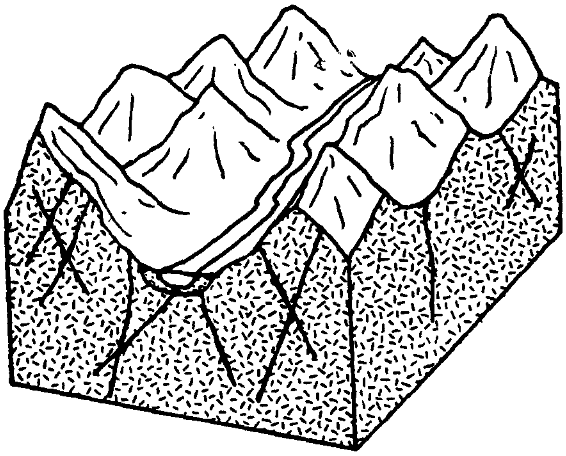
SETTING 2 A2 Mountain Slopes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Thin Bedded SS-LS-SH	3	6	18
Soil Media	Shrinking/Agg. Clay	2	7	14
Topography	18+	1	1	1
Impact Vadose Zone	Bedded SS-LS-SH	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	75

SETTING 2 A3 Mountain Slopes		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	0-2	4	1	4
Aquifer Media	Thin Bedded SS-LS-SH	3	6	18
Soil Media	Clay Loam	2	3	6
Topography	18+	1	1	1
Impact Vadose Zone	Bedded SS-LS-SH	5	6	30
Hydraulic Conductivity	1-100	3	1	3
			Drastic Index	67

ALLUVIAL BASINS

(2B) Alluvial Mountain Valleys

This hydrogeologic setting is characterized by thin bouldery alluvium which overlies fractured bedrock of sedimentary, metamorphic or igneous origin. Slopes in the valley typically range from 2 to 6 percent. The alluvium, which is derived from the surrounding steep slopes serves as a localized source of water. Water levels are moderate in depth, but because of the low rainfall, ground-water recharge is low. Ground water may also be obtained from the fractures in the underlying bedrock which are typically in direct hydraulic connection with the overlying alluvium.

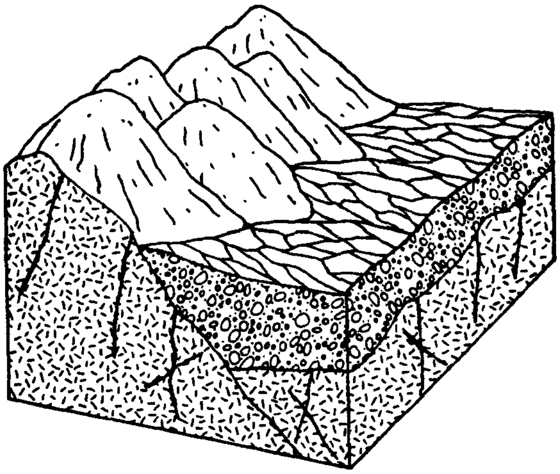


SETTING 2 B1 Alluvial Mountain Valleys		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	2	4	8
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	148

ALLUVIAL BASINS

(2C) Alluvial Fans

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



SETTING 2 C1 Alluvial Fan		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt/Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	119

SETTING 2 C2 Alluvial Fan		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt/Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	141

SETTING 2 C3 Alluvial Fan		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Clay Loam	2	3	6
Topography	2-6%	1	9	9
Impact Vadose Zone	S&G w/sig Silt/Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	151

SETTING 2 C4 Alluvial Fans		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	10+	4	9	36
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Clay Loam	2	3	6
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt/Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	154

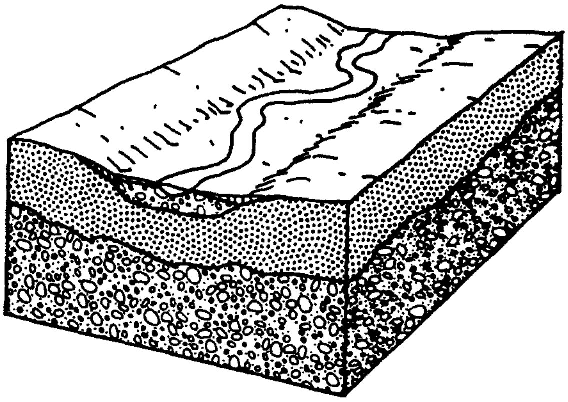
SETTING 2 C5 Alluvial Fans		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	30-50	5	5	25
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Clay Loam	2	3	6
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt/Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	150

SETTING 2 C6 Alluvial Fans		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	15-30	5	7	35
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Clay Loam	2	3	6
Topography	0-2%	1	10	10
Impact Vadose Zone	S&G w/sig Silt/Clay	5	7	35
Hydraulic Conductivity	700-1000	3	6	18
			Drastic Index	160

ALLUVIAL BASINS

(2Ha) River Alluvium With Overbank Deposits

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



SETTING 2 Ha1 River Alluvium w/Overbank Deposit		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	4-7	4	6	24
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Shrinking/Agg. Clay	2	7	14
Topography	0-2%	1	10	10
Impact Vadose Zone	Silt/Clay	5	2	10
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	139

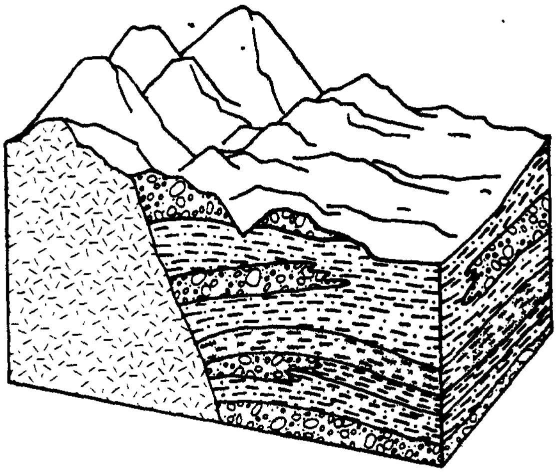
SETTING 2 Ha2 River Alluvium w/Overbank Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silt Loam	2	4	8
Topography	0-2%	1	10	10
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	2000+	3	10	30
			Drastic Index	189

SETTING 2 Ha3 River Alluvium		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	5-15	5	9	45
Net Recharge	7-10	4	8	32
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Sand	2	9	18
Topography	2-6%	1	9	9
Impact Vadose Zone	Sand and Gravel	5	8	40
Hydraulic Conductivity	1000-2000	3	6	24
			Drastic Index	192

ALLUVIAL BASINS

(2K) Continental Deposits

This hydrogeologic setting is characterized by moderate to low topographic relief and thick deposits of interbedded sand, silt and clay with discontinuous lenses of coarser sand and gravel which formed on broad floodplains. The deposits may be partially consolidated due to subsequent deformation. The sand and gravel deposits within the alluvium serve as locally important sources of water. The deposits are underlain by sedimentary, metamorphic and igneous rocks which typically do not yield significant quantities of water. Recharge is limited throughout most of the area by low precipitation.



SETTING 2 K3 Continental Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Shrinking/Agg. Clay	2	7	14
Topography	6-12%	1	5	5
Impact Vadose Zone	S&G w/sig Silt/Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	112

SETTING 2 K1 Continental Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	100+	5	1	5
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silty Loam	2	4	8
Topography	18+	1	1	1
Impact Vadose Zone	S&G w/sig Silt/Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	92

SETTING 2 K2 Continental Deposits		GENERAL		
FEATURE	RANGE	WEIGHT	RATING	NUMBER
Depth to Water	50-75	5	3	15
Net Recharge	2-4	4	3	12
Aquifer Media	Sand and Gravel	3	8	24
Soil Media	Silt Loam	2	4	8
Topography	6-12%	1	5	5
Impact Vadose Zone	S&G w/sig Silt/Clay	5	6	30
Hydraulic Conductivity	300-700	3	4	12
			Drastic Index	106

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