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Regional Assessment of Aquifer Vulnerability and Sensitivity in the Conterminous United States

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REGIONAL ASSESSMENT OF AQUIFER VULNERABILITY AND SENSITIVITY IN THE CONTERMINOUS UNITED STATES

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FOREWORD

EPA is charged by Congress to protect the Nation's land, air and water systems. Under a mandate of national environmental laws focused on air and water quality, solid waste management and the control of toxic substances, pesticides, noise and radiation, the Agency strives to formulate and implement actions which lead to a compatible balance between human activities and the ability of natural systems to support and nurture life.

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 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 ground 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 provides techniques for determining the vulnerability and sensitivity of shallow or surficial aquifers to contamination from Class V wells. A representation of ground-water vulnerability, which is determined by the geology of a system, precipitation distribution, population density, potential well yields, and aquifer sensitivity, which is related to potential for contamination, is presented for each of the 48 conterminous states.

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ABSTRACT

The EPA through the UIC program, is developing regulations for the protection of USDW's from contamination by the subsurface emplacement of fluids through wells. This report deals with Class V wells, most of which inject into or above shallow or surficial aquifers; that is, into or above USDW's.

The purpose of this report is to provide, in a generalized, largely graphical format, a representation of ground-water vulnerability, precipitation distribution, population density, potential well yields, and aquifer sensitivity for each of the 48 conterminous states.

The geology of the physical system determines vulnerability. Population density and distribution are important because people are associated with sources of contamination. The greatest number of shallow injection wells occurs in areas of high population density. The distribution and quantity of precipitation has a bearing on ground-water recharge. Well yield also plays a role in prioritizing aquifer protection. Aquifer sensitivity is related to the potential for contamination. That is, aquifers that have a high degree of vulnerability and are in areas of high population density are considered to be the most sensitive. This implies that even though an aquifer is highly vulnerable, only that part covered by population centers actually has a high degree of sensitivity.

The classification scheme developed for this report is based on an assessment of the vulnerability of surficial and relatively shallow aquifers.

Class I (Surficial or shallow, permeable units; highly vulnerable to contamination).
Unconsolidated Aquifers (Class Ia). Class Ia aquifers consist of surficial, unconsolidated, and permeable alluvial, terrace, outwash, beach, dune and other similar deposits.
Soluble and Fractured Bedrock Aquifers (Class Ib). Lithologies in this class include limestone, dolomite, and, locally, evaporitic units that contain documented karst features or solution channels, regardless of size. Also included are sedimentary strata, and metamorphic and igneous rocks that are significantly faulted, fractured, or jointed.
Semiconsolidated Aquifers (Class Ic). Semiconsolidated systems generally contain poorly to moderately indurated sand and gravel that is interbedded with clay and silt.
Covered Aquifers (Class Id). This class consists of any Class I aquifer that is overlain by less than 50 feet of low permeability, unconsolidated material, such as glacial till, lacustrian, and loess deposits.

Class II (Consolidated bedrock aquifers, moderately vulnerable)
Higher Yield Bedrock Aquifers (Class IIa). These aquifers generally consist of fairly coarse sandstone or conglomerate that contain lesser amounts of interbedded fine-grained clastics and occasionally carbonate units. In general, well yields must exceed 50 gpm to be included in this class.
Lower Yield Bedrock Aquifers (Class IIb). Most commonly, lower yield systems consist of the same clastic rock types present in the higher yield systems. Well yields are commonly less than 50 gpm.
Covered Bedrock Aquifers (Class IIc). This group consists of a Class IIa and IIb aquifers that are overlain by less than 50 feet of unconsolidated material of low permeability.

Class III (Covered consolidated or unconsolidated aquifers). This class includes those aquifers that are overlain by more than 50 feet of low permeability material.

Class U (Undifferentiated aquifers).This classification is used where several lithologic and hydrologic conditions are present within a mappable area. This class is intended to convey a wider range of vulnerability than is usually contained within any other single class.

Subclass v (Variably covered aquifers). The modifier "v" is used to describe areas where an undetermined or highly variable thickness of low permeability sediments overlies the major water-bearing zone.

About 46 percent of the land area of the conterminous United States consists of vulnerable Class I aquifers. Of this amount, 26.4 percent is Class Ia, 10.4 percent is Class Ib and Ib-v, 8.1 percent is Class Ic, and

Class Id accounts for an additional 1.4 percent. The moderately vulnerable Class II aquifers cover about 14 percent of the United States, while the least vulnerable, Class III, makes up about 19 percent. The undefined systems, Class U, account for an additional 19 percent.

This report was submitted in fulfillment of contract number EPA CR-815754-01-0 by the School of Geology, Oklahoma State University under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from 4-10-89 to 4-9-91, and work was completed as of 4-9-91

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Section 1

INTRODUCTION

In 1974 Congress enacted the Safe Drinking Water Act (PL 93-523) to protect public health and welfare, as well as existing and future underground sources of drinking water. To achieve this end, the EPA (U.S. Environmental Protection Agency), through the UIC (Underground Injection Control) program, has and is developing regulations for the protection of USDW's (Underground Sources of Drinking Water) which contain less than 10,000 mg/L of dissolved solids) from contamination by the subsurface emplacement of fluids through wells.

UIC regulations defined and established 5 classes of injection wells.

Class I—used to inject hazardous and non-hazardous waste beneath the lowermost formation containing a USDW.

Class II—used to inject brine from oil and gas production.

Class III—used in conjunction with solution mining of minerals.

Class IV—used to inject hazardous or radioactive wastes into or above a USDW (banned nationally).

Class V—none of above but which typically inject non-hazardous waste into or above a USDW. Also known as shallow injection wells.

UIC regulations define a well as a bored, drilled, or driven shaft or dug hole, whose depth is greater than its largest surface dimension. Well injection is the subsurface emplacement of any substance that flows or moves. There are two general types of injection wells—high technology and low technology. The latter include agricultural drainage, storm water/industrial drainage, improved sinkholes, raw sewage disposal and cesspools, septic systems, some industrial process water and waste disposal wells, auto service station waste disposal wells, and abandoned water wells used for disposal, among others.

Many, if not most, Class V wells inject into or above shallow or surficial aquifers; that is, into or above USDW's. According to the most recent inventory reported by EPA, there are approximately 170,000 Class V or shallow injection wells in the United States, but this estimate is probably far too low. An assessment is provided in the Report to Congress, Class V Injection Wells (EPA, 1987).

The greatest number of shallow injection wells occurs in areas of high population density. The types most likely to be present in industrial/urban/suburban areas include storm water and industrial drainage, improved sinkholes, domestic waste water disposal, industrial process water and waste, auto service station waste disposal, and abandoned water supply wells used for waste disposal.

Injection wells typically present in rural areas are used primarily for agricultural drainage and secondarily for raw sewage waste disposal.

As a group, abandoned wells are the most pervasive and potentially dangerous of all the shallow injection wells; they are found in both rural and urban areas.

An evaluation of the potential for ground-water contamination caused by shallow injection wells is a major undertaking because of the vast number of wells and their wide distribution throughout an extensive array of diverse hydrogeologic settings. To limit the potential impact of shallow injection wells on the Nation's ground water, a scheme is needed to prioritize regions so that, initially, the most sensitive and productive or potentially productive ground-water areas receive maximum attention.

Although this investigation was designed specifically to answer a need in the Underground Injection Control program, the products are equally valuable to assess the potential for ground-water contamination from other surface or near surface sources.

Aquifer Vulnerability, Potential Yield, and Sensitivity

There is a general relation of permeability to geologic age and rock type in the conterminous United States. The geologic age of the major rock groups is shown in Figure 1. Figure 2 illustrates the regional distribution of the principal types of water-bearing rocks.

The geology of the physical system

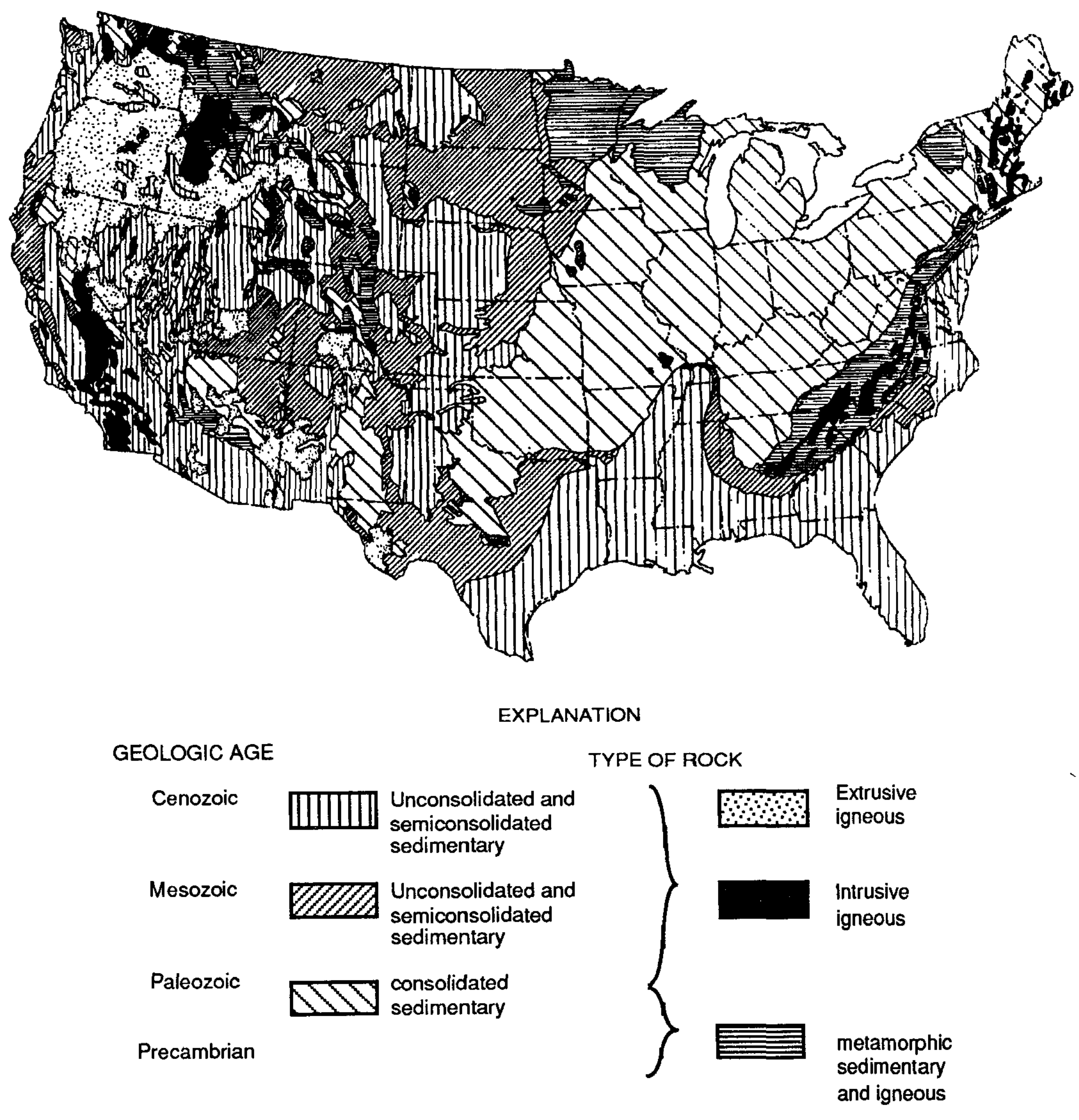


Figure 1. Geologic age of major rock groups (modified from Heath, 1984)

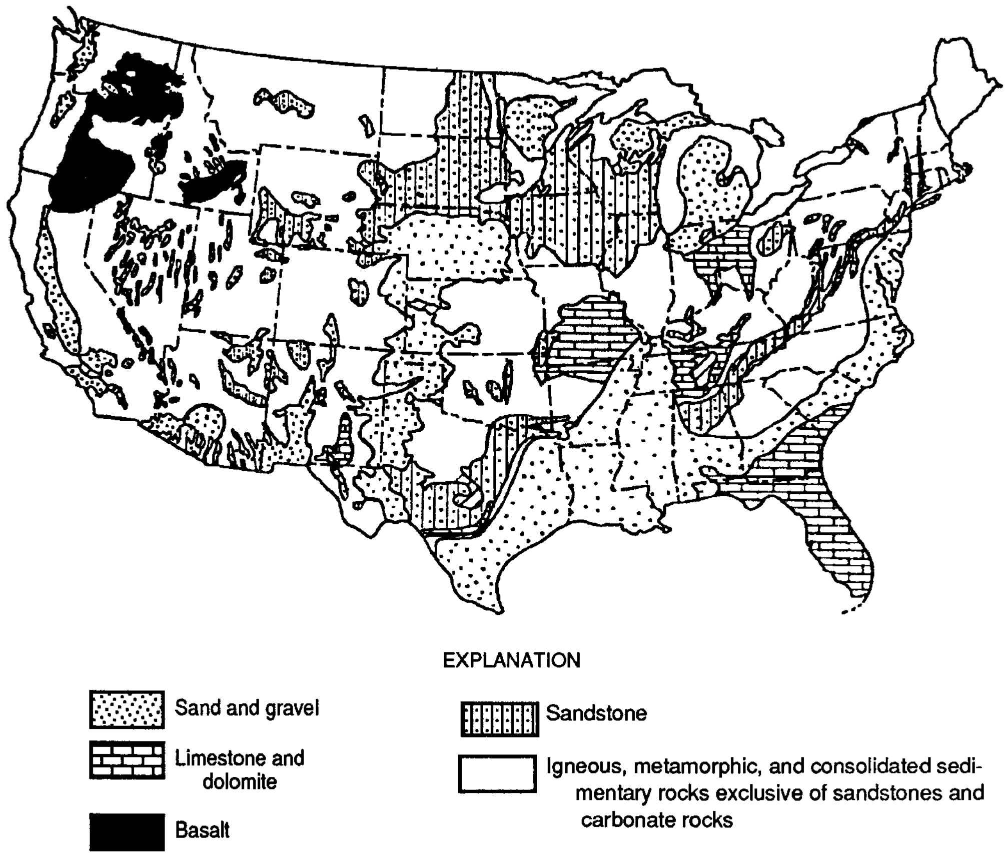


Figure 2. Generalized distribution of major types of aquifers (modified from Heath, 1984)

determines vulnerability. That is, aquifers that have little or no natural protection, such as overlying deposits of low permeability material (e.g., clay, shale, or glacial till), are the most susceptible to contamination from shallow or near-surface sources.

Some of the most productive aquifers in the United States lie along rivers; they are quickly recharged and generally contain water of low mineral content. But the characteristics that make them desirable water-supply sources also make them susceptible to contamination from surface or near surface sources, and from shallow injection wells, most of which are less than 50 feet deep. These aquifers have little or no natural protection other than that provided by the unsaturated zone.

Population density and distribution are important because people are associated with sources of contamination. The higher the population density, the more likely there will be a greater number of potential contamination sources. For example, the probability of a large number of sources is substantially higher in a municipal area than it is in a rural region.

The distribution and quantity of precipitation have a bearing on the potential for ground-water contamination because infiltration or ground-water recharge provides a driving force that tends to leach water-soluble materials from the surface or unsaturated zone to the water table.

As a practical matter, well yield also plays a role in prioritizing aquifer protection. Municipalities and industries are usually located in areas where there is an adequate supply of water. Therefore, a vulnerable, high yield aquifer in a densely populated area is likely to have a higher priority for investigation and protection than an area where the aquifer would provide only a limited amount of water.

A municipality with a population of 10,000 would require a water supply capable of producing at least 1.63 mgd (million gallons per day), which is equal to a continuous pumping rate of nearly 1,200 gpm (gallons per minute). This yield could be obtained from two wells each pumping 600 gpm or a dozen wells producing 100 gpm continuously. Most well fields, however, are operated only 8 to 10 hours per day and, consequently, larger yields, longer pumping periods, or more wells would be required to meet the average daily demand.

Well yields in the range of 100 gpm or more can only be obtained from aquifers that are quite permeable and quickly recharged or those that contain a huge volume of water in storage. Aquifers that meet these criteria are not common.

Aquifer sensitivity is related to the potential for contamination. That is, aquifers that have a high degree of vulnerability and are in areas of high population density, are considered to be the most sensitive, regardless of potential well yield or ground-water recharge. In turn, this implies that even though an aquifer is highly vulnerable, only that part covered by population centers actually has a high degree of sensitivity. For example, the highly vulnerable sand deposits along Oklahoma's Cimarron River cover about 1740 square miles, but less than 6 square miles lie within or adjacent to corporation boundaries. Consequently, even though the aquifer is highly vulnerable, the aquifer sensitivity is very small owing to the low population density.

Purpose and Scope

The purpose of this report is not to classify ground water or ground-water regions, but rather to provide, in a generalized, largely graphical format, a manual that displays, for each of the 48 conterminous states, a representation of ground-water vulnerability, precipitation distribution, population density, potential well yields, and aquifer sensitivity. This manual can be used by local, state, or federal regulatory agencies to rapidly assess and, in a general manner, prioritize ground-water protection activities relative to shallow injection wells and other surface or near surface sources of contamination.

In addition, the maps can be used to delineate areas that provide or potentially provide the greatest amount of ground water to the largest number of people. Likewise, they also can be used to evaluate the more remote areas. The maps can provide the investigator with a quick, inexpensive means to review the potential for ground-water contamination and thus develop rapid but generalized evaluations of large areas. This, in turn, would permit agencies to develop a protocol for shallow injection well permitting or impact evaluations.

The generalized regional assessment can be used to prioritize selected areas for additional investigations where more detail is required. Obviously, any assessment is scale dependent, and a larger scale requires a more extensive data base.

Once a generalized evaluation has been completed, it might then be appropriate to further assess a region, area, or site by means of more detailed approaches.

A number of methods have been available for several years to evaluate a site relative to the potential for ground-water contamination. These rating techniques are valuable, in a qualitative sense, for the formulation of a detailed investigation. One of the most noted is the LeGrand (1983) system, which takes into account the hydraulic conductivity, sorption, thickness of the water-table aquifer, position and gradient of the water table, topography, and distance between a source of contamination and a well or receiving stream. The LeGrand system was modified by the EPA (1983) for the Surface Impoundment Assessment study.

Fenn and others (1975) formulated a water balance method to predict leachate generation at solid waste disposal sites. Gibb and others (1983) devised a technique to set priorities for existing sites relative to their threat to health. An environmental contamination ranking system was developed by the Michigan Department of Natural Resources (1983). On a larger scale, DRASTIC, prepared by the National Water Well Association for EPA (Aller and others, 1985), is a method to evaluate the potential for ground-water contamination based on the hydrogeologic setting. A methodology for the development of a ground-water management and aquifer protection plan was described by Pettyjohn (1990).

Although no specific ground-water contamination prevention protocol is herein suggested, it might be reasonable to first examine those areas that have the greatest aquifer sensitivity relative to vulnerability, high well yield, and population density. A second priority would include those areas that are less susceptible to contamination owing to decreased aquifer vulnerability and a lower population density.

Classification System

The classification scheme developed for this report is based on an assessment of the vulnerability of surficial and relatively shallow aquifers to contamination from shallow injection wells and other surface or near surface sources of contamination. The investigation was not limited to currently proven aquifers or aquifers of some designated yield. Rather, an attempt was made to evaluate all aquifers on the basis of their reported physical properties and related hydrologic characteristics and behavior, keeping in mind the fact that the assessment had to be based entirely on published reports and maps.

Physical properties that were considered included:

1. Degree of consolidation (unconsolidated, semiconsolidated, consolidated) resulting from variable degrees of compaction, welding, induration, etc.

2. Presence of primary porosity and permeability.

3. Presence of secondary porosity and permeability, such as solutional features, faults, fractures, joint systems, bedding planes and schistocity, vesiculation, and interformational breccia zones, among others.

4. Presence of intercalated units of different hydraulic characteristics.

The general ranges in well yield, as reported by the U.S. Geological Survey and state agencies, also was used to designate different aquifer classes. An arbitrary limit of 50 gpm was used to differentiate between lower yield and higher yield bedrock systems. It seems likely that higher yield bedrock systems would be more permeable and, therefore, more vulnerable than lower yield bedrock systems, although yield is a function of several different factors.

The degree to which a particular physical feature is present also affects the classification. For example, a densely jointed surficial sandstone would be considered as Class Ib, which has a high degree of vulnerability, but a similar unit that is reported to be fractured only locally would be considered as an undifferentiated (Class U) unit; it is assumed that it would be less vulnerable.

Most surficial fine-grained material, which appears to have a very low permeability, may indeed be quite transmissive. Fine-grained alluvium, for example, may be as permeable as a fractured sandstone. Glacial till is commonly weathered and fractured to a depth of 20 to 30 feet. Likewise, the alternating layers of cemented, fine-grained sandstone, siltstone, and mudstone of Late Paleozoic age in the Southern Plains (and very likely elsewhere as well), are fractured to a depth of 40 to 60 feet or so. The postulated widespread fracturing has not been well documented, but the few field studies presently available indicate that there may be rapid ground-water recharge through fine-grained material and this makes an underlying aquifer quite vulnerable to contamination despite the presence of a cover of fine-grained material. The presence and potential effects of fracturing of surficial, fine-grained materials, from whatever cause, were not considered in this classification scheme.

Characteristics of Individual Classes

Class I (Surficial or shallow, permeable units; highly vulnerable to contamination)

Unconsolidated Aquifers (Class Ia). Class Ia aquifers consist of surficial, unconsolidated, and permeable alluvial, terrace, outwash, beach, dune and other similar deposits. These units generally contain layers of sand and gravel that, commonly, are interbedded to some degree with silt and clay. Not all deposits mapped as Class Ia are important water-bearing units, but they are likely to be both permeable and vulnerable. The only natural protection of aquifers of this class is the thickness of the unsaturated zone and the presence of fine-grained material.

Soluble and Fractured Bedrock Aquifers (Class Ib). Lithologies in this class include limestone, dolomite, and, locally, evaporitic units that contain documented karst features or solution channels, regardless of size. Generally these systems have a wide range in permeability. A generalized map showing the major karst areas and those locations where soluble strata (carbonates and sulfates) lie at a shallow depth or crop out is shown in Figure 3. Also included in this class are sedimentary strata, and metamorphic and igneous (intrusive and extrusive) rocks that are significantly faulted, fractured, or jointed. In all cases ground-water movement is largely controlled by secondary

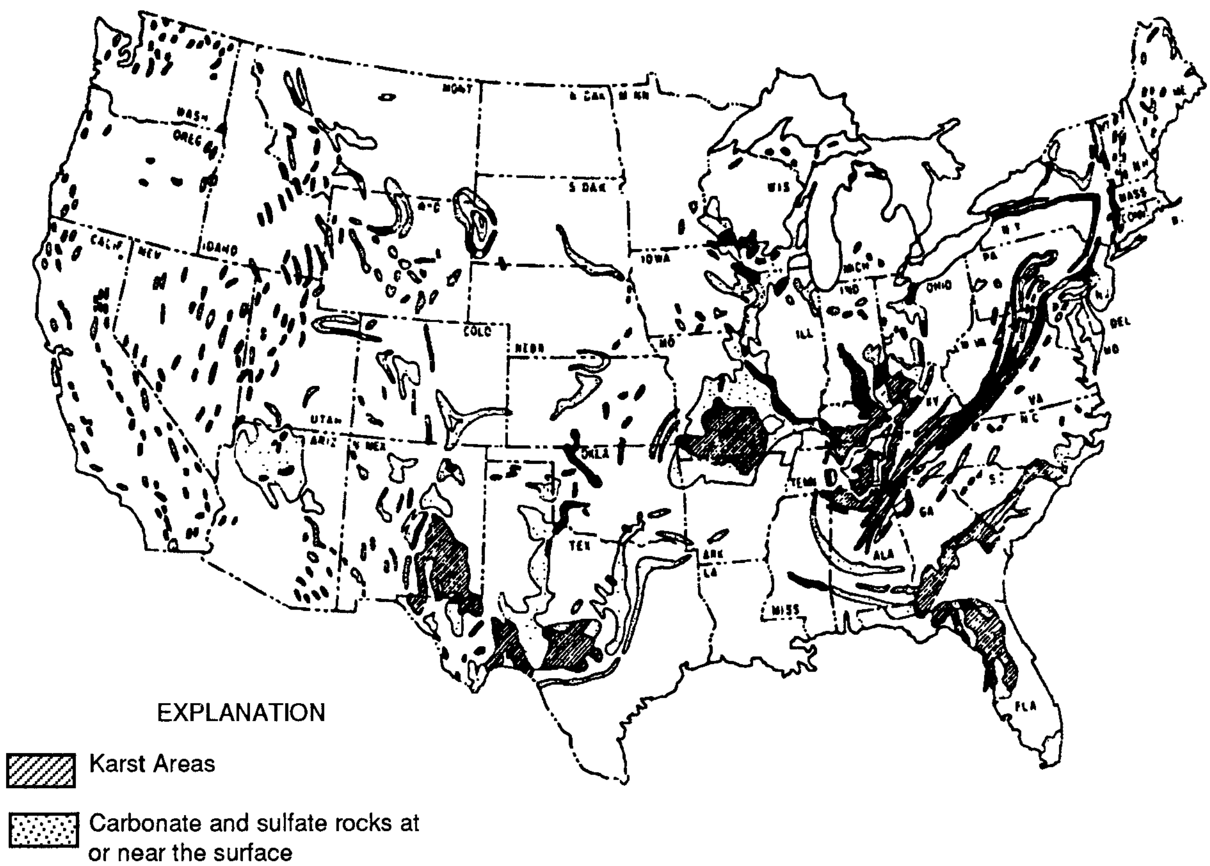


Figure 3. Generalized distribution of karst areas and regions where soluble rocks are at or near land surface (modified from LeGrand and others, 1976)

openings. Well yields range widely, but the important feature is the potential for rapid vertical and lateral ground-water movement along preferred pathways, which result in a high degree of vulnerability.

Semiconsolidated A quifers (Class I c). Semiconsolidated systems generally contain poorly- to moderately-indurated sand and gravel that is interbedded with clay and silt. This group is intermediate to the unconsolidated and consolidated end members. These systems are common in the Tertiary age rocks that are exposed throughout the Gulf and Atlantic coastal states. Semiconsolidated conditions also arise from the presence of intercalated clay and caliche within primarily unconsolidated to poorly consolidated units, such as occurs in parts of the High Plains Aquifer.

Covered Aquifers (Class Id). This class consists of any Class I aquifer that is overlain by less than 50 feet of low permeability, unconsolidated material, such as glacial till, lacustrian, and loess deposits.

Class II (Consolidated bedrock aquifers; moderately vulnerable)

Higher Yield Bedrock Aquifers (Class IIa). These aquifers generally consist of fairly permeable sandstone or conglomerate that contain lesser amounts of interbedded fine-grained clastics (shale, siltstone, mudstone) and occasionally carbonate units. In general, well yields must exceed 50 gpm to be included in this class. Locally fracturing may contribute to the dominant primary porosity and permeability of these systems.

Lower Yield Bedrock Aquifers (Class IIb). In most cases these aquifers consist of sedimentary or crystalline rocks. Most commonly, lower yield systems consist of the same clastic rock types present in the higher yield systems, but in the former case grain size is generally smaller and the degree of cementation or induration is greater, both of which lead to a lower permeability. In many existing and ancient mountain regions, such as the Appalachians (Blue Ridge and Piedmont), the core consists of crystalline rocks that are fractured to some degree. Well yields are commonly less than 50 gpm, although they may be larger in valleys than on interstream divides.

Covered Bedrock Aquifers (Class IIc). This group consists of Class IIa and IIb aquifers that are overlain by less than 50 feet of unconsolidated material of low permeability, such as glacial till, lacustrian, or loess deposits. It is assumed that most Class V wells are relatively shallow and, therefore, 50 feet or less of fine-grained cover could reduce but not necessarily eliminate the vulnerability of underlying Class II systems.

Class III (Consolidated or unconsolidated aquifers that are overlain by more than 50 feet of low permeability material; low vulnerability)

Aquifers of this type are the least vulnerable of all the classes because they are naturally protected by a thick layer of fine-grained material, such as glacial till or shale. Examples include parts of the Northern Great Plains where the Pierre Shale of Cretaceous age crops out over thousands of square miles and is hundreds of feet thick. In many of the glaciated states, till forms an effective cover over bedrock or buried outwash aquifers, and elsewhere alternating layers of shale, siltstone, and fine-grained sandstone insulate and protect the deeper major water-bearing zones.

Class III aquifers are not likely to become contaminated by surface sources, as a result of leaching of contaminants stored in the unsaturated zone, or by shallow injection wells. These aquifers can become contaminated, however, largely by waste disposal in abandoned wells, particularly abandoned water wells or supply wells that were not properly constructed.

Class U (Undifferentiated aquifers)

This classification is used where several lithologic and hydrologic conditions are present within a mappable area. Units are assigned to this class because of constrains of mapping scale, the presence of undelineated members within a formation or group, or the presence of nonuniformly occurring features, such as fracturing. This class is intended to convey a wider range of vulnerability than is usually contained within any other single class.

Subclass v (Variably covered aquifers)

The modifier "v", such as Class IIa-v, is used to describe areas where an undetermined or highly variable thickness of low permeability sediments overlie the major water-bearing zone. To provide the largest amount of information, the underlying aquifer was mapped as if the cover were absent, and the "v" designation was added to the classification. The "v" indicates that a variable thickness of low permeability material covers the aquifer and, since the thickness of the cover, to a large degree, controls vulnerability, this aspect is undefined.

Methodology

This manual is based entirely on published information. State and federal agency publications catalogs were examined to obtain information that appeared to fill the needs of the project. Several workers were assigned states in which they had actual experience to increase the accuracy of the products.

In most cases, aquifer vulnerability maps were prepared by outlining geologic units on a 1:500,000 scale base map. Each unit was assigned a classification that reflected published geologic and hydrogeologic descriptions. The geologic units were transferred to a page size map of the state, and the area of each unit was measured by planimeter.

Maps showing the distribution of precipitation were prepared by means of national climatological data that are stored on compact disks and the software package, MapMaker II. Climate data were stripped from the compact disks, and manipulated to obtain combined files of precipitation and latitude and longitude of each station. Rather than using a predetermined time interval, the entire period of record was used for each station. This data set and state/county boundary files were used as input to the MapMaker II program.

Population density maps were prepared by means of MapMaker II files. The population data are based on 1986 estimates.

Aquifer sensitivity maps represent composite illustrations in that they show the location of population centers that overlie vulnerable or Class I aquifers. Maps of this type indicate that even though the aquifer may be exceptionally vulnerable, only a small part of the system is highly susceptible to contamination, and these sites are represented by the location of municipalities, both large and small. Aquifer sensitivity maps were prepared by overlaying scanned maps of aquifer vulnerability and the latitude and longitude of cities. All population centers that fell outside of Class I aquifers were deleted.

U.S. Geological Survey reports and maps proved to be the major sources of information on potential well yield. The generalized maps were prepared by transferring published information to a map of appropriate scale. These data were then incorporated into a computer generated map

Aquifer classification units do not necessarily match at state borders. This is the result of compiling geologic and hydrologic information that was obtained for each state. Consequently, a geologic unit in one state may have been described in such a manner that it appeared to be largely, for example, unconsolidated Class Ia material. The same earth materials in an adjacent state may have been described in such a broad sense that it only could be classified as "undifferentiated" or Class U.

Scale Dependency

The maps in this report are regional in nature and provide only a broad, generalized overview of aquifer vulnerability and sensitivity. They are not designed for site specific evaluations. Detailed investigations of a county or municipal area would require a large data base, and this, in turn, would provide a greater degree of accuracy.

Oklahoma and North Dakota will serve as examples of scale dependency. The major activity in the lightly populated state of Oklahoma is agriculture, which is coupled with a meager aggregate of light industry and oil and gas production. Ground water serves as a major source of supply in several municipal and industrial environs and throughout the rural area.

An accounting of the aquifer classifications in Oklahoma indicates that of the 70,304 square miles within the state borders, 36 percent is Class I, 7.8 percent is Class II, and the remaining 61 percent is Class III. Of these, Class Ia, the most vulnerable, amounts to only 18.6 percent of the entire state.

Areas where wells will yield more than 100 gpm and those that will yield less than 25 gpm account for 36 and 64 percent of the total area, respectively.

Precipitation ranges widely, decreasing westward from nearly 58 inches in the Ouachita Mountains to less than 15 inches in the Panhandle.

The population of Oklahoma is only about 3.3 million and the greatest density is in Tulsa and Oklahoma counties. The Garber-Wellington or Central Oklahoma Aquifer, which in conjunction with surface reservoirs supplies much of Oklahoma County, is a Class IIa system that has at least a moderate degree of natural protection. Thus, despite the high population density, and the moderate precipitation and recharge, the aquifer is only slightly vulnerable to contamination from shallow injection wells, other than pervasive abandoned wells.

The flood plain of the Arkansas River, which trends through Tulsa County, is a vulnerable Class Ia unit. In the vicinity of Tulsa there is some ground-water contamination, but the aquifer presently is not used as a major source of water supply. In this case, the aquifer sensitivity is high owing to the aquifer vulnerability, population density, precipitation, and high rate of ground-water recharge, but the aquifer, for all practical purposes, is unused.

Likewise, the wide, highly vulnerable Class Ia sandy flood plain and terrace deposits along the Cimarron River, cover about 1740 square miles, but the population density is so slight that there is no significant widespread threat. In fact, urban and suburban areas encompass less than 6 square miles or .3 of 1 percent of the valley. Consequently, even though the high yield aquifer has a high degree of vulnerability to contamination, the regional aquifer sensitivity is very low.

On the other hand, when examining the Cimarron valley from the perspective of a county or a municipality, the situation is quite different. Payne County contains about 700 square miles of which nearly 177 square miles or about 25 percent consist of Class Ia materials (fig. 4). More than 70 square miles of these materials will yield no more than a gallon or two per minute (fig. 5). The high yield area in Payne County covers about 105 square miles or about 15 percent.

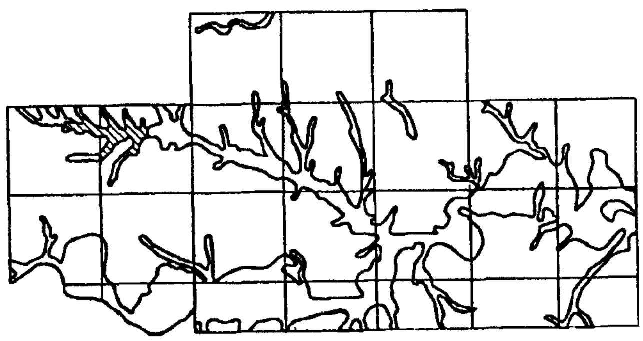


Figure 4. Aquifer vulnerability map of Payne County, Oklahoma

The village of Perkins (fig. 6), which lies entirely on permeable terrace deposits adjacent to the Cimarron, covers less than a square mile. All the municipal wells lie downgradient of several potential sources of contamination. Here both the aquifer vulnerability and sensitivity are very high.

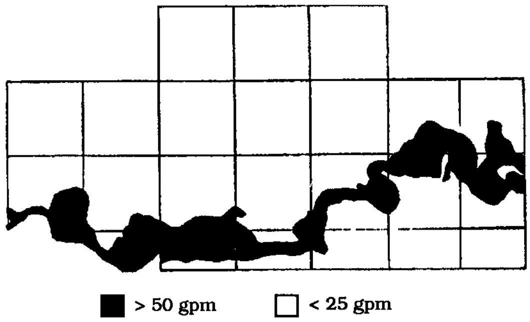


Figure 5. Potential well yield map of Payne County, Oklahoma

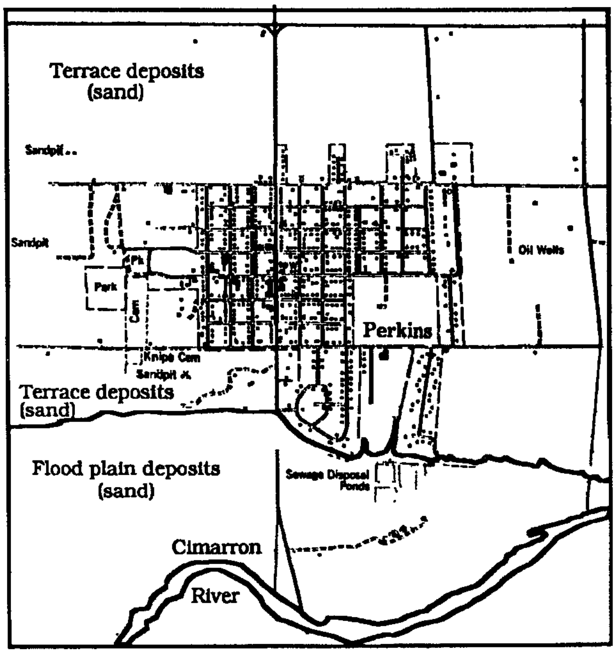


Figure 6. The village of Perkins, OK lies on highly vulnerable, sandy terrace deposits and the aquifer has a high degree of sensitivity.

North Dakota lies largely within the glaciated Northern Great Plains and, in many respects, is similar to Oklahoma. North Dakota contains about 70,700 square miles, precipitation ranges from about 13 to 22 inches annually, and the total population is about 667,000 or about 9 individuals per square mile.

All but the southwestern quarter of the state is mantled by glacial deposits. Vulnerable Class I aquifers comprise about 13 percent of North Dakota, and Class IIa and IIc make up about 36 percent. The remaining 51 percent is Class III.

Ward County, which contains about 2300 square miles and lies in the north-central part of the state, also is largely covered by glacial deposits. These deposits range widely in thickness, reaching more than 600 feet in preglacial or interglacial buried valleys, but bedrock locally crops out along several water courses. The Souris and Des Lacs rivers, which trend southeastward across Ward County, separate the relatively steep, northeast sloping two-thirds of the county from the nearly flat remainder.

Throughout most of the county, well yields are quite small, except for several buried valleys that, in places, contain a substantial thickness of sand and gravel (fig. 7). In most places, aquifers in buried valleys are covered by several tens to several

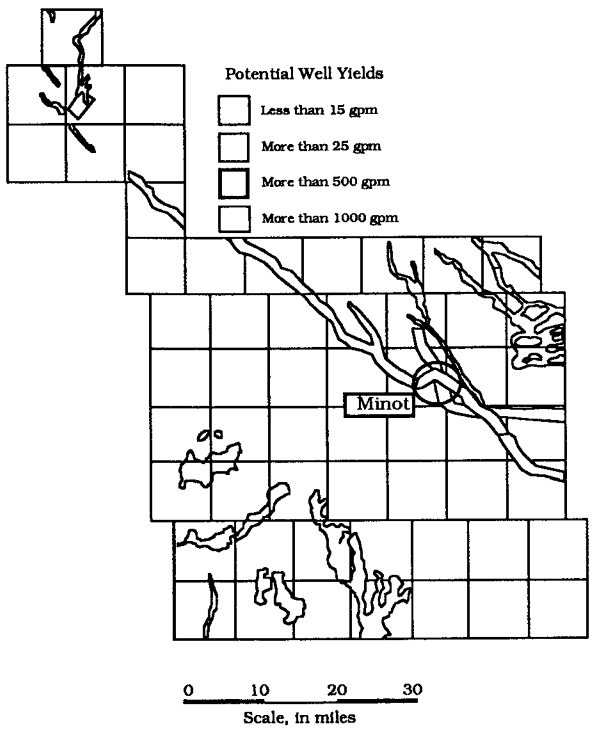


Figure 7. Potential well yield map of Ward County, ND.

hundreds of feet of glacial till. Even in present day valleys the aquifers generally are covered by till and fine-grained alluvium. Surficial outwash deposits can provide moderate supplies, but they are not widely used.

The county vulnerability map shows the location of several Class Ia outwash deposits, but most of the region consists of alternating layers of unconsolidated sand, silt, clay, and lignite of the Fort Union Formation of Paleocene age, which is covered by glacial till (fig. 8) Throughout a wide area the till is quite thick (Class III), but trending diagonally across the middle of the county is a belt of Class Id-v, which reflects a cover of glacial till of variable thickness over the Fort Union. Similarly, buried outwash in the valleys of the Souris and Des Lacs rivers is classified as Class Id-v because of the variable thickness of the cover. Thus, from the county perspective, the only areas of high vulnerability are the Class Ia aquifers.

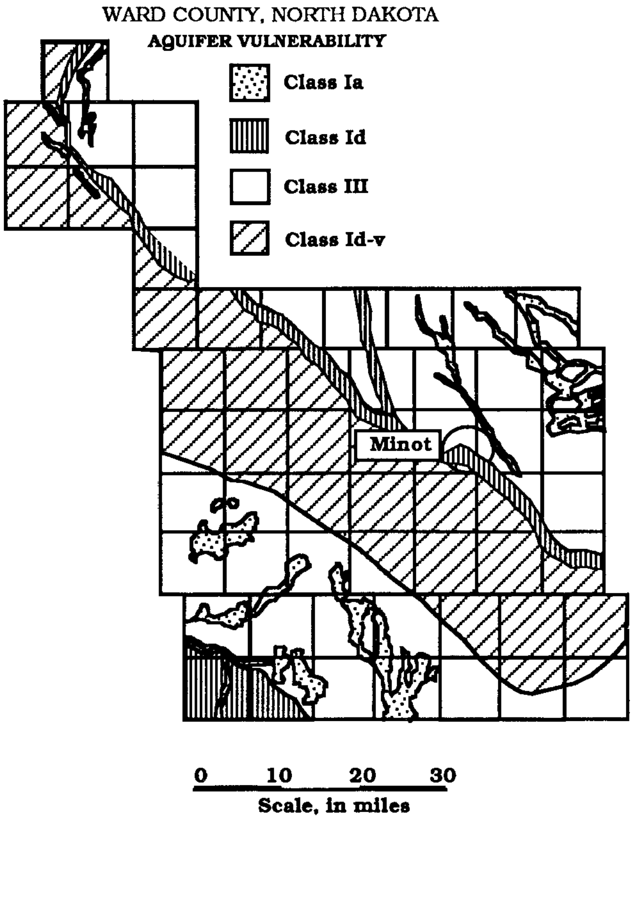


Figure 8. Aquifer vulnerability map of Ward County, ND.

A vulnerability map of the Minot area, which includes 15 square miles, indicates in greater detail the susceptibility to contamination of the buried outwash in the Souris River valley (fig. 9). At this location Minot's municipal well field taps sand and gravel that are confined within the valley walls. By means of logs of wells and test holes, it was possible to subdivide the regional Class Id-v deposits into areas listed as "critical", "caution", and "moderately safe", using as a criterion the thickness of fine-grained material overlying the aquifer. The city of Minot is spread throughout the flood plain and the adjacent bluffs. Consequently, the high population density in the area marked "critical" makes the aquifer highly sensitive to contamination, and the area shown as "caution" is only slightly less sensitive. Several municipal wells occur within these two zones.

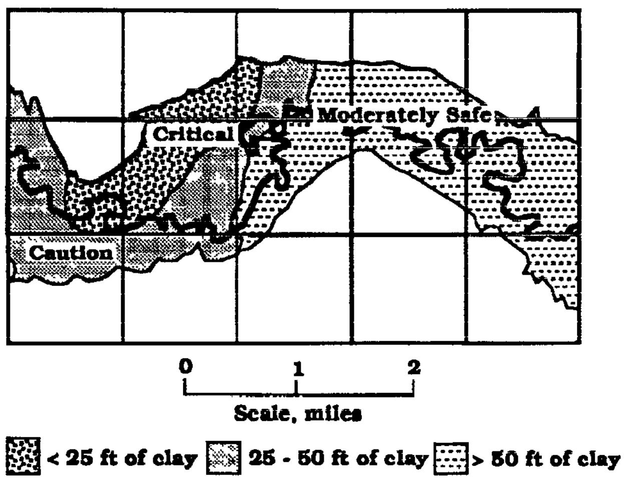


Figure 9. Aquifer vulnerability and sensitivity range widely in the area surrounding Minot's municipal well field.

The examples of Oklahoma and North Dakota indicate that the degree of accuracy and detail is closely related to the scale of mapping. The state maps of well yield, vulnerability, and sensitivity in this report were designed only for generalized regional assessments, but they can be used to determine what areas require additional evaluation.

A considerable number of individuals were involved in this project, which was under the overall direction of Wayne A. Pettyjohn. Jerry Thornhill, Robert S. Kerr Environmental Research Laboratory, served as Project Officer for the U.S. Environmental Protection Agency. Detailed management was directed by Mark Savoca, Research Associate. During the last few months of the project this responsibility was assumed by Dale Self, a research assistant.

Individuals involved in geologic and hydrogeologic assessments included Carol Becker, Tim Brandon, Scott Crouch, David Edwards, John Field, Greg McCain, Betty Pierson, Dale Self, Craig Stafford, Richard Shields, Alberta Stephenson, Rex Stout, Vanessa Tigert, and Patti Zietlow. Computer graphics were accomplished by Lana Bruggeman, Melissa Hitch, and Cindy McClellan, and areas were determined by Scott Henderson. Kelly Goff, who was in charge of all computer work, also prepared the population density and precipitation maps.

Section 2

REGIONAL EVALUATIONS

SUMMARY

Table 1 lists details concerning population, area, and water use in each of the conterminous states. These data indicate that about 42.4 percent of the population served by public water-supply systems use ground water as a source. Clearly, these subsurface reservoirs need to be protected against contamination.

About 46 percent of the land area of the conterminous United States consists of vulnerable Class I aquifers. Of this amount, 26.4 percent is Class Ia, 10.4 percent is Class Ib and Ib-v, 8.1 percent is Class Ic, and Class Id accounts for an additional 1.4 percent. The moderately vulnerable Class II aquifers cover about 14 percent of the United States, while the least vulnerable, Class III, makes up about 19 percent. The undefined systems, Class U, account for an additional 19 percent. The percentage of each class of aquifer present in each state is listed in Table 2.

Although large areas of several states consist of vulnerable Class I aquifers, aquifer sensitivity is not necessarily high. Aquifer sensitivity is related both to vulnerability and population density. In aquifer sensitivity investigations, the potential effect of population density is best viewed by means of population centers, which generally are concentrated along water courses, shorelines, and transportation routes. Consequently, the areas where ground water is most likely to become contaminated by means of shallow injection wells are in and adjacent to towns, regardless of size. For example, all of the population centers in a county may amount to only a small percentage of the total area of the county. Therefore, the areal extent of an investigation of aquifer sensitivity could be much smaller than originally anticipated.

Specific examples of ground-water contamination are not described in this report. A review of examples, however, would show that no state is free from contamination. Moreover, no example is unique to any one state.

State	Population x 1000	Area Square Miles	Percent of Population Using Ground Water	Daily Fresh Ground Water Use mgd	Daily Saline Ground Water Use mgd
Alabama	4102	51705	35	343	3.4
Arizona	3489	114000	62	3090	8.4
Arkansas	2395	53187	48	3810	0.0
California	28314	158706	67	14800	284.0
Colorado	3301	104091	15	2310	32.0
Connecticut	3233	5018	19	144	0.0
Delaware	660	2044	53	79	0.0
Florida	12335	58664	89	4050	0.0
Georgia	6342	58910	31	1000	0.0
Idaho	1003	83564	87	4800	0.0
Illinois	11614	56345	39	930	38.0
Indiana	5556	36185	49	635	0.0
Iowa	2834	56275	74	671	0.0
Kansas	2495	82277	50	4800	0.0
Kentucky	3727	40409	11	205	0.0
Louisiana	4408	47752	50	1430	5.6
Maine	1205	33265	26	66	0.0
Maryland	4662	10460	17	219	0.0
Massachusetts	5889	8284	30	315	0.0
Michigan	9240	58527	19	596	4.5
Minnesota	4307	84402	69	685	0.0
Mississippi	2620	47689	92	1580	0.0
Missouri	5141	69697	36	640	0.3
Montana	805	147046	37	203	0.0

Table 1. Population, area, and water use.

State	Population x 1000	Area Square Miles	Percent of Population Using Ground Water	Daily Fresh Ground Water Use mgd	Daily Saline Ground Water Use mgd
Nebraska	1602	77355	89	5590	0.0
Nevada	1054	110561	34	905	2.8
New Hampshire	1085	9279	33	84	0.0
New Jersey	7721	7787	42	667	0.1
New Mexico	1507	121593	86	1510	0.0
New York	17909	49108	26	1100	0.0
North Carolina	6489	52669	23	435	0.0
North Dakota	667	70702	50	127	0.0
Ohio	10855	41330	32	730	0.1
Oklahoma	3242	69956	24	568	0.0
Oregon	2767	97073	22	660	0.0
Pennsylvania	12001	45308	16	799	0.0
Rhode Island	993	1212	17	27	0.0
South Carolina	3470	31113	24	274	0.0
South Dakota	713	77116	79	249	0.0
Tennessee	4895	42144	37	444	0.0
Texas	16841	266807	45	7180	229.0
Utah	1690	84899	65	790	25.0
Vermont	557	9614	31	37	0.0
Virginia	6015	40767	14	341	0.2
Washington	4648	68139	42	1220	0.0
West Virginia	1876	24231	28	227	0.0
Wisconsin	4855	56153	54	570	0.0
Wyoming	479	97803	44	504	23.0

Table 1. Continued

State	Total Area	Ia	Ib	Ibv	Ic	Id	IIa	IIav	IIb	IIbv	IIc	III	U	Uv
Alabama	51705	11.3	10.9		35.7				13.6			6.9	11.9	9.7
Arizona	114000	27.7	7.2		9.4				43.4			12.3		
Arkansas	53187	50.8	16.7		0.6							11.8	20.5	
California	158706	32.1	16.8		8.9				5.4			34.6	2.2	
Colorado	104091	9.8	0.2		15.8		5.8		18.9		0.4	36.7	12.4	
Connecticut	5018	38.8		4.8						8.4				48
Delaware	2044	92.4	0.2						7.4					
Florida	58664	42	25.1		30.7	6						15.3	2.1	
Georgia	58910	13	17.5		30.1				1.2			1.1	3	34.3
Idaho	83564	38.4	31.3	0.8			5.4					23.7		
Illinois	56345	13.8	0.6		0.8	3.9			1.3		25.1	51.5	3	
Indiana	36185	27.2	6.1	3.4		3			7.7	7.3	2.7	38.7	3.9	
Iowa	56275	14.3	11.9	22.5			0.2					51.1		
Kansas	82277	28.8			24		4.4		11.2	1		30.7		
Kentucky	40409	10.1	12.7		1.31	1.1			32.4				42.3	
Louisiana	47752	39.7			16.8							2.2	39.5	
Maine	33265	19.9		2.9								1.6	3.8	71.8
Maryland	10460	55.7	7.1				1.3		9.8					26.2
Massachusetts	8284	29.4		3.9				3.2						63.5
Michigan	58527	13.6		11.5				15.7		4.8		48.3		6
Minnesota	84402	21.7				2.9					2.8	58.6		12.9
Mississippi	47689	39.5	1.5		35.7	6						15.3	2.1	
Missouri	69697	18.3	44	5.2	0.5		0.7		7.7	21.5			2	
Montana	147046	16.4	5.2		5.7				34.6			38		

Table 2. Percent of state area covered by each vulnerability class.

State	Total Area	Ia	Ib	Ibv	Ic	Id	IIa	IIav	IIb	IIbv	IIc	III	U	Uv
Nebraska	77355	20.9		5.2	57.2			5				8.1		3.6
Nevada	110561	50.9	7.4									41.71		
New Hampshire	9279	25.7												74.3
New Jersey	7787	53.3	6.3	8.4	3.3				1.9	1.9		9.1	8.8	7
New Mexico	121593	30.2	1.1		7.4		6.4					54.9		
New York	49108	23.9		15.2				6.5		17.9		36.5		
North Carolina	52669	38.5	1.2		6.1							3.2		51
North Dakota	70702	15					28.2				8.8	48		
Ohio	31330	11.4	0.5			35.6			22.2		9.6	20.6		
Oklahoma	69956	18.1	4.7		8.3		8.1					60.8		
Oregon	97073	7.5	44.5	0.6	13.9							33.5		
Pennsylvania	45308	8.5	8.3	0.9					55	22.1		1.1	4	
Rhode Island	1212	42.1			0.1									56.3
South Carolina	31113	41.1	6.9		15.2									36.1
South Dakota	77116	28.5			9.6		1.9		15.4			44.6		
Tennessee	42144	11.4	24.4		4.1	10			10.9			1.2	32.8	5.3
Texas	266807	24.5	13.2		24.6							25.3	5.9	
Utah	84899	13.3	10.7		6.9		27.3	2.1	6.6			18.3	11.7	
Vermont	9614	20.1	1.2							6.9				69.4
Virginia	40767	24.1	23.3				3.3		48.3				0.9	
Washington	68139	16.7	13.4	19	4.5							46.4		
West Virginia	24231	7.4	2.7				39.1		7.5			0.3	43.1	
Wisconsin	56153	16.3		9.5									64.6	
Wyoming	97803	13.9			12.9				4				32.2	

Table 2. Continued.

CLASSIFICATION		GENERAL DESCRIPTION	EXAMPLE AQUIFER TYPES
CLASS I HIGH VULNERABILITY	Ia	● Unconsolidated Deposits	● Alluvial, terrace, beach, glacial outwash
	Ib	● Highly fractured ● Soluble Aquifers	● Soluble carbonate, fractured limestone, karst, fractured consolidated or crystalline
	Ic	● Semiconsolidated Deposits	● Partially indurated sand and clay
	Id	● Covered Aquifer Classification	● Ia, Ib or Ic overlain by < 50' of low permeability deposits
CLASS II MODERATE VULNERABILITY	IIa	● High Yield > 50 GPM Consolidated Bedrock	● Consolidated sedimentary or crystalline rock
	IIb	● Low Yield < 50 GPM Consolidated Bedrock	● Consolidated sedimentary or crystalline rock
	IIc	● Covered Aquifer Classification	● IIa or IIb overlain by < 50' of low permeability deposits
CLASS III LOW VULNERABILITY	III	● Not a principal Aquifer	● Shale, clay, glacial till
CLASS U WIDE RANGE OF VULNERABILITY	U	● Undifferentiated ● Undivided	● Crystalline aquifers ● Heterogeneous aquifers ● Thin alternating layers
THE MODIFIER	"-_v"	● Covered Aquifer Classifications	● Ia, Ib, Ic, IIa, IIb, or U overlain by a

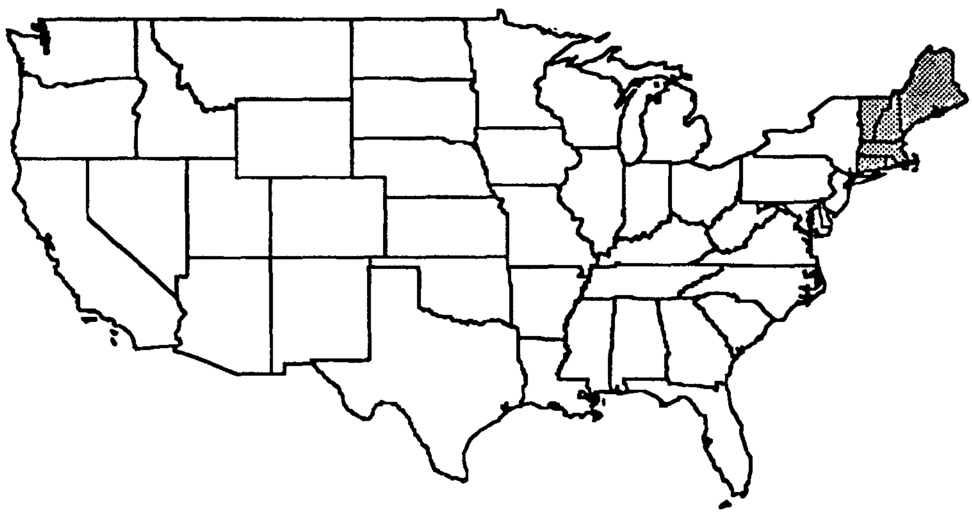
COVERED AQUIFER CLASSIFICATIONS

Any aquifer that is overlain by low permeability deposits

LOW PERMEABILITY DEPOSITS	
Clay	Glacial till
Loess	Lake Clay

	Cover Thickness	Classification
Id	Less than 50' thick	Class I
IIc	Less than 50' thick	Class II
U-v	Variable thickness for both	Class U
_-v	Variable thickness for both	Class I, II, U

Table 3. Explanation of aquifer classifications.



REGION 1

Connecticut
Maine
Massachusetts
New Hampshire
Rhode Island
Vermont

CONNECTICUT

General Setting

Connecticut contains approximately 5,018 square miles, and lies within the Connecticut Valley Lowland, and Seaboard Lowland sections of the New England physiographic province. The Connecticut Valley Lowland, which extends north-south through central Connecticut, is underlain by Lower Mesozoic sedimentary and igneous extrusive rocks that have been heavily faulted. Topographic relief is low except for resistant ridges formed by extrusive rock. The remainder of the state, characterized by a gently rolling topography, is underlain by Precambrian to Middle Paleozoic age metamorphic and extrusive igneous rocks, which have been extensively folded and faulted. With the exception of local bedrock outcrops, Connecticut is overlain by Pleistocene age glacial deposits of varying lithology and thickness.

Connecticut is drained principally by the Housatonic, Quinnipiac, Connecticut, and Thames rivers, all of which flow generally north to south and empty into Long Island Sound. Average annual precipitation in the state, about 47 inches, is distributed fairly evenly throughout the year. Connecticut's population, approximately 3.2 million, is concentrated along the southern coast and the central part of the state. Daily use of fresh ground water amounts to about 144 million gallons.

Unconsolidated Aquifers (Class Ia)

Stratified drift aquifers are exposed extensively in north-central Connecticut and intermittently throughout the rest of the state. They consist of unconsolidated sand and gravel and commonly are interbedded with lenses of silt and clay. Well yields generally range from 50 to 500 gpm, and may exceed 2,000 gpm. Also included in this class are gravel and sand-rich alluvial deposits, which are exposed locally in the central part of the state. Specific well yields for alluvial deposits were not cited. About 39 percent of Connecticut is covered by Class Ia aquifers.

Variably Covered Soluble and Fractured Bedrock Aquifers (Class Ib-v)

Soluble bedrock aquifers overlain by an undetermined thickness of glacial till occur in western Connecticut. The bedrock consist of Early Paleozoic age marble and dolomite marble, with some schist and quartzite zones. Well yields commonly range from 1 to 50 gpm, and may exceed 200 gpm. Fractured bedrock aquifers overlain by a variable thickness of glacial till occur in central Connecticut. These Jurassic age fractured rocks consist of basalt and diabase flows and dikes. Well yields commonly range from 2 to 50 gpm, and may exceed 500 gpm. The overlying glacial till consist of a heterogeneous mixture gravel, sand, clay, and silt. The vulnerability of this system is a function of the thickness of the overlying till. Class Ib-v aquifers occupy approximately 5 percent of the state.

Variably Covered Low Yield Bedrock Aquifers (Class IIb-v)

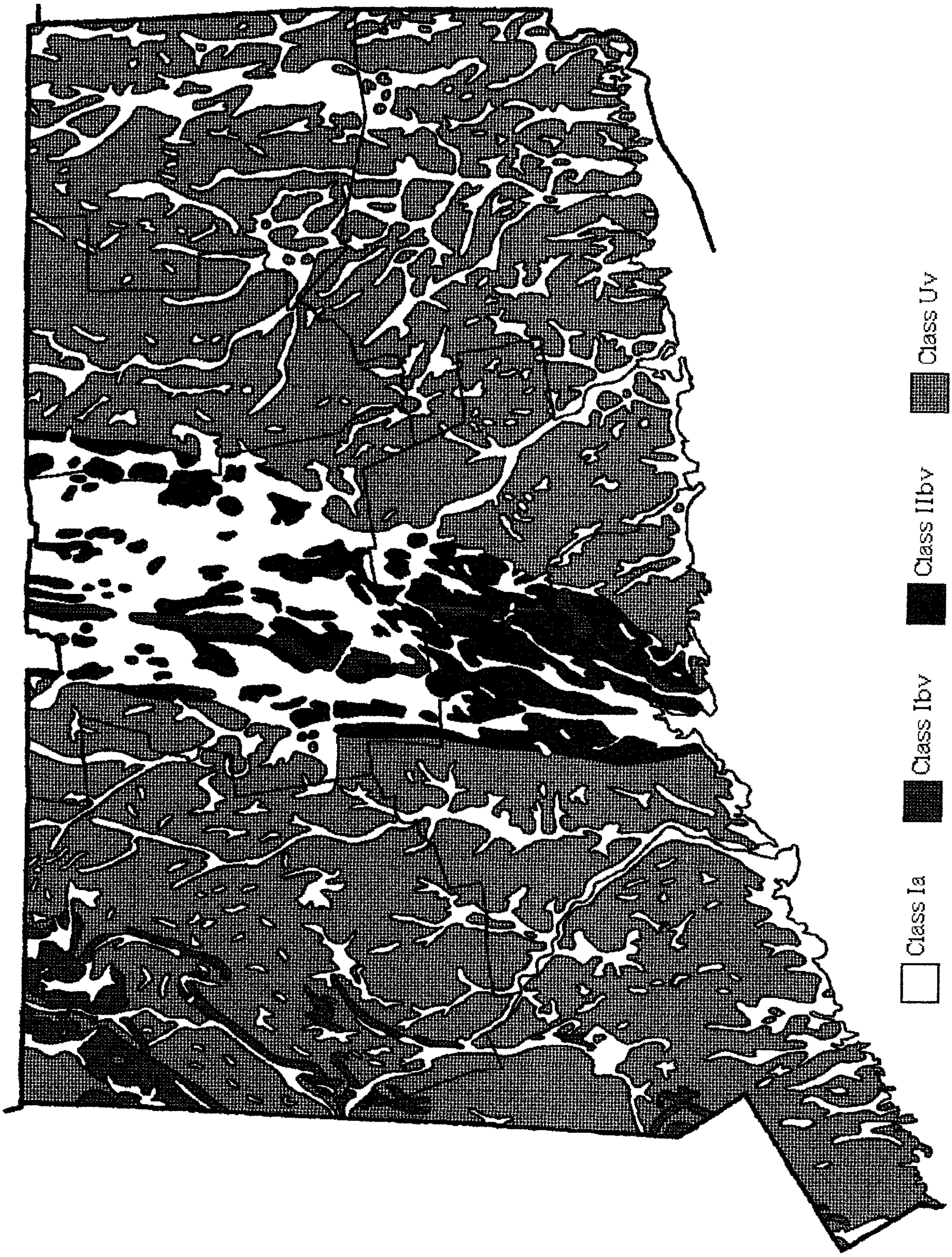
Low yield bedrock aquifers that are covered by a variable thickness of glacial till occur in the central part of Connecticut. The Triassic to Jurassic age bedrock consist of sandstone, shale, siltstone, and conglomerate. Well yields commonly range from 2 to 50 gpm, and may exceed 500 gpm. Variably covered low yield bedrock aquifers occupy about 8 percent of the state.

Variably Covered Undifferentiated Bedrock Aquifers (Class U-v)

Variably covered undifferentiated crystalline aquifers occur throughout Connecticut. These Precambrian to Middle Paleozoic age rocks include gneiss, schist, granite, and quartzite. Overlying them is a variable thickness of glacial till. Well yields commonly range from 1 to 25 gpm, and may exceed 200 gpm. About 48 percent of Connecticut is occupied by variably covered undifferentiated bedrock aquifers.

Sensitivity

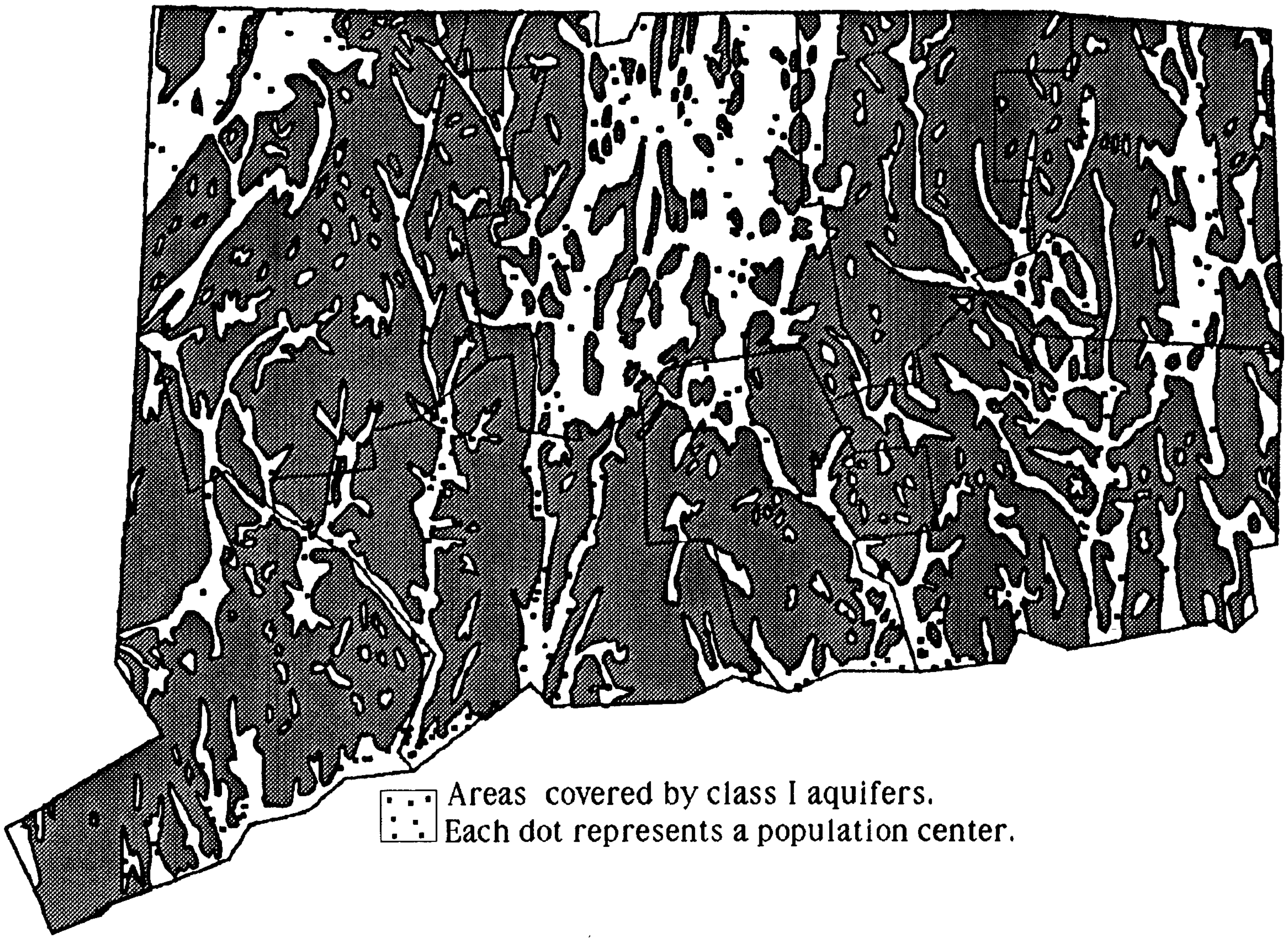
About 44 percent of Connecticut is covered by vulnerable Class I aquifers. The areas most sensitive to contamination from shallow injection wells generally occur along water courses that contain permeable deposits of sand and gravel, and these are widely distributed throughout the state.

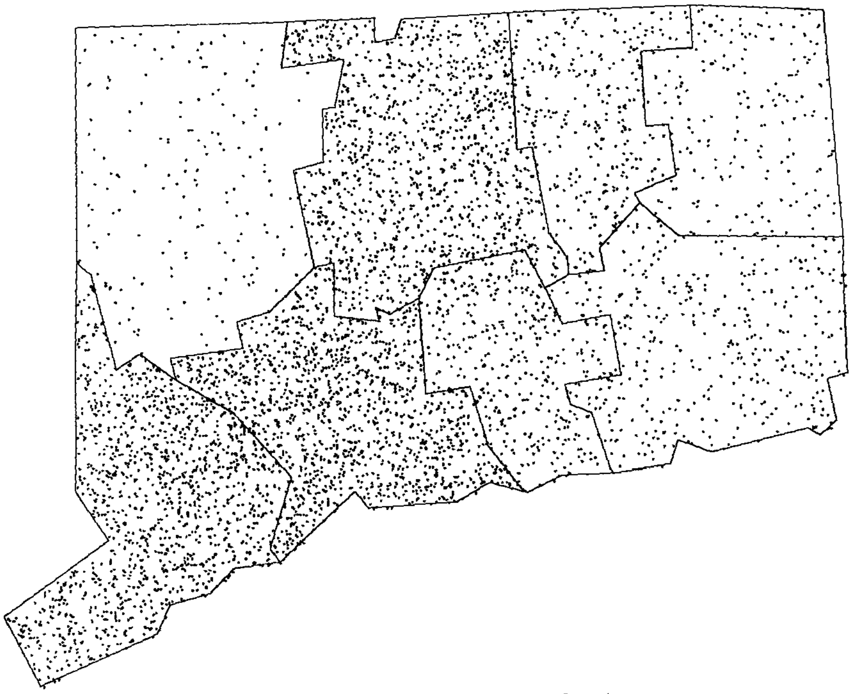


Aquifer Vulnerability Map of Connecticut

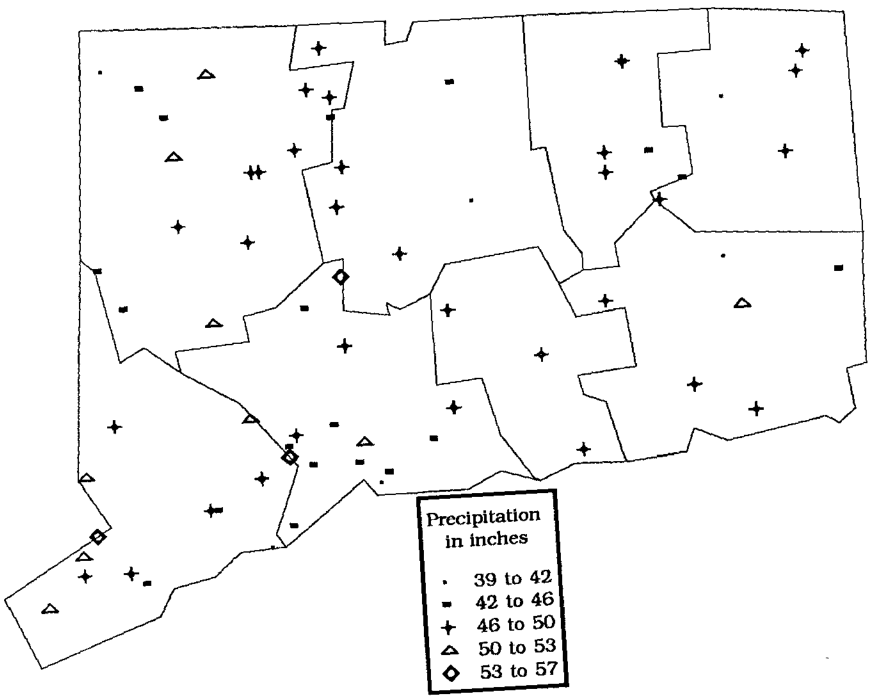
Potential Well Yields in Connecticut

Aquifer Sensitivity Map of Connecticut





Population Density of Connecticut
(Dot equals one person per square mile)



Average Annual Precipitation in Connecticut

MAINE

General Setting

Maine, which contains approximately 33,200 square miles, lies within the New England physiographic province of the Appalachian Highlands. The topography ranges from gently rolling in southwestern Maine to mountain regions elsewhere. Many surficial features were formed or modified during Pleistocene glaciation. The majority of Maine is underlain by structurally complex igneous and metamorphic rocks with minor amounts of rather hard and dense sedimentary rock. With the exception of a few local bedrock outcrops, the state is overlain by glacial deposits of varying lithology and thickness.

Northern Maine is drained by the northeast-flowing St. John River and its tributaries. The remainder of the state is drained by the south-flowing Androscroggin, Kennebec, Penebscot, and St. Croix rivers. Annual precipitation ranges from 34 inches in the northeast to 55 inches in the north-central mountains. The average precipitation, 42 inches, is distributed somewhat uniformly throughout the year. The majority of Maine's population, approximately 1.2 million, is located in the southern part of the state in the vicinity of Portland, Lewiston, and Augusta. The remainder of the state is sparsely populated. Daily use of fresh ground water is about 66 million gallons.

Unconsolidated Aquifers (Class Ia)

Glaciofluvial aquifers are exposed intermittently throughout Maine and form some of the most vulnerable aquifers in the state. Glacial outwash aquifers consist of stratified sand and gravel with minor amounts of silt, clay, and cobbles. Well yields commonly range from 10 to 100 gpm, and may exceed 2,000 gpm. Glacial ice-contact deposits consist of well- to poorly-stratified sand, gravel, and cobbles with some silt, clay, and boulders. Well yields commonly range from 50 to 1,000 gpm, and may exceed 3000 gpm. Also included in Class Ia are small exposures of Quaternary age alluvium, stream terrace, and alluvial fan deposits, all of which consist of sand, gravel, and silt. About 20 percent of Maine is covered by Class Ia aquifers.

Variably Covered Soluble and Fractured Bedrock Aquifers (Class Ib-v)

A soluble bedrock aquifer, which is overlain by an undetermined thickness of glacial till, occurs in northeast Maine. This Ordovician to Silurian age carbonate bedrock unit consists of limestone, calcareous shale, and calcareous siltstone. The overlying glacial till consists of a heterogeneous mixture of sand, silt, and clay with some boulders. The vulnerability of this system is a function of the thickness of the overlying till. Well yields commonly range from 10 to 30 gpm and may exceed 600 gpm. Class Ib-v aquifers occupy about 3 percent of the state.

Undifferentiated Aquifers (Class U)

With the exception of the carbonate bedrock unit in the northeast, Maine is underlain by lithologically varied Precambrian and Paleozoic age crystalline rock. Some of the rocks include schist, gneiss, quartzite, and slate. These rocks are relatively impermeable, but they do contain recoverable water in secondary openings, such as fractures and joints. Surface exposures of crystalline bedrock occur locally throughout the state. Well yields commonly range from 2 to 10 gpm, and may exceed 500 gpm. Surface exposures of undifferentiated crystalline bedrock occupy approximately 4 percent of the state.

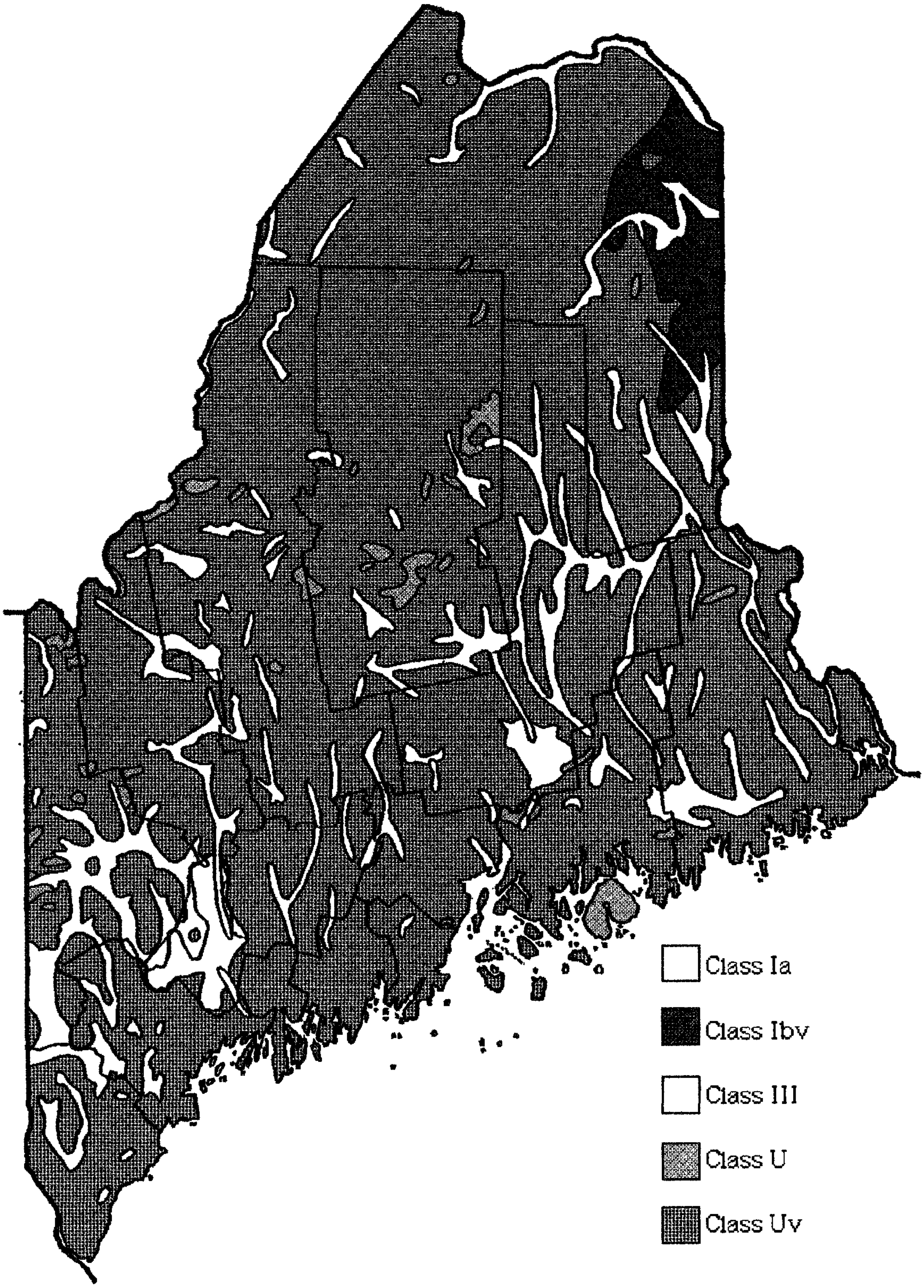
Variably Covered Undifferentiated Aquifers (Class U-v)

Variably covered undifferentiated crystalline aquifers occur extensively throughout the state. Overlying the crystalline bedrock is variable thickness of glacial till, which consist of sand, silt, clay, and boulders. The vulnerability of these systems is a function of the thickness of the till. Well yields commonly range from 2 to 10 gpm, and may exceed 500 gpm.

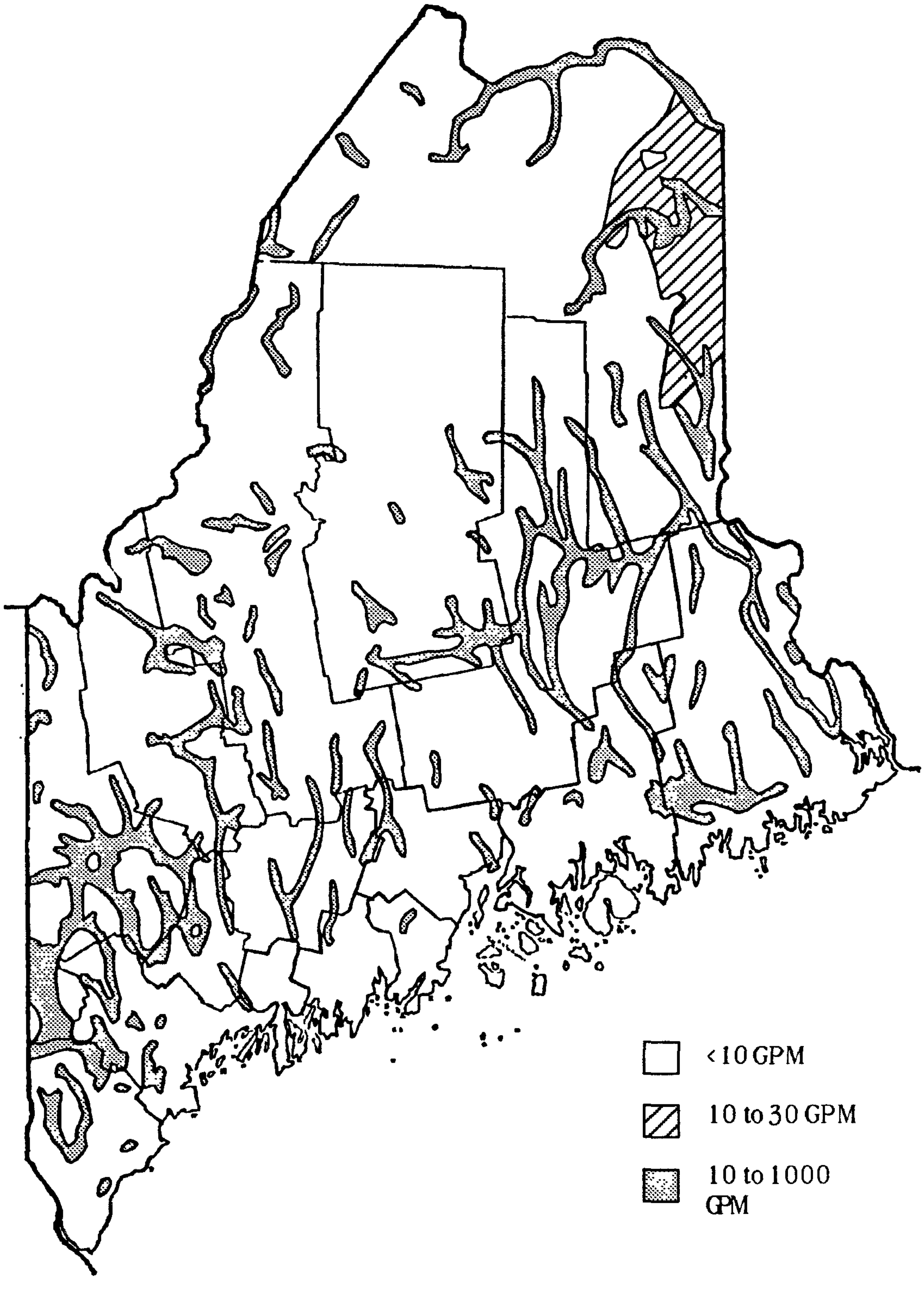
About 72 percent of Maine is underlain by variably covered undifferentiated crystalline bedrock aquifers.

Sensitivity

About 23 percent of Maine is covered by Class I aquifers. The most sensitive of these aquifers lie along water courses that contain sand and gravel. Owing to the relatively low population density, the potential for ground-water contamination from shallow injection wells is quite small. In northeastern and southwestern Maine a considerable number of population centers lie on vulnerable aquifers.

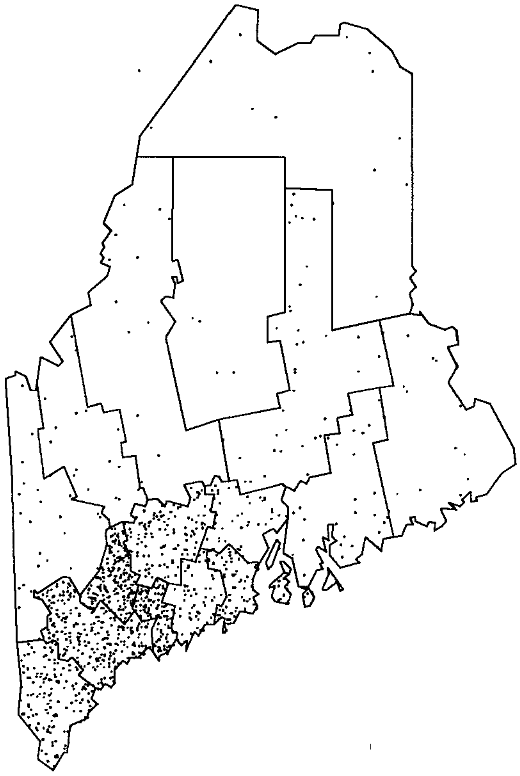


Aquifer Vulnerability Map of Maine

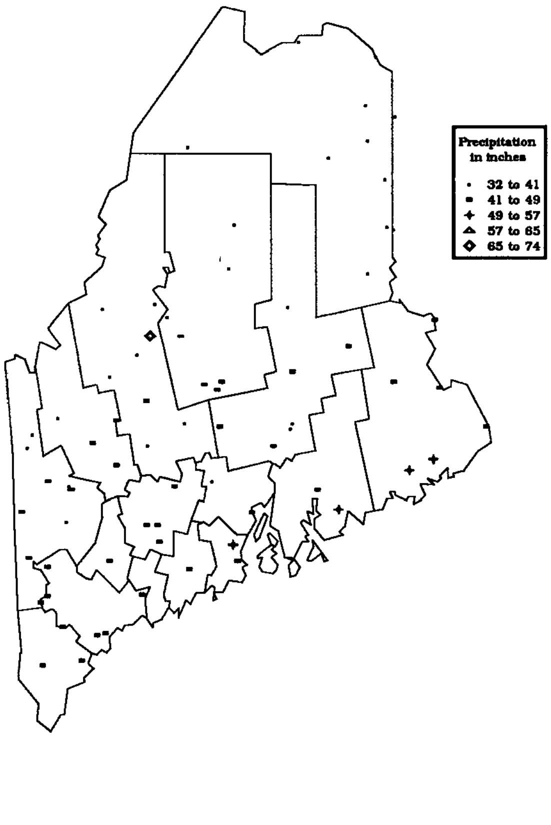


Potential Well Yields in Maine

Aquifer Sensitivity Map of Maine



Population Density of Maine (Dot equals one person per square mile)



Average Annual Precipitation in Maine

MASSACHUSETTS

General Setting

Massachusetts contains approximately 9300 square miles. The extreme southeastern part of the state, including Cape Cod, Martha's Vineyard and Nantucket, lies within the flat lying Coastal Plain physiographic province. The remainder of the state is in the New England Upland province, which contains gently rolling hills in the east that give way to increased topographic relief westward. The Coastal Plain is covered by thick sequences of unconsolidated glacial outwash and Holocene age beach deposits that dip gently eastward. The majority of the New England Upland is underlain by faulted and folded Precambrian to Jurassic age metamorphic and igneous crystalline rocks. Precambrian to Ordovician age limestone, dolomite, and marble underlie the western part of the state, and Triassic and Jurassic age sedimentary rocks occur in the west-central part. The entire New England Upland is mantled by glacial outwash and till of variable thickness.

The northeastern part of Massachusetts is drained by a network of northeast-flowing rivers, while elsewhere the state is drained by several south-flowing rivers. Annual precipitation averages about 45 inches and is distributed fairly evenly throughout the year. The majority of Massachusetts' population, approximately 5.9 million, is concentrated in the eastern part of the state. The remainder of the state is moderately populated. About 315 million gallons of fresh ground water are used daily in Massachusetts.

Unconsolidated Aquifers (Class Ia)

Mantling the Coastal Plain in southeastern Massachusetts are glacial outwash, delta, beach and dune deposits, and glacial till. This continuous mass of unconsolidated material forms a vulnerable and productive aquifer. The aquifer consists of sand, gravel, and silt with minor amounts of clay and boulders. Locally exposed throughout the state are small but very permeable valley-fill aquifers that were deposited by glacial meltwaters and recent streams. These unconsolidated sediments consist of stratified sand and gravel with some silt. Well yields commonly range from 100 to 1,000 gpm, and may exceed 2,000 gpm. Approximately 29 percent of the state is overlain by unconsolidated aquifers.

Variably Covered Soluble and Fractured Bedrock Aquifers (Class Ib-v)

Variably covered soluble aquifers occur in far western Massachusetts. The Cambrian to Ordovician age bedrock, which is covered by till, consists of limestone, dolomite, and marble units that are interbedded with schist and quartzite. Where present, solutional features contribute to the vertical and lateral permeability of the rock. The vulnerability of these systems is a function of the thickness and permeability of the overlying glacial till. Well yields commonly range from 1 to 50 gpm, and may exceed 1,000 gpm. Nearly 4 percent of the state is occupied by Class Ib-v aquifers.

Variably Covered Higher Yield Bedrock Aquifers (Class IIa-v)

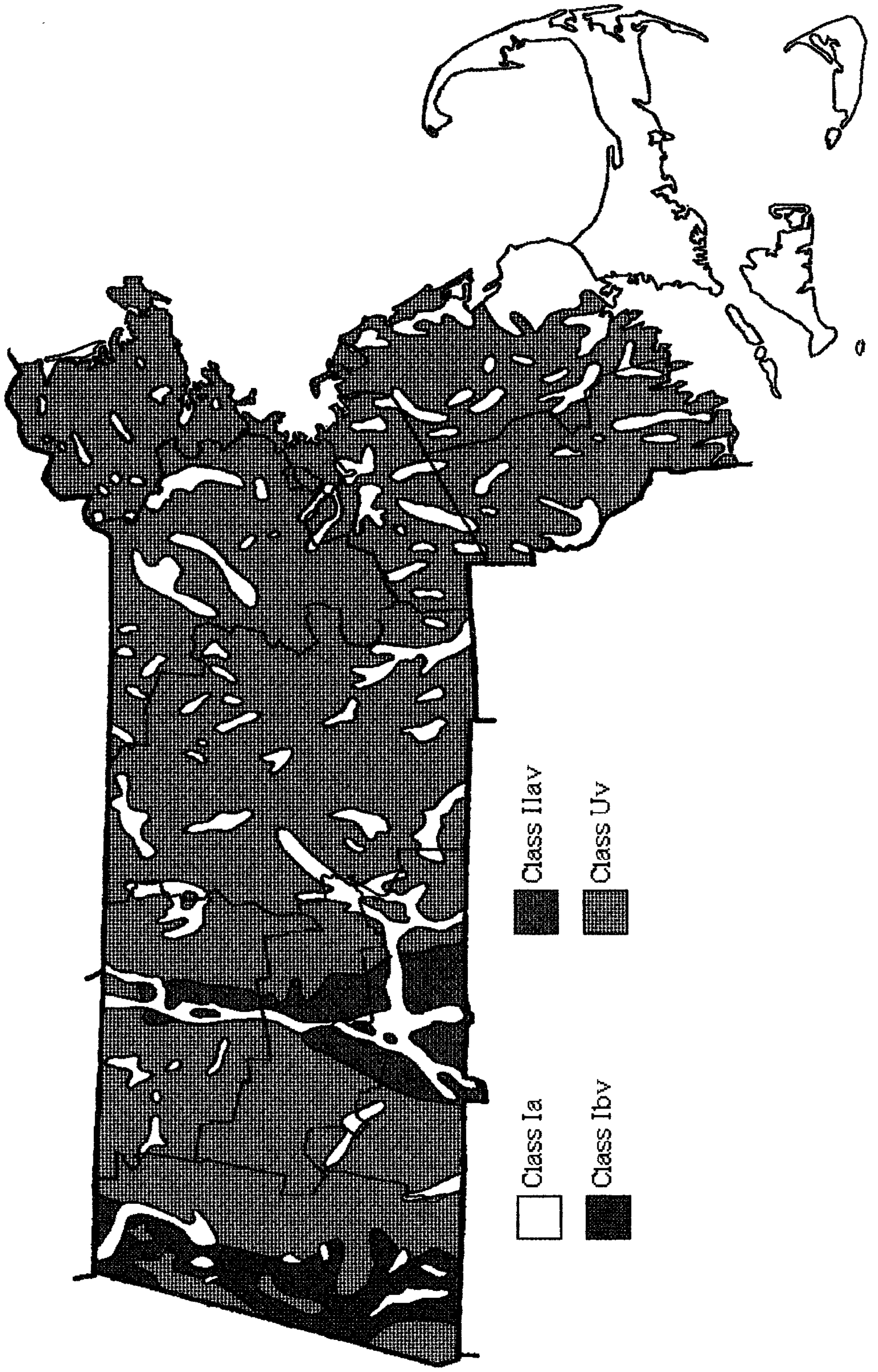
Higher yield bedrock aquifers, which are covered by a variable thickness of till, occur in the central part of the state. The underlying Triassic and Jurassic age bedrock consists of sandstone, shale, arkosic conglomerate, and basaltic lava flows. Well yields commonly range from 10 to 100 gpm, and may exceed 500 gpm. The vulnerability of these systems is a function of the thickness of the overlying low permeability sediments. About 3 percent of Massachusetts is occupied by Class IIa-v aquifers.

Variably Covered Undifferentiated Aquifers (Class U-v)

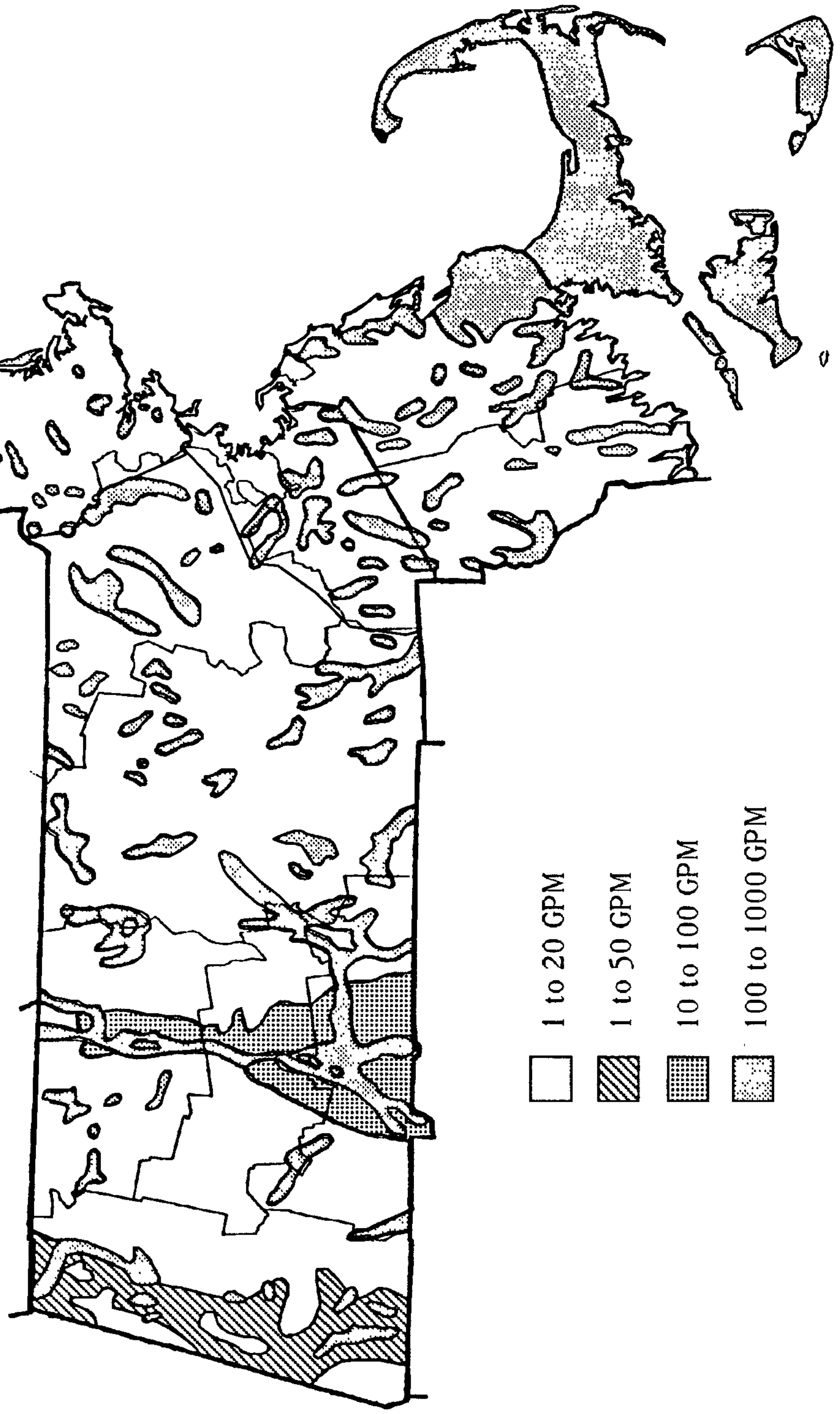
Occurring in the majority of the state are variably covered undifferentiated aquifers. The underlying bedrock consists largely of Precambrian to Paleozoic age crystalline rock. The bedrock is covered by a variable thickness of glacial till. Aquifer vulnerability is a function of the thickness and permeability of the overlying glacial till. Well yields commonly range from 1 to 20 gpm, and may exceed 300 gpm. Nearly 64 percent of the state is occupied by Class U-v aquifers.

Sensitivity

About 33 percent of Massachusetts is covered by vulnerable Class I aquifers. Along major river valleys and Cape Cod there is a considerable number of population centers. These areas have a high degree of sensitivity. Elsewhere within the state the potential for ground-water contamination from shallow injection wells is relatively low.

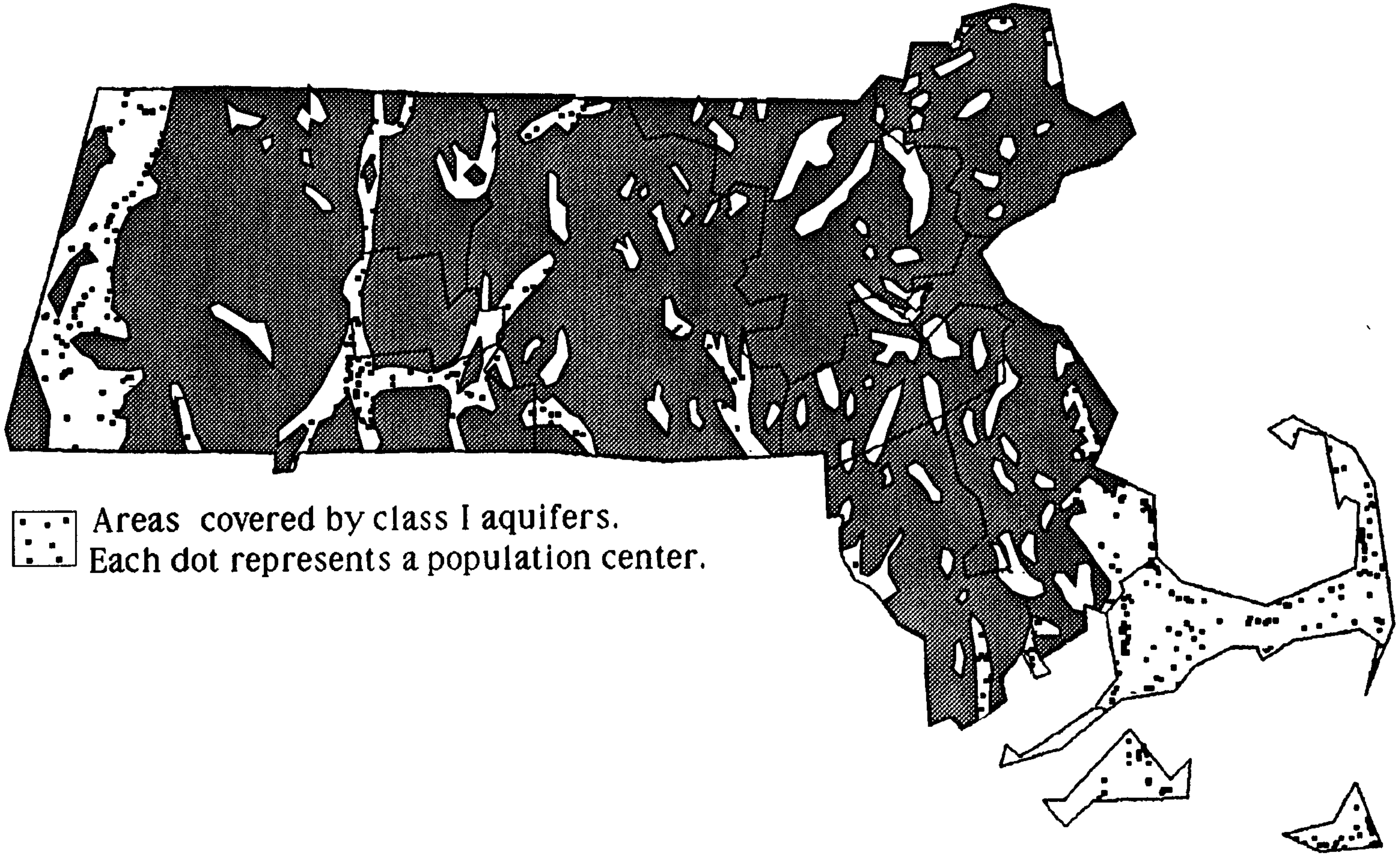


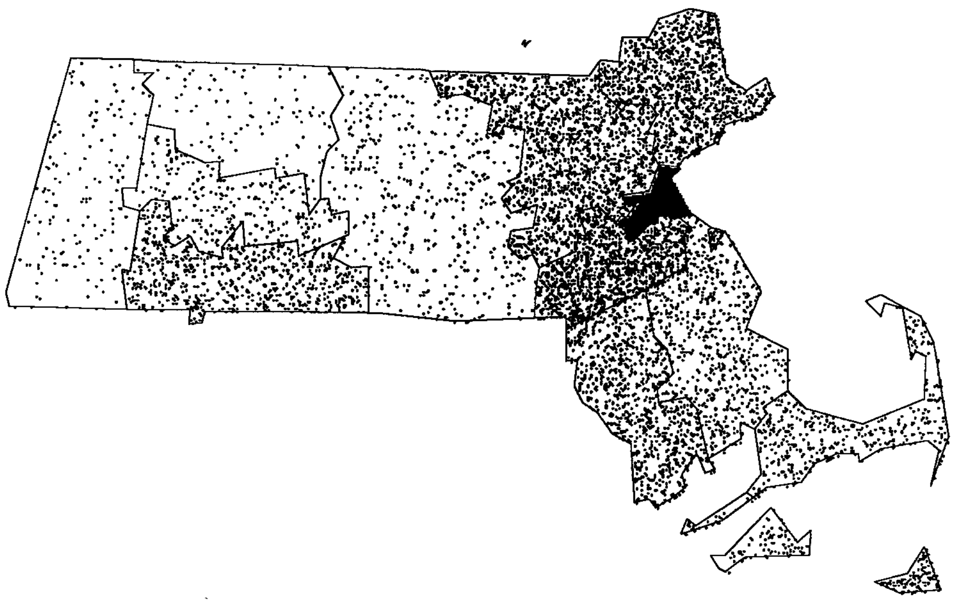
Aquifer Vulnerability Map of Massachusetts



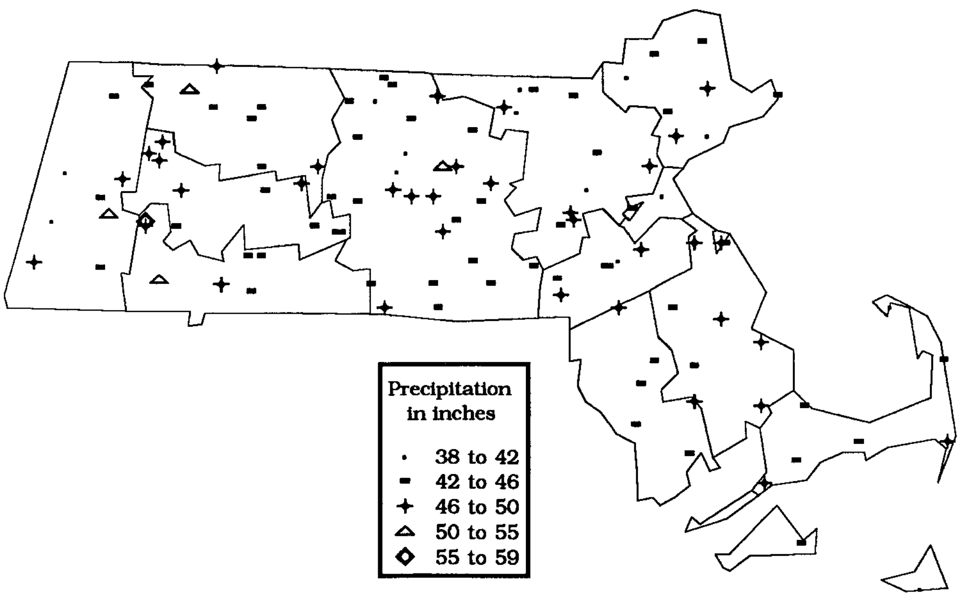
Potential Well Yields in Massachusetts

Aquifer Sensitivity Map of Massachusetts





Population Density of Massachusetts (Dot equals one person per square mile)



Average Annual Precipitation in Massachusetts

NEW HAMPSHIRE

General Setting

New Hampshire, which lies within the Seaboard Lowland, New England Upland, and White Mountain sections of the New England physiographic province, contains nearly 9300 square miles. The topography varies from gently rolling hills to rugged mountains. Bedrock consists of faulted and folded Precambrian and Paleozoic age metasedimentary and intrusive igneous rocks. The crystalline bedrock is overlain by Pleistocene deposits of variable lithology and thickness. Glacial deposits generally are thicker in the lowlands and valleys than they are on the upland mountainous regions.

The extreme western part of the state is drained by the south-flowing Connecticut River. The Merrimack River, which also flows generally southward, drains the central part of New Hampshire. Several easterly flowing water courses drain the eastern part of the state. Annual precipitation averages about 43 inches, ranging from about 34 inches in the Connecticut River Valley to more than 80 inches in the White Mountains, which are located in the north-central part of the state. The precipitation is distributed fairly evenly throughout the year. The majority of New Hampshire's population, approximately 1,085,000, is located in the southeast part of the state and the remainder of the state is sparsely populated. Use of fresh ground water amounts to about 27 mgd.

Unconsolidated Aquifers (Class Ia)

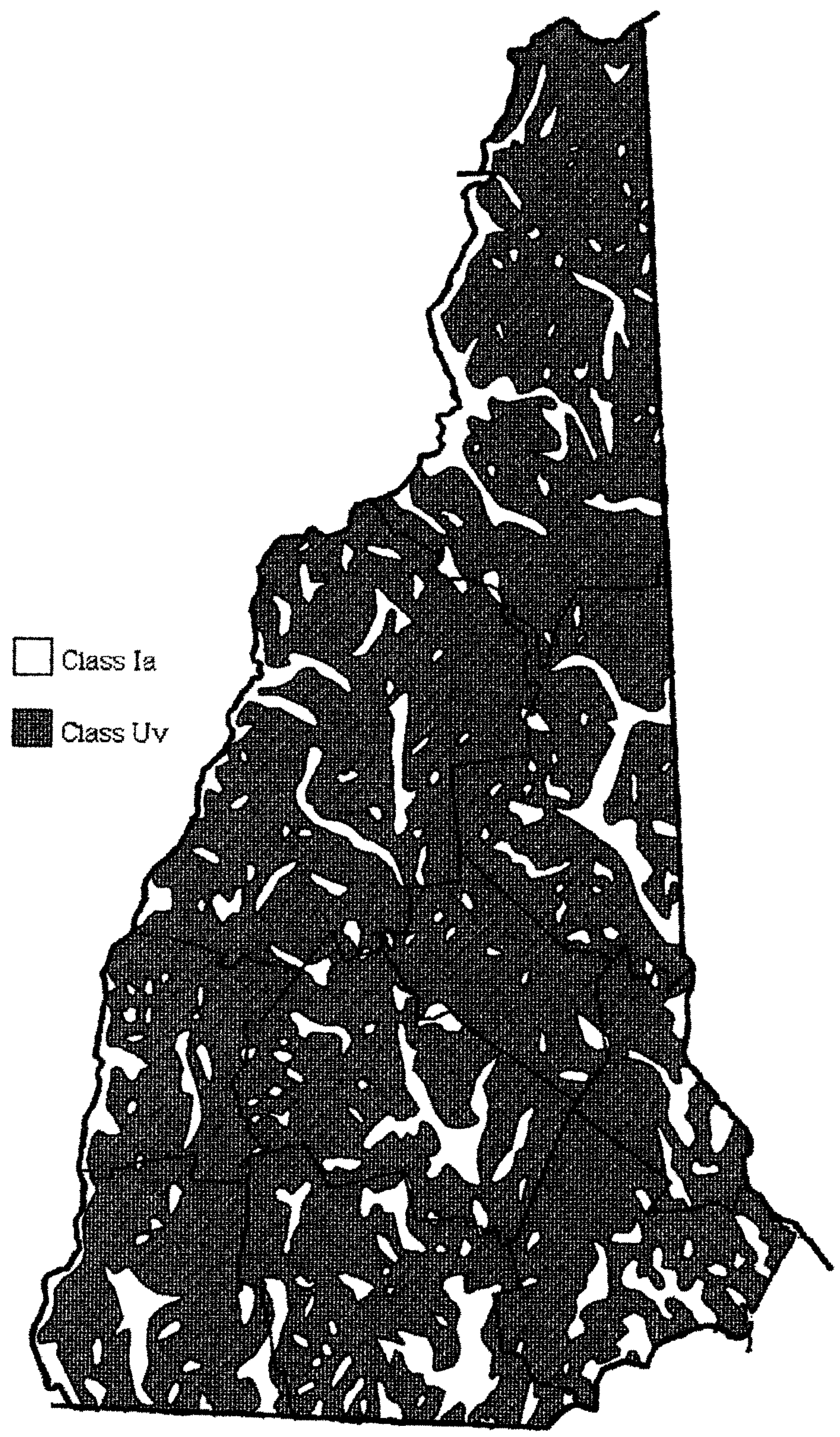
Stratified drift aquifers are exposed intermittently throughout New Hampshire and form vulnerable and productive aquifers. These aquifers consist of unconsolidated glaciofluvial sand or sand and gravel. Included in this class are finer-grained lacustrine deposits, stratified outwash, and coarser grained, higher yielding ice-contact deposits. Well yields commonly range from 100 to 500 gpm, and may exceed 600 gpm. Approximately 26 percent of New Hampshire is covered by unconsolidated stratified drift aquifers

Variably Covered Undifferentiated Aquifers (Class U-V)

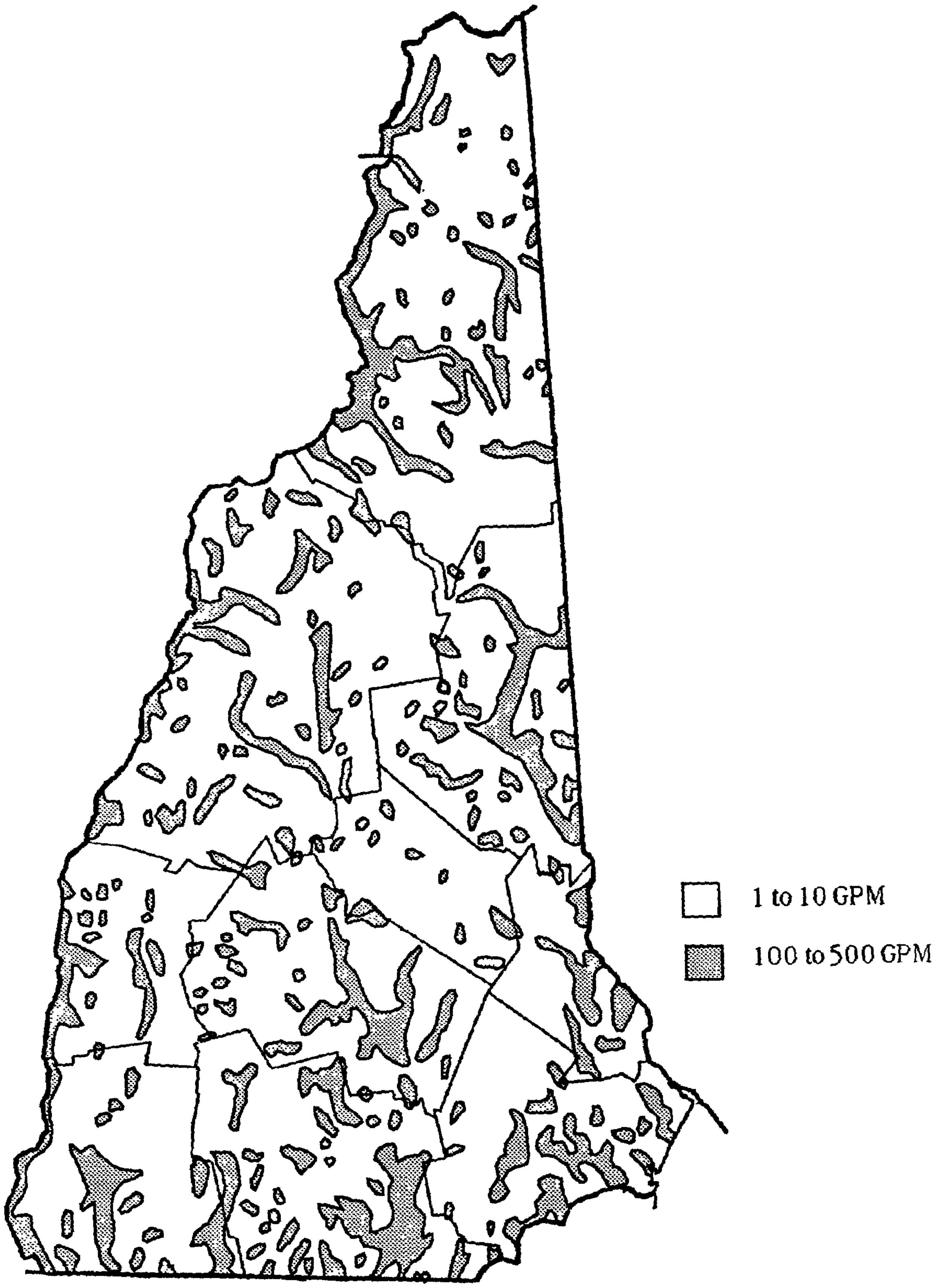
Variably covered undifferentiated crystalline bedrock aquifers occur extensively throughout New Hampshire. The bedrock consists of Ordovician to Devonian age metasedimentary rock and Precambrian to Mississippian age igneous rock. Overlying the bedrock is a variable thickness of glacial till, which consists of an unconsolidated, nonstratified, heterogeneous mixture of clay to boulder size deposits. Water available to wells occurs in fractures in the crystalline bedrock. These fractures are few and, when present, decrease in size and number with depth. Well yields commonly range from 1 to 10 gpm, and may exceed 100 gpm. About 74 percent of New Hampshire is covered by Class U-v aquifers.

Sensitivity

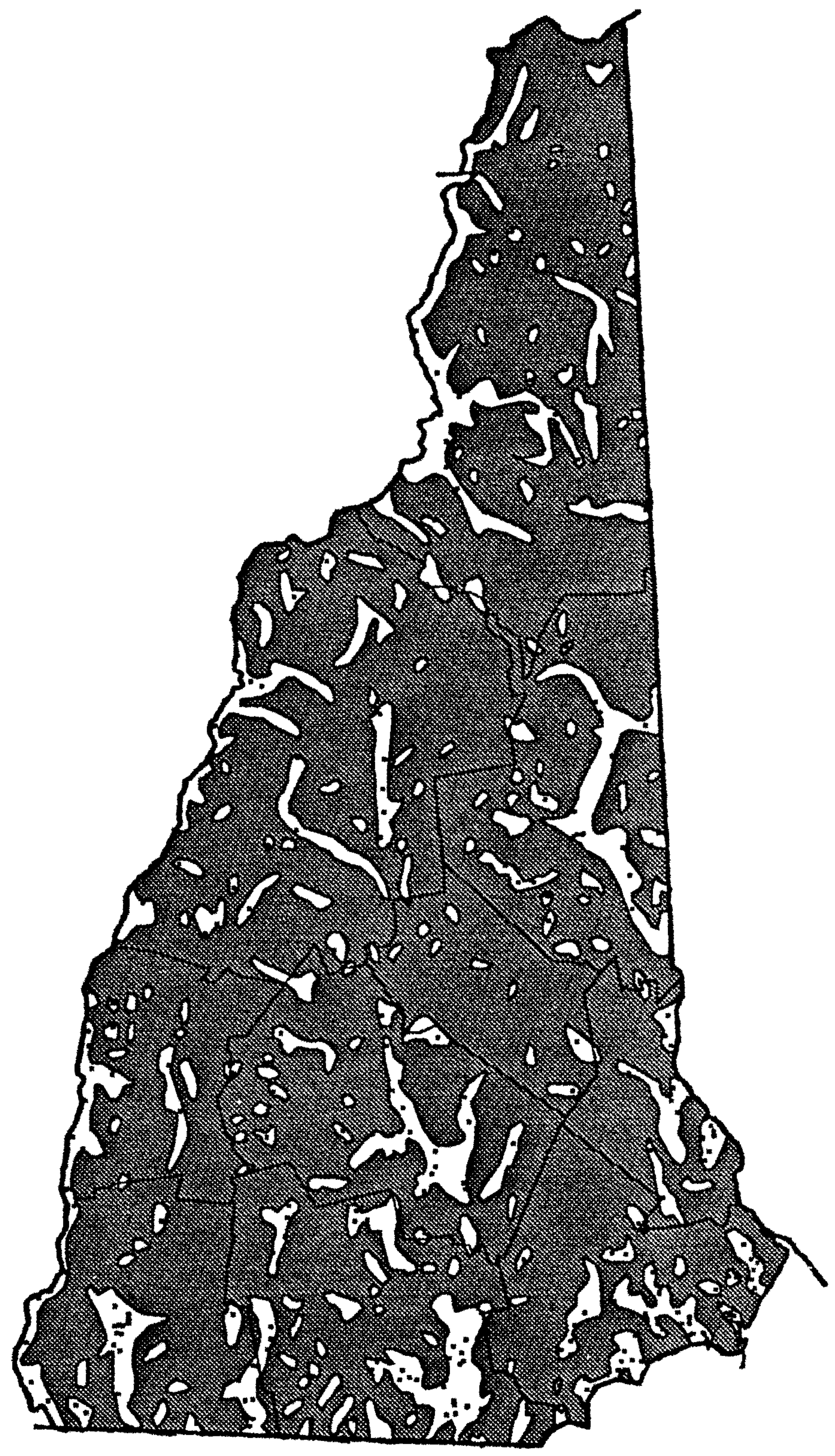
Nearly 26 percent of New Hampshire is covered by Class I aquifers. These vulnerable areas generally occur along water courses that contain masses of sand and gravel. The number of population centers that overlie vulnerable aquifers increases southward, but most of these are small. The regional aquifer sensitivity of New Hampshire is low.



Aquifer Vulnerability Map of New Hampshire

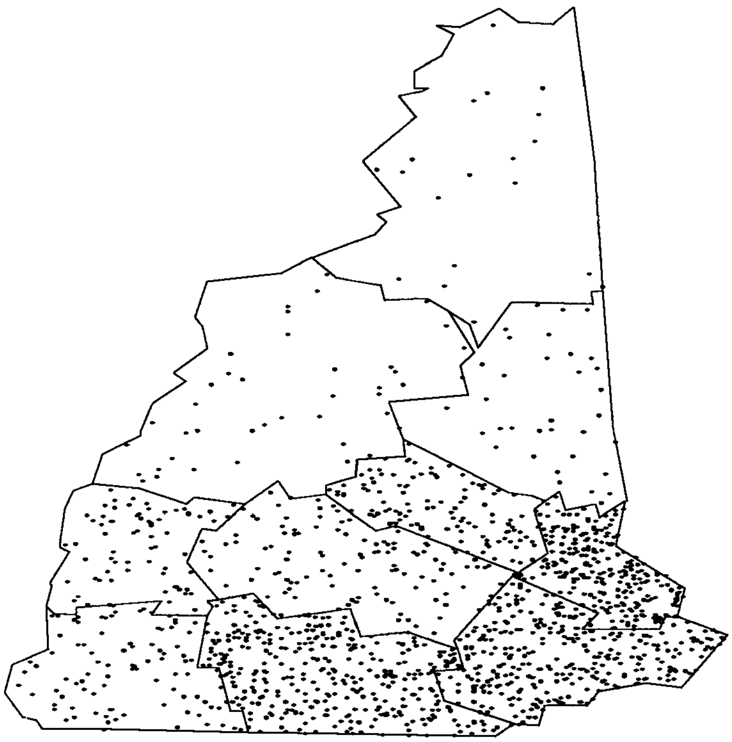


Potential Well Yields in New Hampshire

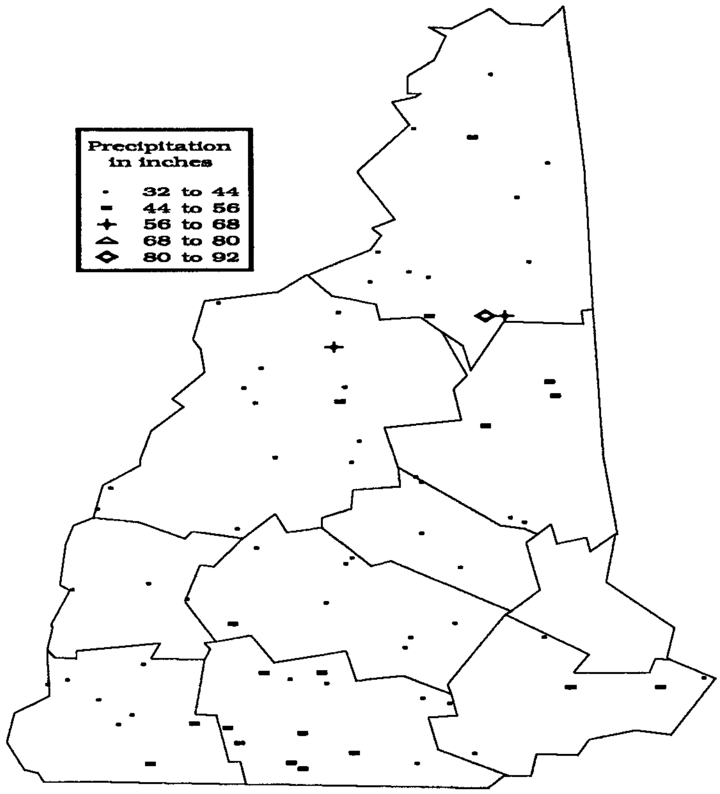


Areas covered by class I aquifers.
Each dot represents a population center.

Aquifer Sensitivity Map of New Hampshire



Population Density of New Hampshire (Dot equals one person per square mile)



Average Annual Precipitation in New Hampshire

RHODE ISLAND

General Setting

Rhode Island, which contains approximately 1,200 square miles, lies within the New England Upland and Seaboard Lowland sections of the New England physiographic province. The topography is gently rolling with maximum elevations of about 800 feet in the hilly northwest part of the state. The area around Narragansett Bay is underlain by folded sedimentary rock of Pennsylvanian age, while the remainder of the state is underlain by metasedimentary and igneous rocks that range in age from Precambrian to Middle Paleozoic. With the exception of a few local bedrock outcrops, Rhode Island is overlain by glacial deposits of variable lithology and thickness.

West of Narragansett Bay the state is drained by the south-flowing Pawcatuck River. Central and northern parts of Rhode Island are drained by the Pawtuxet and Blackstone rivers, both of which empty into Narragansett Bay. Rhode Island's annual precipitation ranges from 45 to 48 inches, and is distributed fairly evenly throughout the year The population, approximately 993,000, is concentrated in the eastern part of the state. About 27 million gallons of fresh ground water are used each day.

Unconsolidated Aquifers (Class Ia)

Stratified drift aquifers occur intermittently throughout Rhode Island and form the most vulnerable aquifers in the state. They consist of unconsolidated, moderately- to well-sorted lenses of gravel, sand, and silt deposited by meltwater streams. In places these deposits are interbedded with clay, silt, and silty sand deposited in glacial lakes. Well yields commonly range from 100 to 700 gpm, and may exceed 1500 gpm. Approximately 42 percent of Rhode Island is covered by Class Ia aquifers.

Semiconsolidated Aquifers (Class Ic)

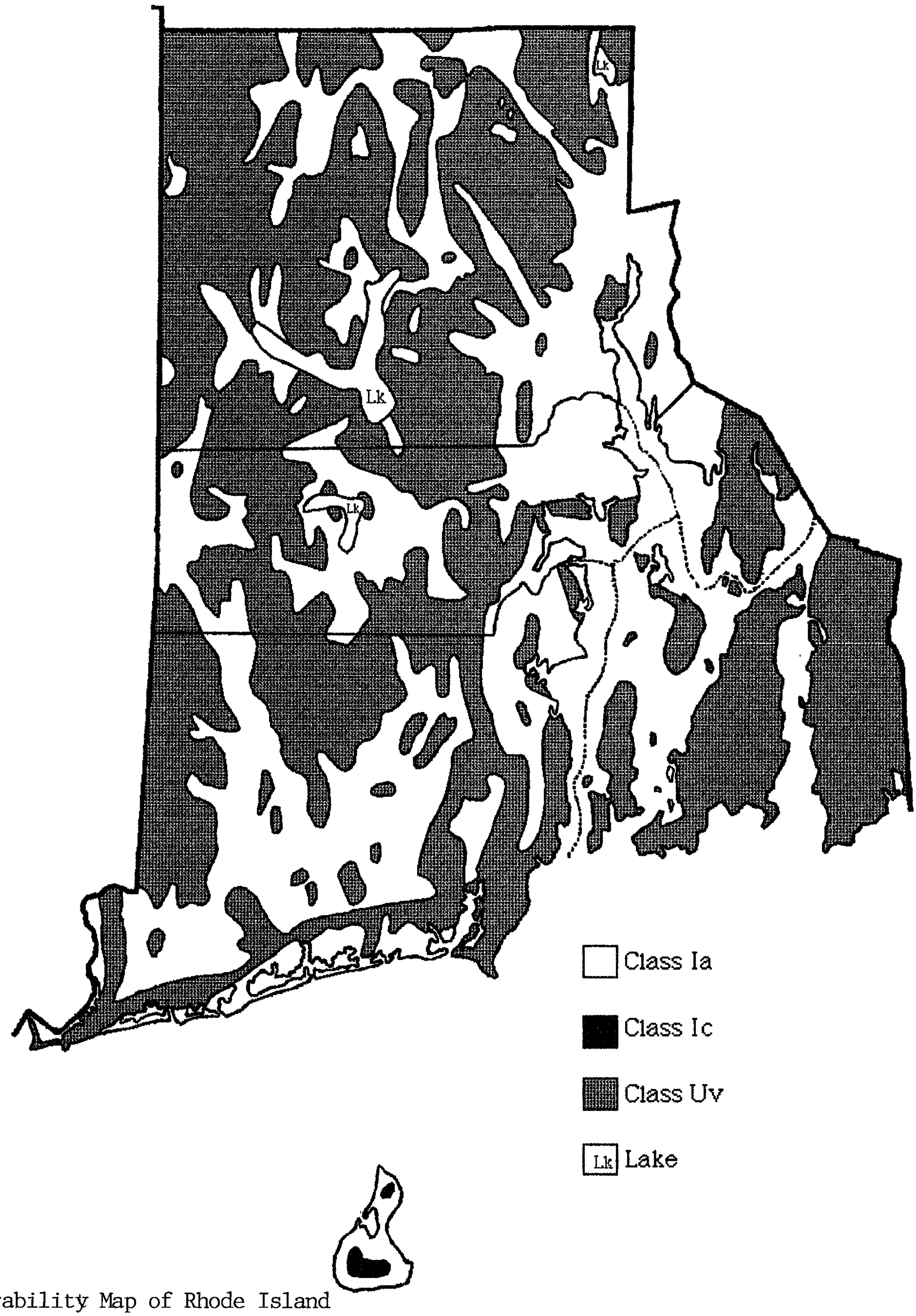
Located on the higher elevations of Block Island, which is just south of Rhode Island's coast, are surface exposures of Upper Mesozoic age semiconsolidated sandstone. Well yields commonly range from 1 to 30 gpm (Hansen and Schiner, 1964). Surface exposures of semiconsolidated aquifers occupy about .13 percent of the state.

Variably Covered Undifferentiated Aquifers (Class U-v)

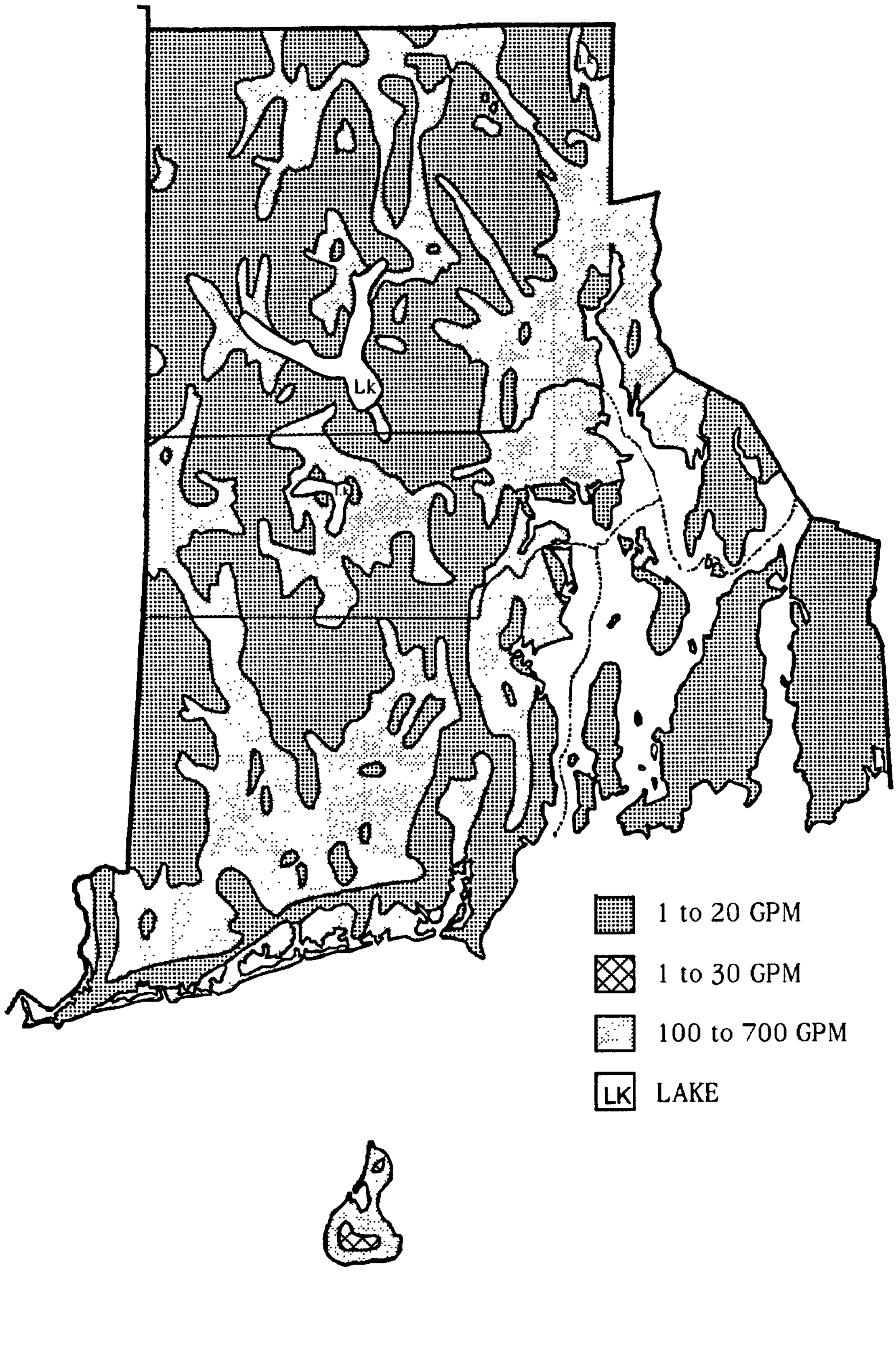
Variably covered undifferentiated bedrock aquifers occur throughout Rhode Island. Near Narragansett Bay bedrock is composed of well indurated to metamorphosed sedimentary rock of Pennsylvanian age. The units include conglomerate, sandstone, shale, and anthracite. Elsewhere the bedrock consists of igneous and metamorphic rocks, largely granite and granite gneiss. Recoverable water from these rocks occurs in a network of narrow and widely spaced fracture systems that decrease both in size and number with depth. Overlying the bedrock is a variable thickness of glacial till, which consists of heterogeneous mixture of sand, silt, gravel, clay, and boulders. The vulnerability of this system is a function of the thickness of the overlying glacial till. Well yields commonly range from 1 to 20 gpm, and may exceed 50 gpm. Class U-v aquifers occupy slightly more than 56 percent of Rhode Island.

Sensitivity

About 42 percent of Rhode Island is covered by vulnerable Class I aquifers. Population centers are rather widely distributed in the vulnerable areas. Consequently, the potential for ground-water contamination from shallow injection wells is moderately small.

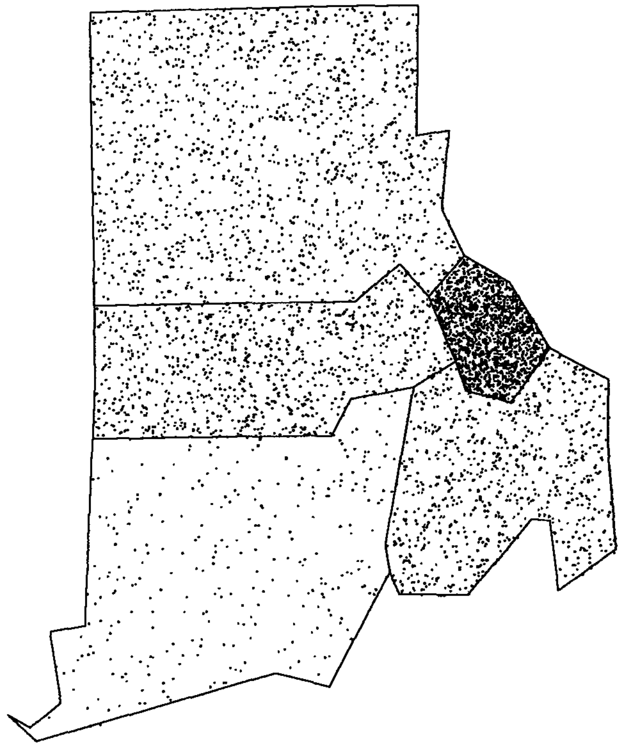


Aquifer Vulnerability Map of Rhode Island

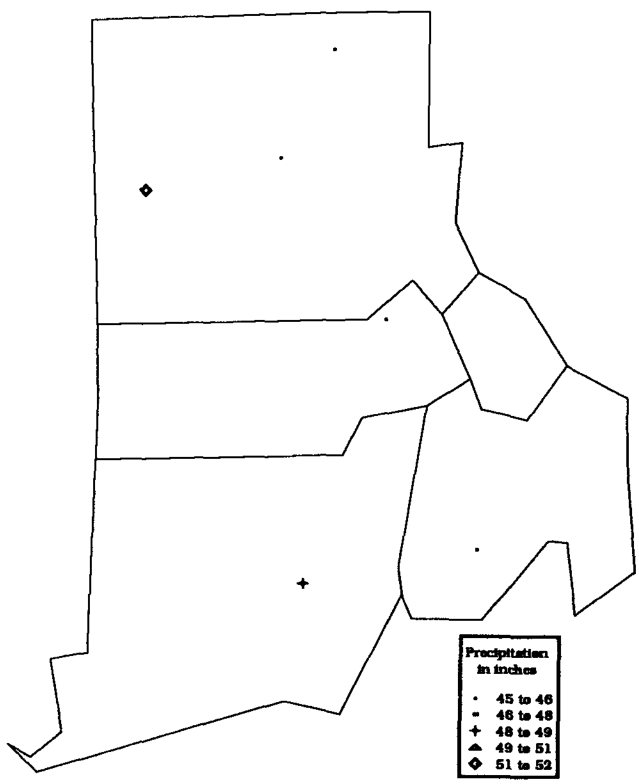


Potential Well Yields in Rhode Island

Aquifer Sensitivity Map of Rhode Island



Population Density of Rhode Island (Dot equals one person per square mile)



Average Annual Precipitation in Rhode Island

VERMONT

General Setting

Vermont contains approximately 9,600 square miles, and lies within the St. Lawrence Valley and New England physiographic provinces. The predominant topographic feature is a north-south trending mountain belt, which extends the entire length of the state. The remainder of Vermont generally exhibits rolling hills. The eastern three-fourths of the state is underlain by Precambrian to Early Paleozoic age igneous and metamorphic rocks that have undergone folding and faulting. The western quarter is composed of Ordovician age carbonate strata with some crystalline rock that has been thrust over the younger Ordovician bedrock. Generally the bedrock is overlain by Pleistocene age deposits of varying lithology and thickness.

Eastern Vermont is drained by the south-flowing Connecticut River. The remainder of the state is drained by several west- and northwest-flowing systems, which empty into Lake Champlain. Annual precipitation ranges from about 33 inches in the eastern and western valleys to about 53 inches in the Green Mountain Belt. Precipitation is lowest during the winter months and somewhat evenly distributed throughout the rest of the year. Of the state's 557,000 inhabitants, the largest concentration is located in the vicinity of Burlington. The remainder of Vermont is sparsely populated. About 37 million gallons of fresh ground water are used daily.

Unconsolidated Aquifers (Class Ia)

Stratified drift aquifers are exposed intermittently throughout Vermont and form vulnerable and productive aquifers. These aquifers, which generally occur in the lowlands, consist of unconsolidated glaciofluvial sand and gravel with minor amounts of silt. Included in this stratified drift class are some thin, fine-grained lacustrine deposits, stratified outwash deposits, and coarse-grained ice contact deposits. Higher well yields can be obtained from the thicker and coarser deposits. Well yields commonly range from 30 to 400 gpm, and may exceed 600 gpm. Approximately 20 percent of Vermont is covered by Class Ia aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Locally, small exposures of carbonates are present in western Vermont. These Ordovician age rocks consist of limestone, dolomite, and marble, all of which have been subjected to solution weathering along fractures. Solutional features contribute to the vertical and lateral permeability of the rock, creating productive and vulnerable aquifers. Well yields commonly range from 5 to 20 gpm, and may exceed 300 gpm. Surface exposures of Class Ib aquifers occupy about 1.2 percent of Vermont.

Variably Covered Soluble and Fractured Bedrock Aquifers (Class Ib-v)

In some places in western Vermont, the Ordovician age carbonate strata that have some solutional features are overlain by glacial till of variable thickness. The overlying till consists of a heterogeneous mixture of sand, silt, clay and some boulders. The vulnerability of this system is a function of the thickness of the overlying till. Well yields commonly range from 5 to 20 gpm, and may exceed 300 gpm. Nearly 7 percent of Vermont consists of Class Ib-v aquifers.

Undifferentiated Aquifers (Class U)

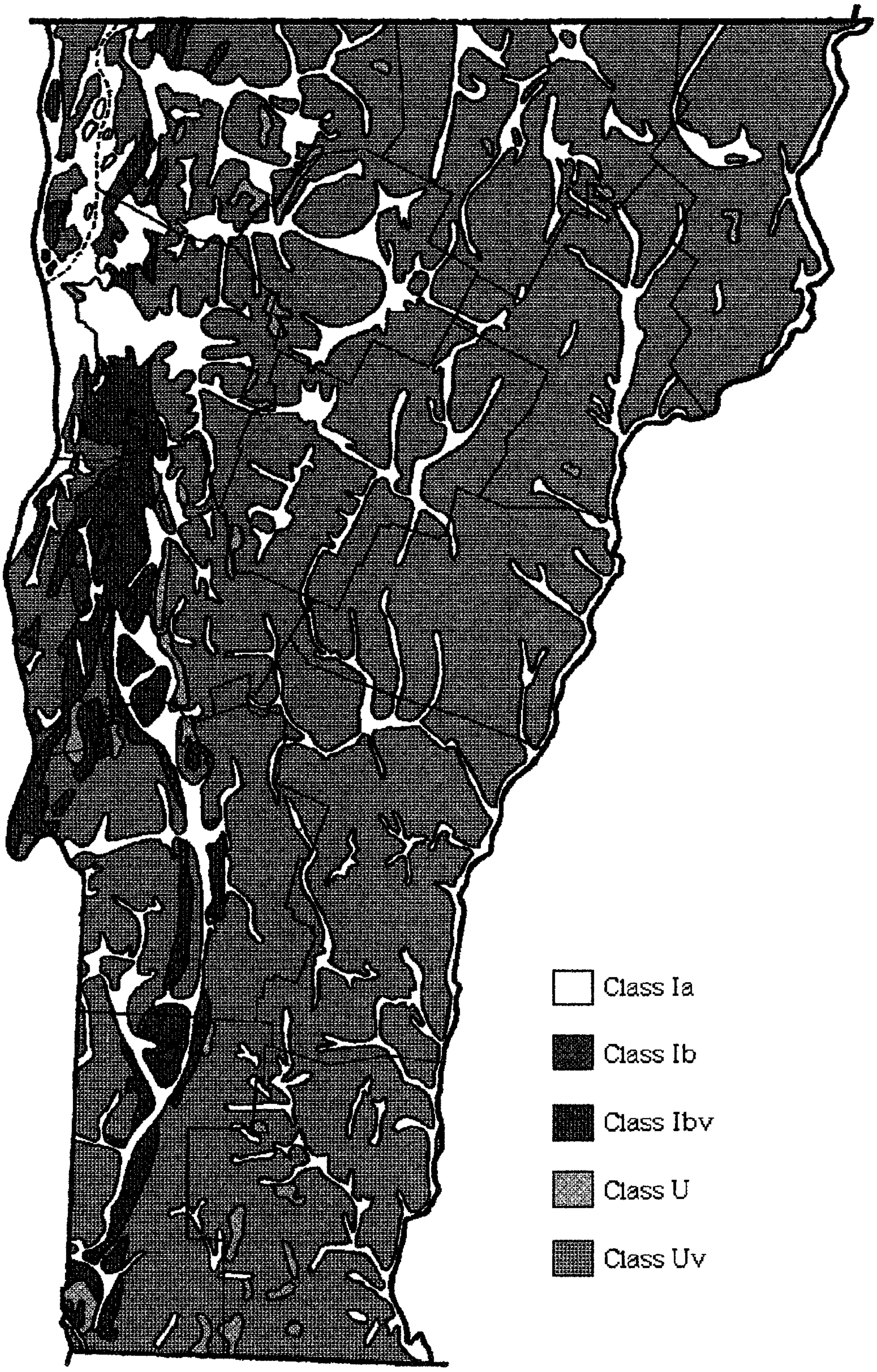
With the exception of the carbonate bedrock in the west, Vermont is underlain by Precambrian to Early Paleozoic age crystalline bedrock, which consists of various metasedimentary, metavolcanic, and igneous rock. These crystalline rock units contain recoverable water in fractures and other similar openings. Fractures decrease in size and number with depth. Local exposures of undifferentiated crystalline bedrock occur in western and central Vermont. Well yields commonly range from 1 to 10 gpm, and may exceed 100 gpm. Surface exposures of undifferentiated crystalline bedrock occupy about 2.3 percent of Vermont.

Variably Covered Undifferentiated Aquifers (Class U-v)

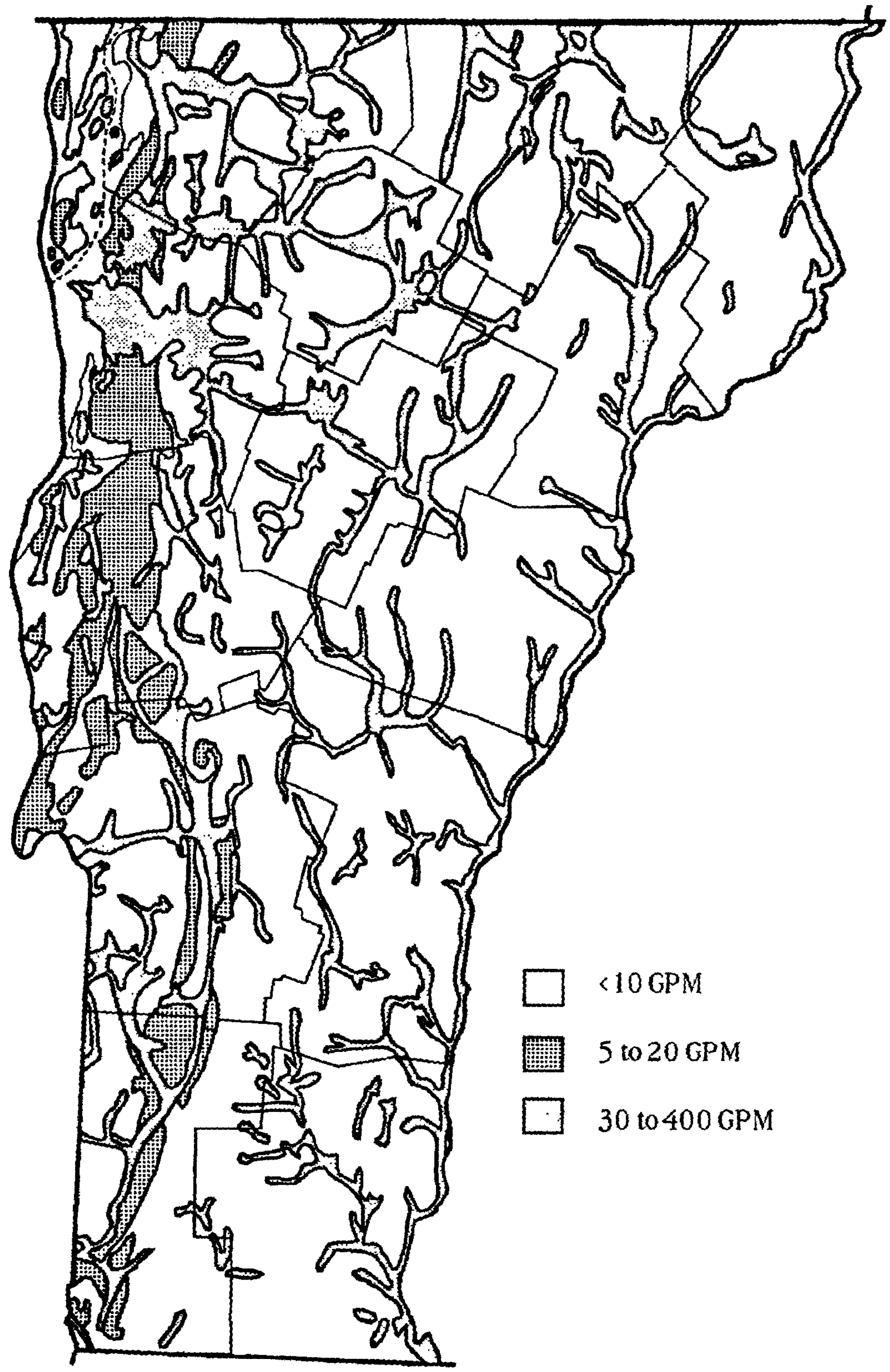
Variably covered undifferentiated crystalline bedrock aquifers occur extensively throughout the state. Overlying the crystalline bedrock is glacial till, which is quite variable in thickness. The vulnerability of these systems is a function of the thickness and permeability of the overlying till. Well yields commonly range from 1 to 10 gpm, and may exceed 100 gpm. Nearly 70 percent of Vermont is underlain by variably covered undifferentiated crystalline aquifers.

Sensitivity

About 21 percent of Vermont is covered by vulnerable Class I aquifers. Owing to the low population density, aquifer sensitivity to contamination by shallow injection wells is low. The most sensitive areas lie in north-south trending belts adjacent to the Connecticut River and along the western part of the state.



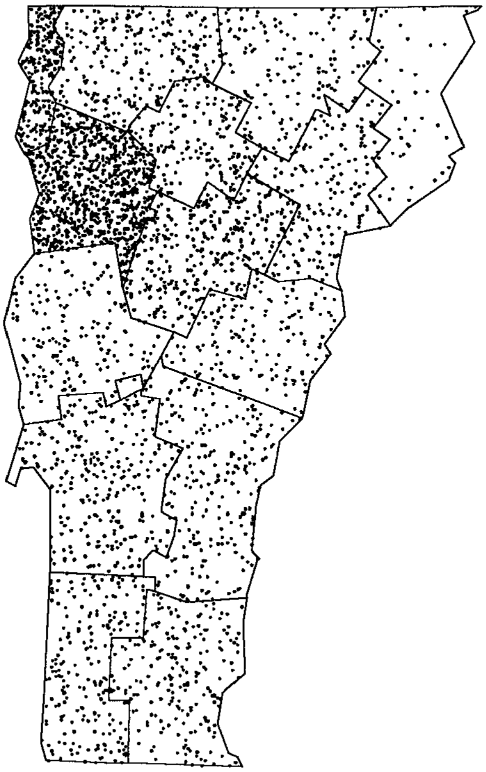
Aquifer Vulnerability Map of Vermont



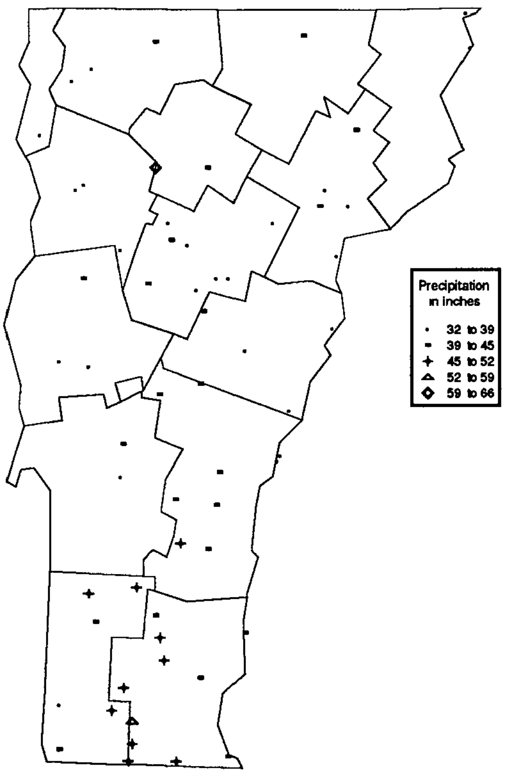
Potential Well Yields in Vermont

Areas covered by class I aquifers.
Each dot represents a population center.

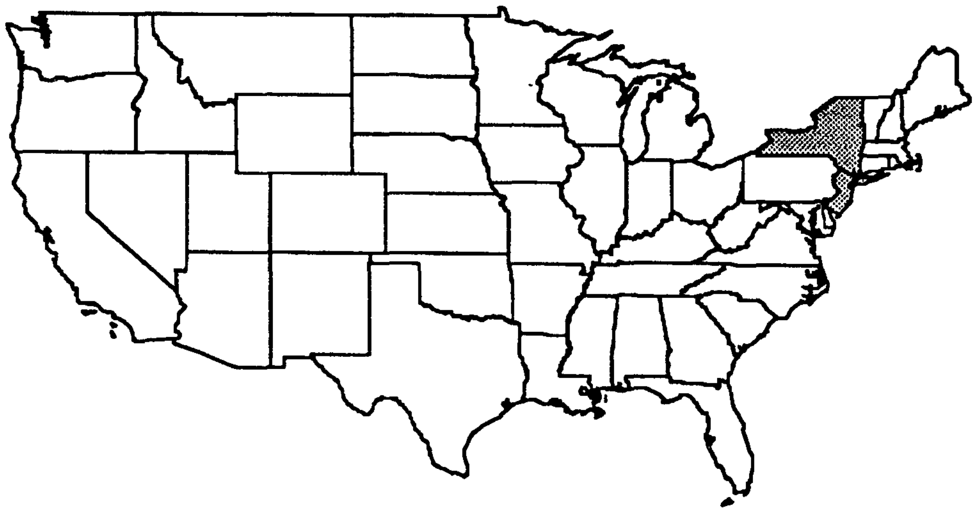
Aquifer Sensitivity Map of Vermont



Population Density of Vermont (Dot equals one person per square mile)



Average Annual Precipitation in Vermont



REGION 2

New Jersey
New York

NEW JERSEY

General Setting

New Jersey, which contains approximately 7,800 square miles, lies largely within four physiographic provinces. The Coastal Plain, which occupies the southern half of the state south of the Fall Line, is characterized by Precambrian age basement rocks that are overlain by Cretaceous to Quaternary age deposits that dip and thicken southeastward. Exposures of the surficial bedrock expresses the complex geology of the northern half of New Jersey. In the Valley and Ridge, Highlands, and Piedmont provinces, Precambrian through Triassic age sedimentary and metamorphic rock have been folded, faulted, and intruded by dikes and sills; extrusive igneous rocks filled the low areas. The northern quarter of New Jersey is covered by a variable thickness of glacial deposits.

The western part of New Jersey is drained by the south-flowing Delaware River and its tributaries. Eastern New Jersey is drained by several southeasterly-flowing water courses that empty into the Atlantic Ocean. Annual average precipitation ranges from 44 inches in the south to 52 inches in the northern part of the state. New Jersey's population, about 6.1 million, is concentrated in the northeast portion of the state. The remainder is moderately populated. About 667 million gallons of fresh and 100,000 gallons of saline ground water are used daily in the state.

Unconsolidated Aquifers (Class Ia)

Exposed extensively in southern, and locally in northern New Jersey, are Tertiary to Quaternary age unconsolidated beach, marine terrace, and stratified glacial outwash deposits. They are composed of sand, gravel, silt, and clay. Well yields range from 500 to 1,000 gpm, and may exceed 2,000 gpm. About 53 percent of the state is covered by Class Ia aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Exposed in west central New Jersey are fractured sedimentary rock aquifers. These densely jointed and fractured Tertiary age strata consist of shale, sandstone, and conglomerate, with lesser amounts of limestone. Where present, fracturing and jointing contribute to the vertical and lateral permeability of the rock. Well yields commonly range from 10 to 500 gpm, and may exceed 1,500 gpm. About 6 percent of the state is occupied by Class Ib aquifers.

Variably Covered Soluble and Fractured Bedrock Aquifers (Class Ib-v)

In northeastern New Jersey are variably covered Tertiary age fractured sedimentary aquifers. The rocks consist of shale, sandstone, and conglomerate, as well as a small amount of limestone. Well yields commonly range from 10 to 500, and may exceed 1,500 gpm. In the northwest are variably covered Ordovician to Silurian age soluble and fractured aquifers. The bedrock consists of limestone and shale. Well yields commonly range from 5 to 500 gpm, and may exceed 1,500 gpm. The vulnerability of these strata is a function of the thickness and permeability of the overlying sediments. Class Ib-v aquifers occupy about 8.4 percent of the state.

Semiconsolidated Aquifers (Class Ic)

Exposed in the central part of New Jersey are Cretaceous age deposits that consist of sand and clay that have been partially cemented by iron oxide. Well yields commonly range from 50 to 500 gpm, and may exceed 1,000 gpm. About 3 percent of the state is covered by semiconsolidated aquifers.

Variably Covered Semiconsolidated Aquifers (Class Ic-v)

A small area covered by glacial till of variable thickness consists of Cretaceous age semiconsolidated strata. These sediments consist of partially cemented sand and clay, occurs east-central coastal part of the state. Well yields commonly range from 50 to 500 gpm, and may exceed 1,000 gpm. Less than a half percent of the state is occupied by variably covered semiconsolidated aquifers.

Low Yield Bedrock Aquifers (Class IIb)

Local exposures of low yield bedrock aquifers occur in northwestern New Jersey. These Tertiary age rocks are composed of sandstone, shale, and conglomerate. Wells yield small quantities of water. Nearly 2 percent of New Jersey is covered by Class IIb aquifers.

Variably Covered Low Yield Bedrock Aquifers (Class IIb-v)

In far northern New Jersey are variably covered Ordovician and Silurian age low yield aquifers. Bedrock consists of sandstone and shale, which yields only small quantities of water. Aquifer vulnerability is a function of the thickness of the overlying low permeability sediments. Nearly 2 percent of the state is occupied by Class IIb-v aquifers.

Undifferentiated Aquifers (Class U)

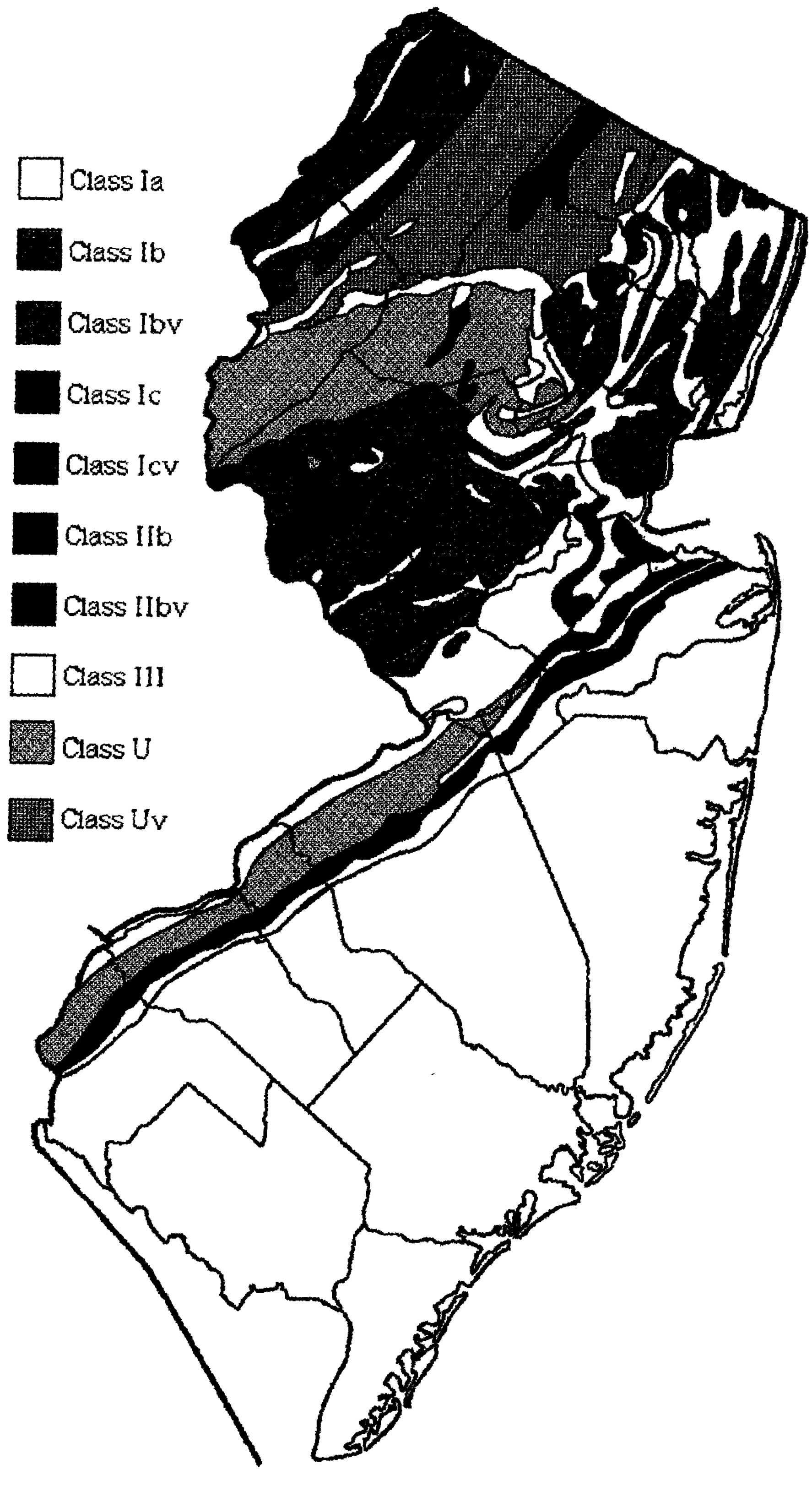
An undifferentiated series of Tertiary to Cretaceous age sand and gravel deposits with bands of shale is exposed in southern New Jersey. Well yields range from 0 to 500 gpm, and may exceed 1,000 gpm. Exposed in the northwest are Precambrian to Cambrian age crystalline rock in which water occurs in fractures. Well yields commonly range from 5 to 50 gpm, and may exceed 400 gpm. Almost 9 percent of New Jersey is covered by undifferentiated aquifers.

Variably Covered Undifferentiated Aquifers (Class U-v)

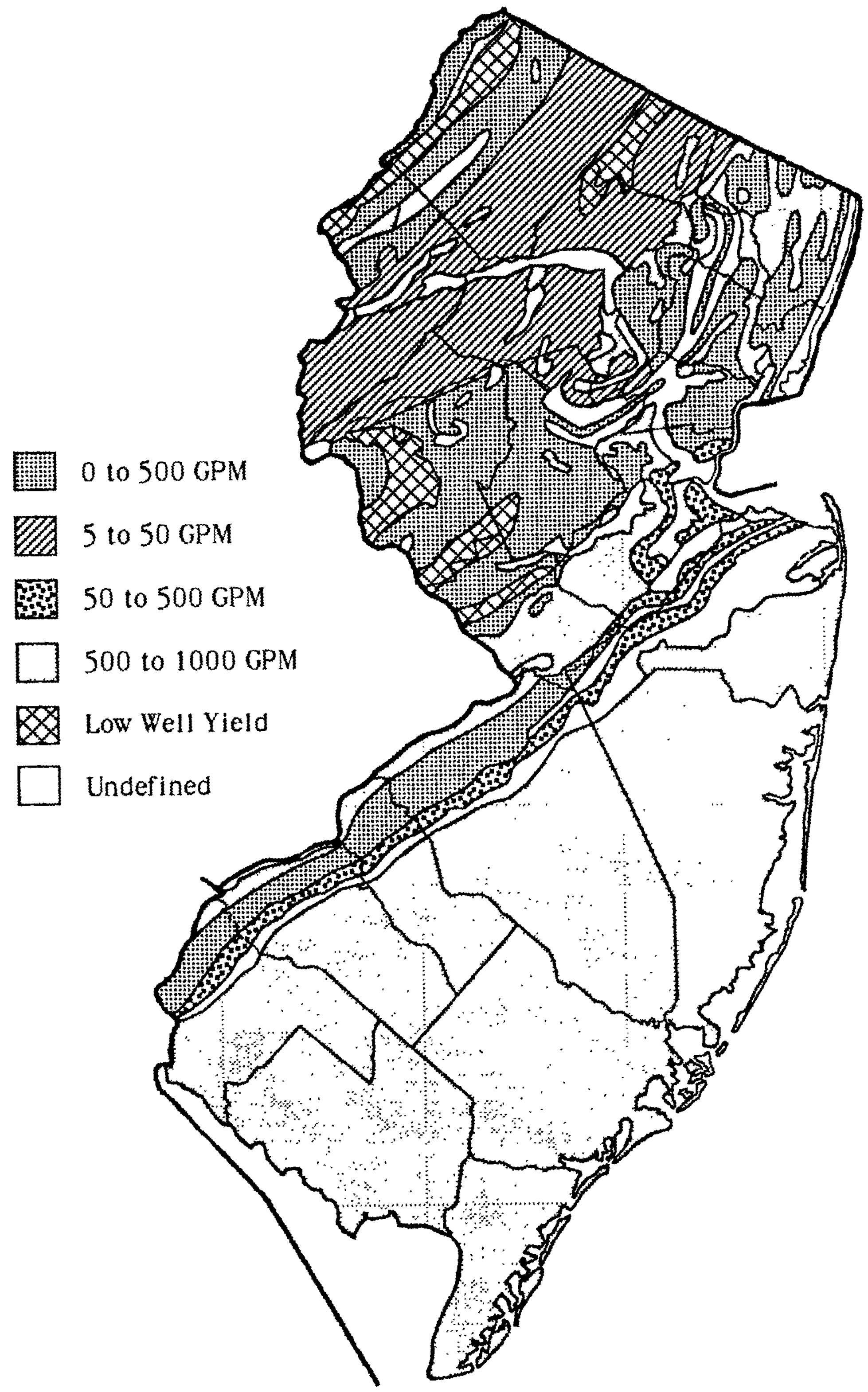
Northern New Jersey contains variably covered undifferentiated Precambrian and Cambrian crystalline rock. Aquifer vulnerability is a function of the thickness and permeability of the overlying sediments. Well yields range from 5 to 50 gpm, and they may exceed 400 gpm. About 7 percent of the state is occupied by Class U-v aquifers.

Sensitivity

About 71 percent of New Jersey is covered by Class I aquifers. The potential for ground-water contamination in the central, vulnerable part of the state is moderately high owing to the distribution of population and population centers. Elsewhere aquifer sensitivity is low to moderate.



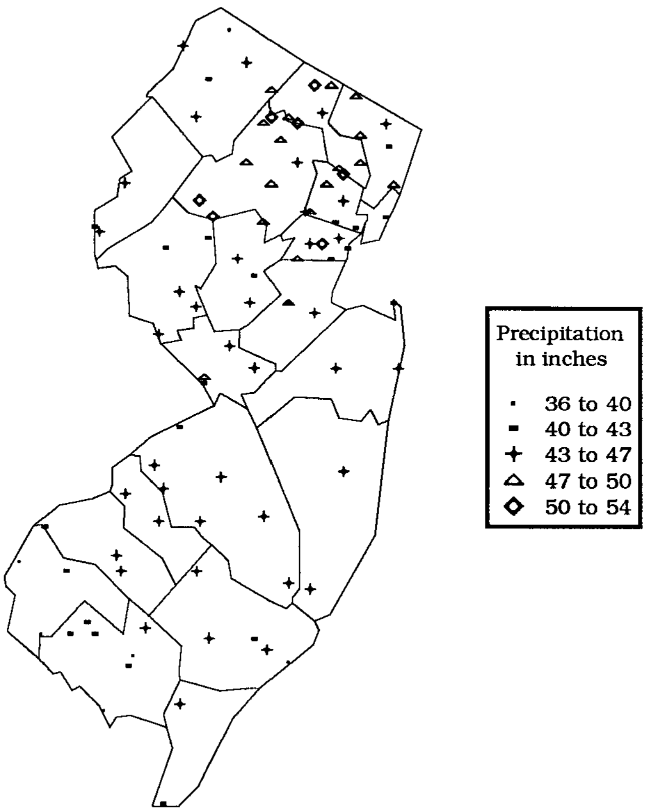
Aquifer Vulnerability Map of New Jersey



Potential Well Yields in New Jersey

Aquifer Sensitivity Map of New Jersey

Population Density of New Jersey (Dot equals one person per square mile)



Average Annual Precipitation in New Jersey

NEW YORK

General Setting

New York, which contains approximately 49,600 square miles, lies within the Central Lowland, Appalachian Plateaus, Adirondack, St. Lawrence Valley, Valley and Ridge, Piedmont, New England, and Coastal Plain provinces. The topography ranges from level and rolling plains near the Great Lakes in western New York to the fairly rugged Adirondack and Catskill regions. The bedrock underlying the western two-thirds of New York is characterized by Early Paleozoic age sedimentary rock that generally dips slightly southward. The Adirondack Mountains in northeast New York consist of metamorphic with some igneous rock of Precambrian age. Bedrock in the eastern part of New York is composed of Precambrian to Mesozoic age sedimentary and metamorphic rocks that have been folded and faulted. Much of New York is mantled by Pleistocene age glacial deposits, which are variable in both thickness and lithology.

Eastern New York is drained by the Hudson River and its tributaries, while the south-central part of the state is drained by several south-flowing rivers. Streams in western New York empty into Lake Ontario and Lake Erie. Annual precipitation ranges from 30 inches in the lowlands to about 52 inches in the Catskill and Adirondack Mountains. The majority of New York's population, about 21.6 million, are located in or around New York City, Buffalo, Rochester, Syracuse, and Albany. The remainder of the state is moderately populated. About 1.1 billion gallons of fresh ground water are used daily in New York.

Unconsolidated Aquifers (Class Ia)

Unconsolidated aquifers are exposed on Long Island and intermittently throughout upstate New York. Quaternary age stratified outwash and valley-fill deposits consist of sand and gravel with variable amounts of silt and clay. Well yields commonly range from 10 to 1,200 gpm, and may exceed 3,000 gpm. About 24 percent of New York is covered by unconsolidated aquifers.

Variably Covered Soluble and Fractured Bedrock Aquifers (Class Ib-v)

Variably covered Ordovician to Silurian age karst carbonate aquifers are present in band-like trends in upstate New York. The bedrock underlying the glacial till cover is composed largely of limestone and dolomite, although there is a minor amount of shale. The vulnerability of this system is a function of the thickness of the overlying low permeability glacial till. Well yields commonly range from 50 to 150 gpm, and they may exceed 200 gpm. About 15 percent of New York is covered by unconsolidated aquifers.

Variably Covered Higher Yield Bedrock Aquifers (Class IIa-v)

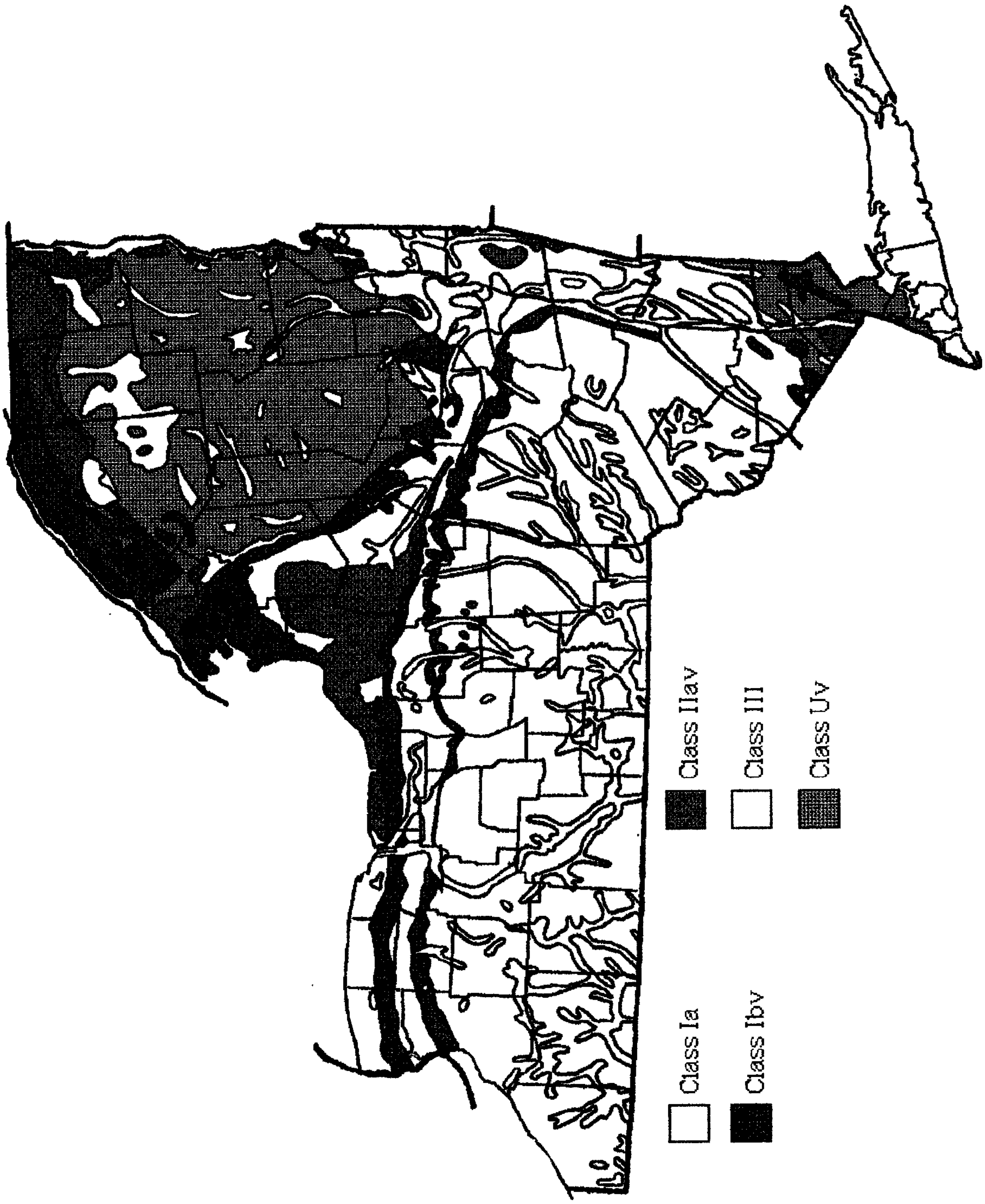
Occurring in northern and, locally in southern, New York are higher yield sedimentary rock aquifers that are covered with a variable thickness of glacial till. The Cambrian to Ordovician age bedrock is composed of sandstone, shale, and conglomerate. Well yields commonly range from 5 to 100 gpm. The vulnerability of these systems is a function of the thickness and permeability of the overlying till. About 7 percent of New York is occupied by Class IIa-v aquifers.

Undifferentiated Aquifers (Class U-v)

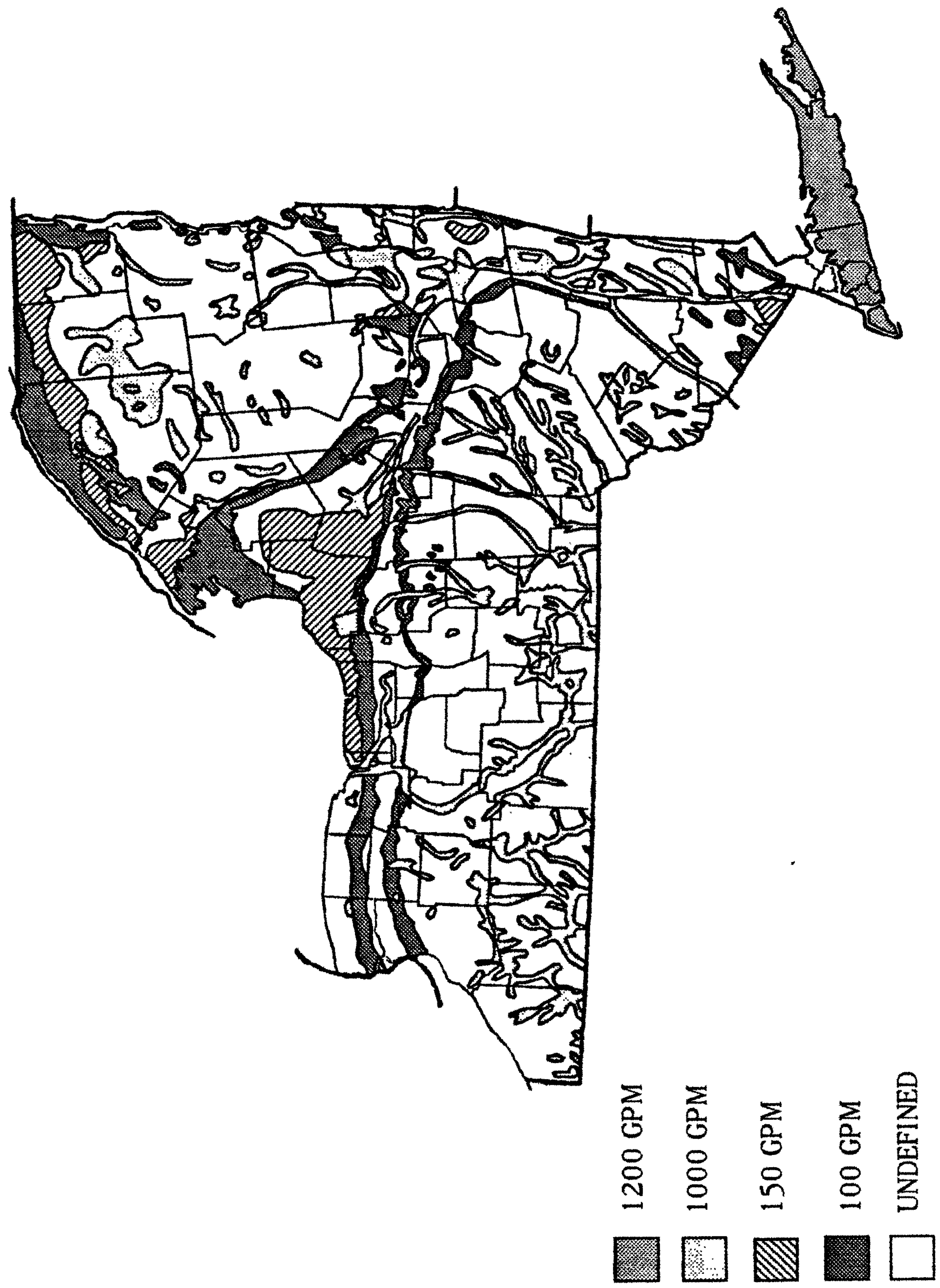
In the Adirondack Mountains, and locally in southeastern New York, are Precambrian to Ordovician age undifferentiated crystalline rocks that are overlain by glacial till of variable thickness. Due to lack of published surficial maps of the Adirondack Mountains, the variable modifier was used because surface exposures of bedrock could not be delineated. Well yields were not cited. About 18 percent of New York is covered by Class U-v aquifers.

Sensitivity

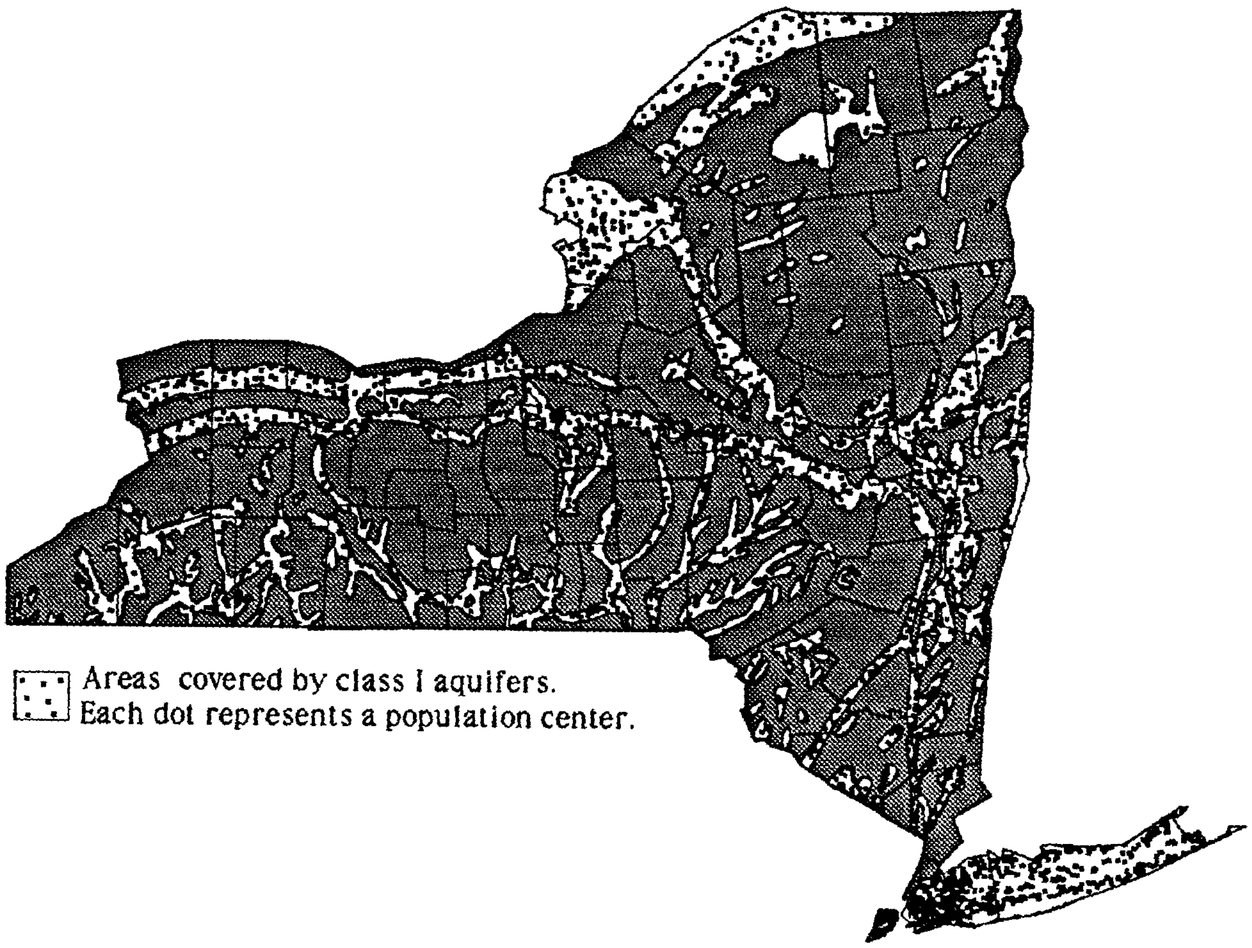
Approximately 39 percent of New York is covered by vulnerable Class I aquifers. The potential for ground-water contamination from shallow injection wells is particularly high in western Long Island and in the lower reaches of Hudson River valley. The potential is moderate to high in the remainder of Long Island, and along many of the other rivers and major transportation routes, such as I-90. Although still significant, the number of population centers on vulnerable aquifers in the northern part of the state is considerably less than it is in the south.



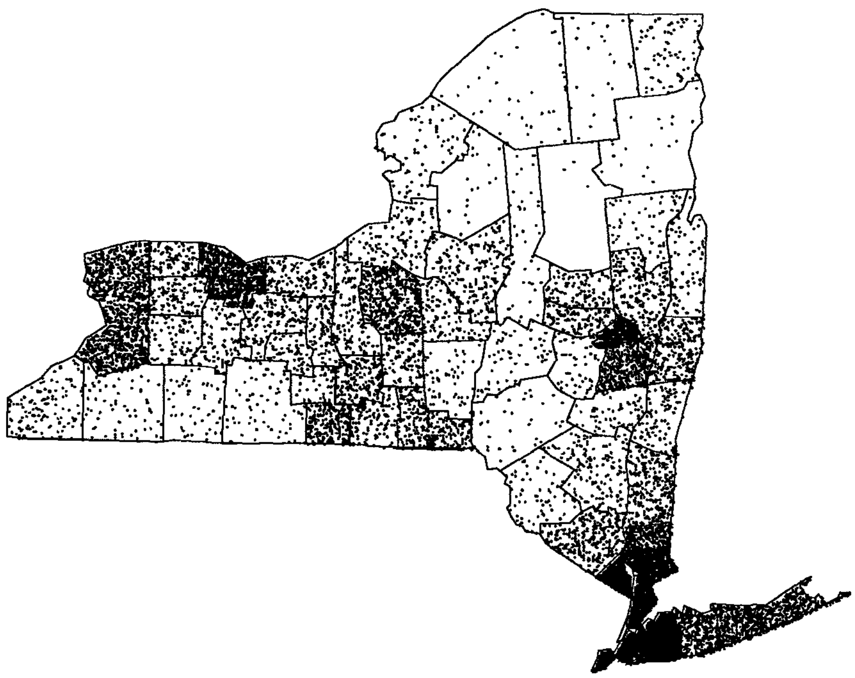
Aquifer Vulnerability Map of New York



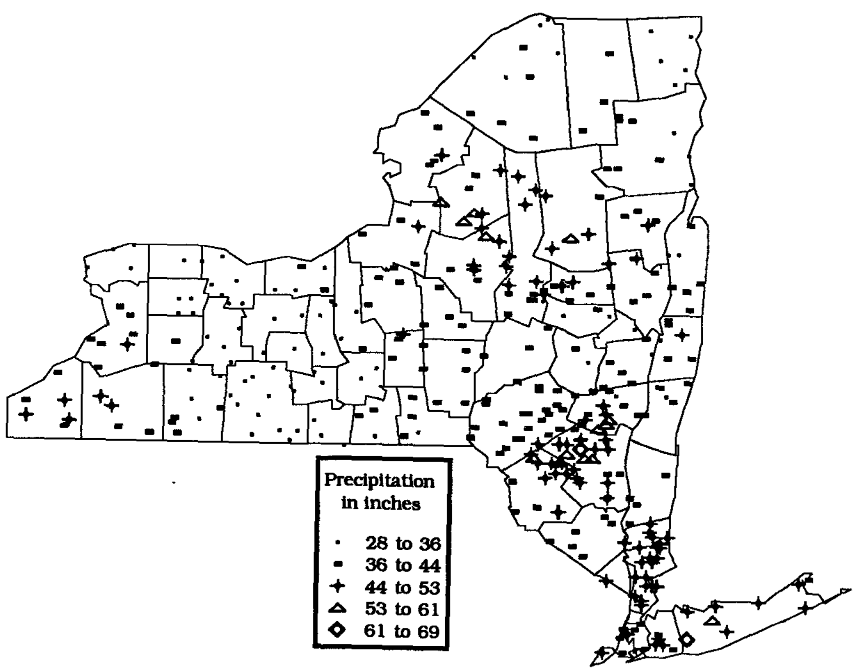
Potential Well Yields in New York



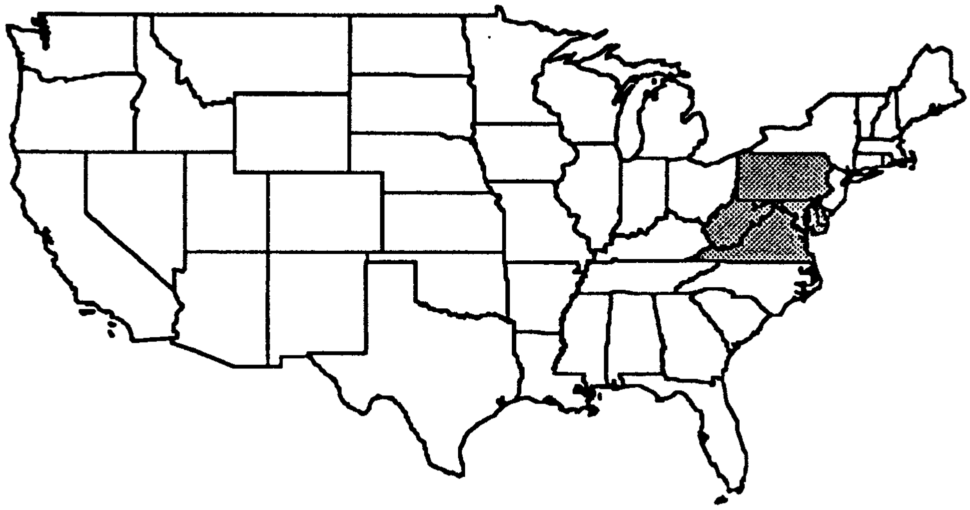
Aquifer Sensitivity Map of New York



Population Density of New York (Dot equals one person per square mile)



Average Annual Precipitation in New York



REGION 3

Delaware
Maryland
Pennsylvania
Virginia
West Virginia

DELAWARE

General Setting

Delaware, which contains approximately 2044 square miles, lies within two physiographic provinces. North of the Fall Line, in the extreme northern part of the state, lies the gently rolling Piedmont physiographic province. Elsewhere is the flat-lying Coastal Plain province. The Piedmont is underlain by Precambrian to Paleozoic age crystalline bedrock, while the Coastal Plain consists of Upper Cretaceous to Miocene age alternating layers of unconsolidated sand and gravel that dip and thicken toward the southeast. Overlying these sediments is a continuous sheet of Quaternary age unconsolidated deposits that range in thickness from a few feet in the north to more than 180 feet in the south (Johnson, 1977). These deposits consist of sand and gravel with some silt and clay. Eastern Delaware is drained by several small rivers that discharge into Delaware Bay. Southwest Delaware is drained by the southwest-flowing Nanticoke River and its tributaries. Stream channel gradients are very low and some areas of the state are poorly drained. Average annual precipitation, about 43 inches statewide, is distributed fairly evenly throughout the year. Delaware's population, approximately 660,000 is concentrated in the northern part of the state, in or around Newcastle. The remainder of the state is moderately populated. Daily use of fresh ground water amounts to about 79 million gallons.

Unconsolidated Aquifers (Class Ia)

Marine, non-marine, and channel fill deposits occur extensively throughout Delaware and form productive, vulnerable aquifers. These unconsolidated deposits consist of sand, gravel, silt and clay, with some shell fragments. Well yields commonly range from 100 to 500 gpm ,and may exceed 1000 gpm. Slightly more than 92 percent of Delaware is covered by permeable Class Ia unconsolidated deposits.

Soluble and Fractured Bedrock Aquifers (Class Ib)

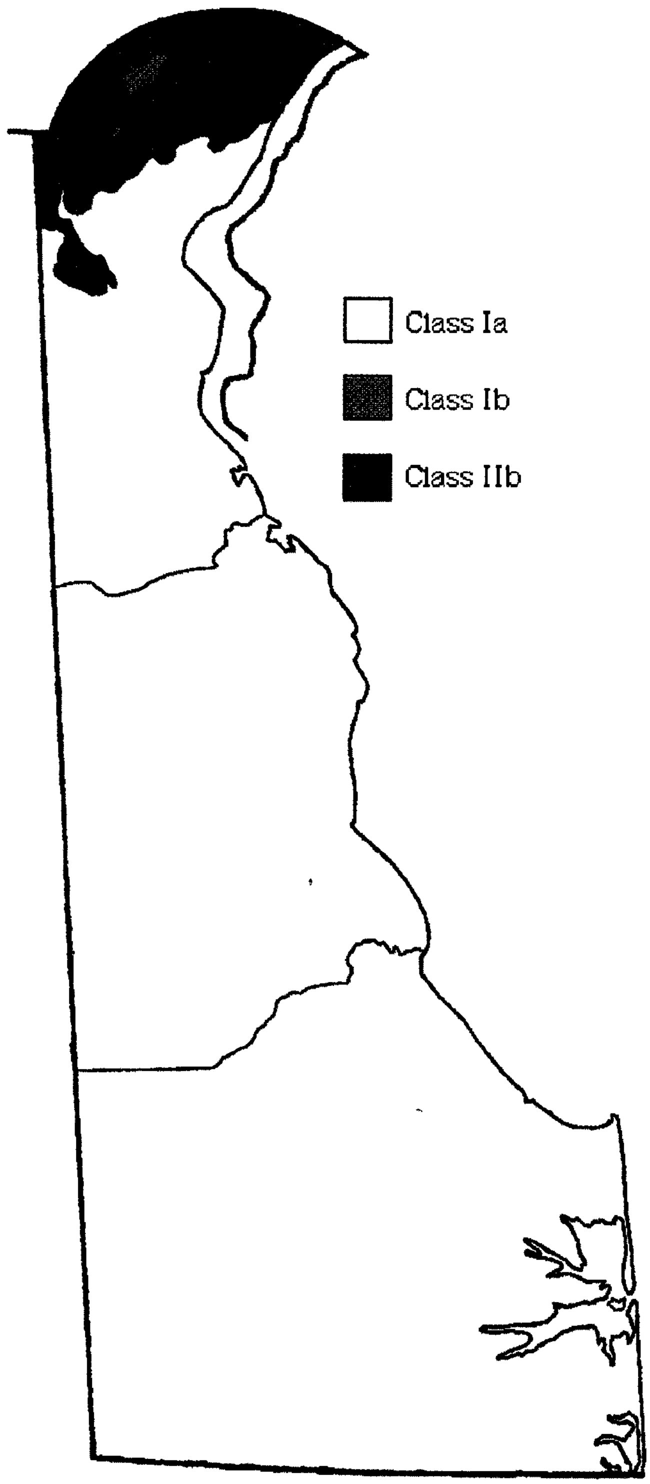
Small local exposures of Paleozoic age dolomite and marble with karst features occur in far northern Delaware. Reports indicate that sinkholes can be observed at numerous locations in the outcrop areas (Talley, 1981). Well yield characteristics are not well documented. About .24 percent of Delaware is covered by karst carbonate aquifers.

Lower Yield Bedrock Aquifers (Class IIb)

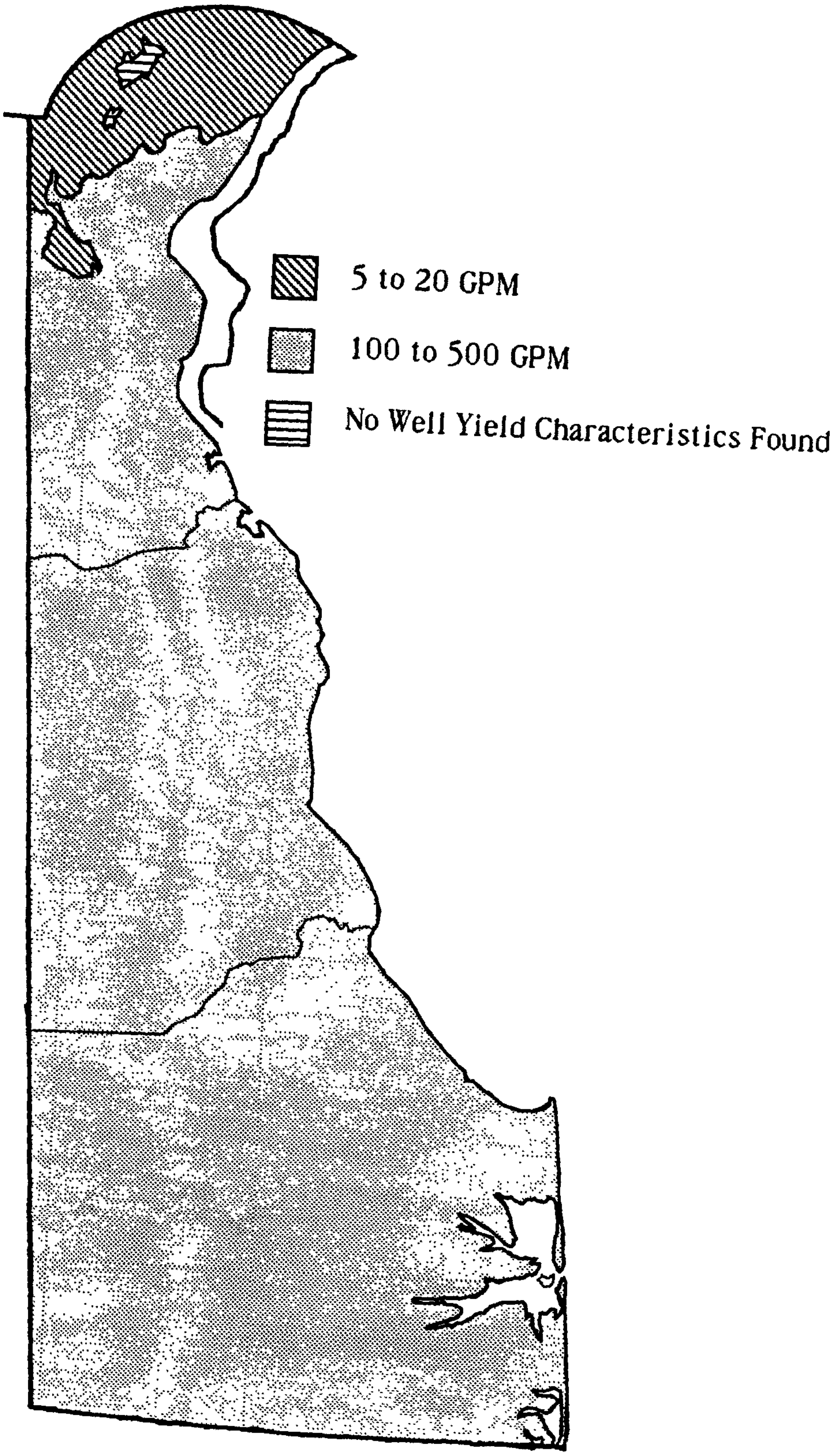
Lower yield Precambrian to Paleozoic age crystalline rocks are exposed in the extreme northern part of Delaware. These exposures include gneiss, schist, gabbro, granodiorite, and some marble. Well yields commonly range from 5 to 20 gpm, and may exceed 200 gpm. Surface exposures of lower yield bedrock aquifers occupy about 7.4 percent of the state.

Sensitivity

Nearly 93 percent of Delaware consists of vulnerable Class I aquifers. The distribution of population centers indicates that, despite the vulnerability, the regional sensitivity of the state is only moderate, except along the major transportation routes where the potential for contamination is greater.



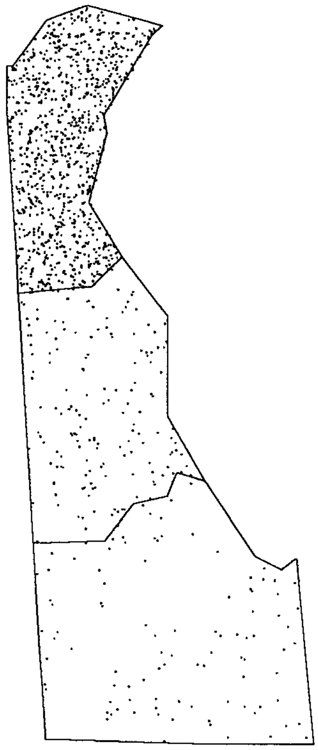
Aquifer Vulnerability Map of Delaware



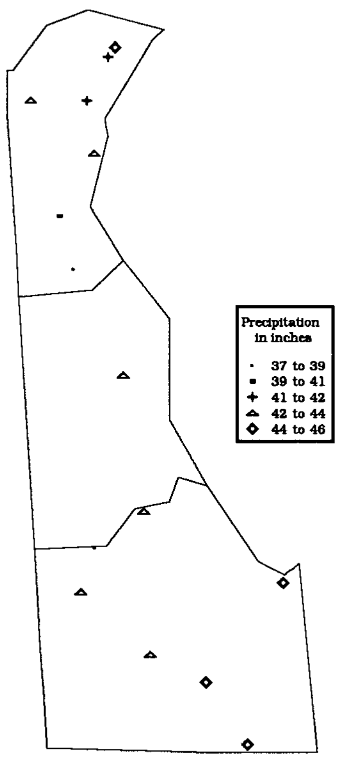
Potential Well Yields in Delaware

Areas covered by class I aquifers.
Each dot represents a population center.

Aquifer Sensitivity Map of Deleware



Population Density of Delaware
(Dot equals one person per square mile)



Average Annual Precipitation in Delaware

MARYLAND

General Setting

Maryland, which contains approximately 10,460 square miles, lies within the Coastal Plain, Piedmont, Blue Ridge, Valley and Ridge, and Appalachian Plateaus provinces. The flat lying Coastal Plain, which is east of the Fall Line, is underlain by gently dipping, Cretaceous to Quaternary age sand and gravel deposits. West of the Fall Line the topography ranges from gently rolling to rugged, and is underlain by Precambrian to Middle Paleozoic age folded and faulted consolidated sedimentary, metamorphic, and igneous rocks.

Western Maryland is drained by the Potomac River, and the Coastal Plain in eastern Delaware is drained by several small river systems, which empty into Chesapeake Bay. Average annual precipitation in Maryland is about 42 inches, and the greatest amount, more than 50 inches, occurs in far western Maryland. Slightly more precipitation occurs in spring and summer than in fall and winter. Maryland's population, approximately 4.6 million, is centered in and around Washington D.C. and Baltimore. The remainder of the state is moderately populated. About 219 million gallons of fresh ground water are used daily in Maryland.

Unconsolidated Aquifers (Class Ia)

A wedge of sediments underlies the Coastal Plain. This mass varies in thickness from a few feet near the Fall Line to more than 8,000 feet in the southeastern part of Maryland. These Cretaceous to Quaternary age deposits generally are unconsolidated with local areas of slight cementation. The deposits consist of interbedded sand, gravel, silt, and clay with some shell beds. Well yields commonly range from 10 to 500 gpm, and may exceed 2,000 gpm. About 56 percent of Maryland is covered by Class Ia deposits.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Carbonate aquifers occur intermittently west of the Fall Line. Where present, solutional features contribute to the vertical and lateral permeability of the rock. These folded Cambrian to Late Paleozoic age rocks consist of limestone, dolomite, marble, and some shale. Well yields commonly range from 5 to 200 gpm, and may exceed 500 gpm. Surface exposures of soluble aquifers occupy about 7 percent of Maryland.

Higher Yield Bedrock Aquifers (Class IIa)

Higher yield sedimentary bedrock aquifers occur in central Maryland. These Triassic age units include sandstone, siltstone, and shale with some diabase dikes and sills. Well yields commonly range from 10 to 100 gpm, and may exceed 800 gpm. Higher yield bedrock aquifers occupy about 1.3 percent of Maryland.

Lower Yield Bedrock Aquifers (Class IIb)

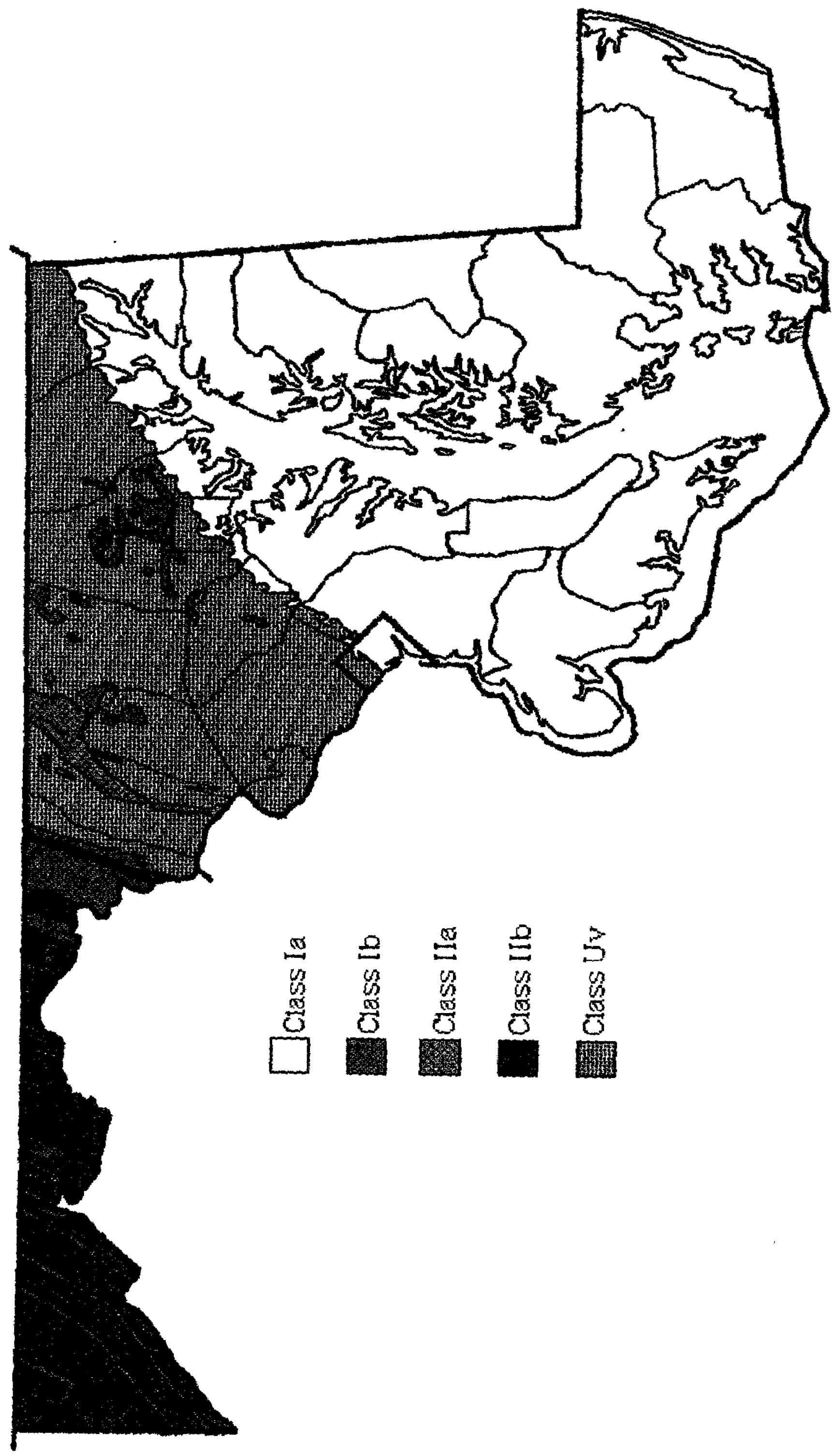
Exposed in western Maryland are folded and faulted lower yield sedimentary units. These Middle to Upper Paleozoic units consist of sandstone, shale, and siltstone. Well yields commonly range from 2 to 50 gpm, and may exceed 200 gpm. Lower yield bedrock aquifers occupy nearly 10 percent of Maryland.

Variably Covered Undifferentiated Aquifers (Class U-v)

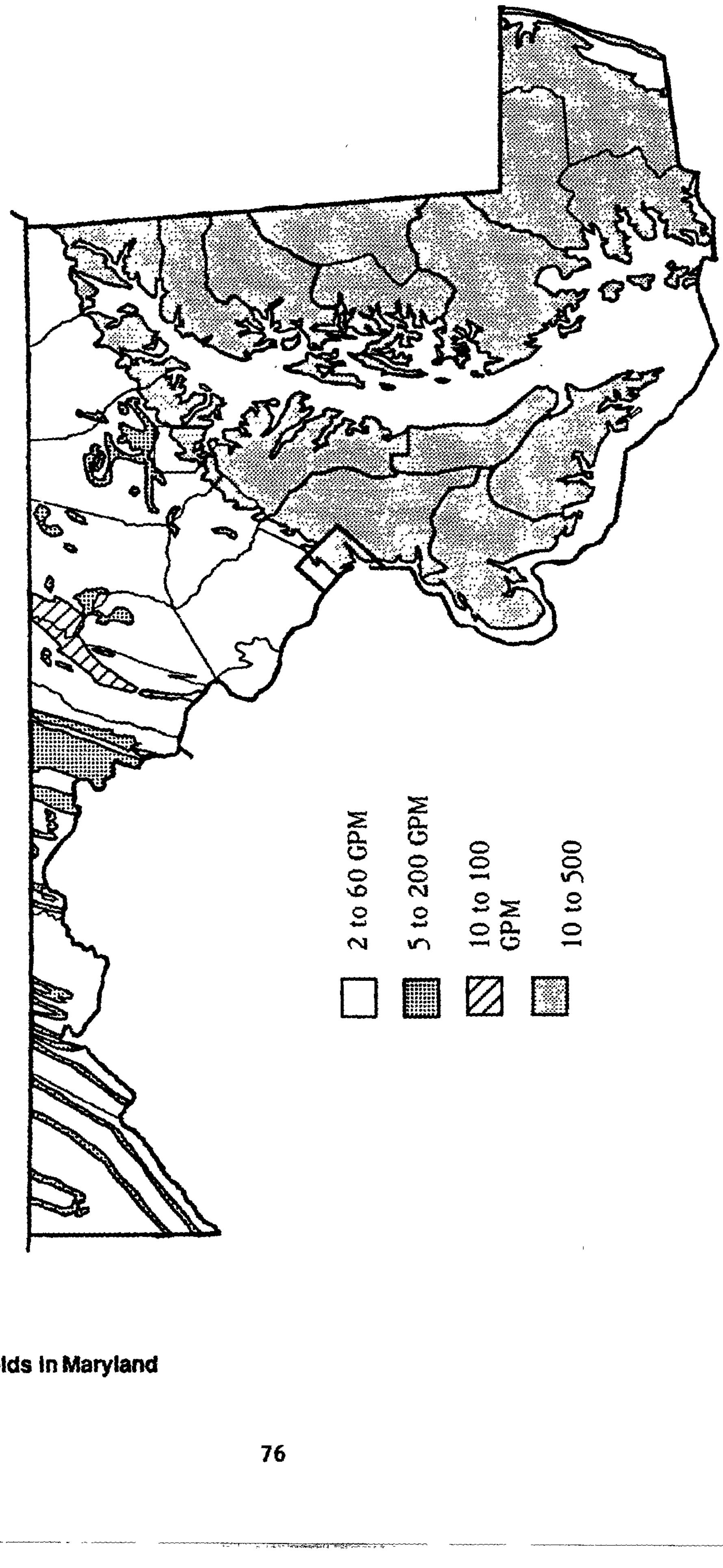
Exposed in central Maryland are Precambrian to Lower Paleozoic metamorphic and metamorphosed igneous rocks, which include schist, gneiss, and phyllite. Well yields commonly range from 2 to 60 gpm, and may exceed 200 gpm. Even though these crystalline units have a range that commonly exceeds 50 gpm, it was classified as a lower yield aquifer because it better represents the general yield characteristics. Class U-v aquifers account for 26 percent of Maryland.

Sensitivity

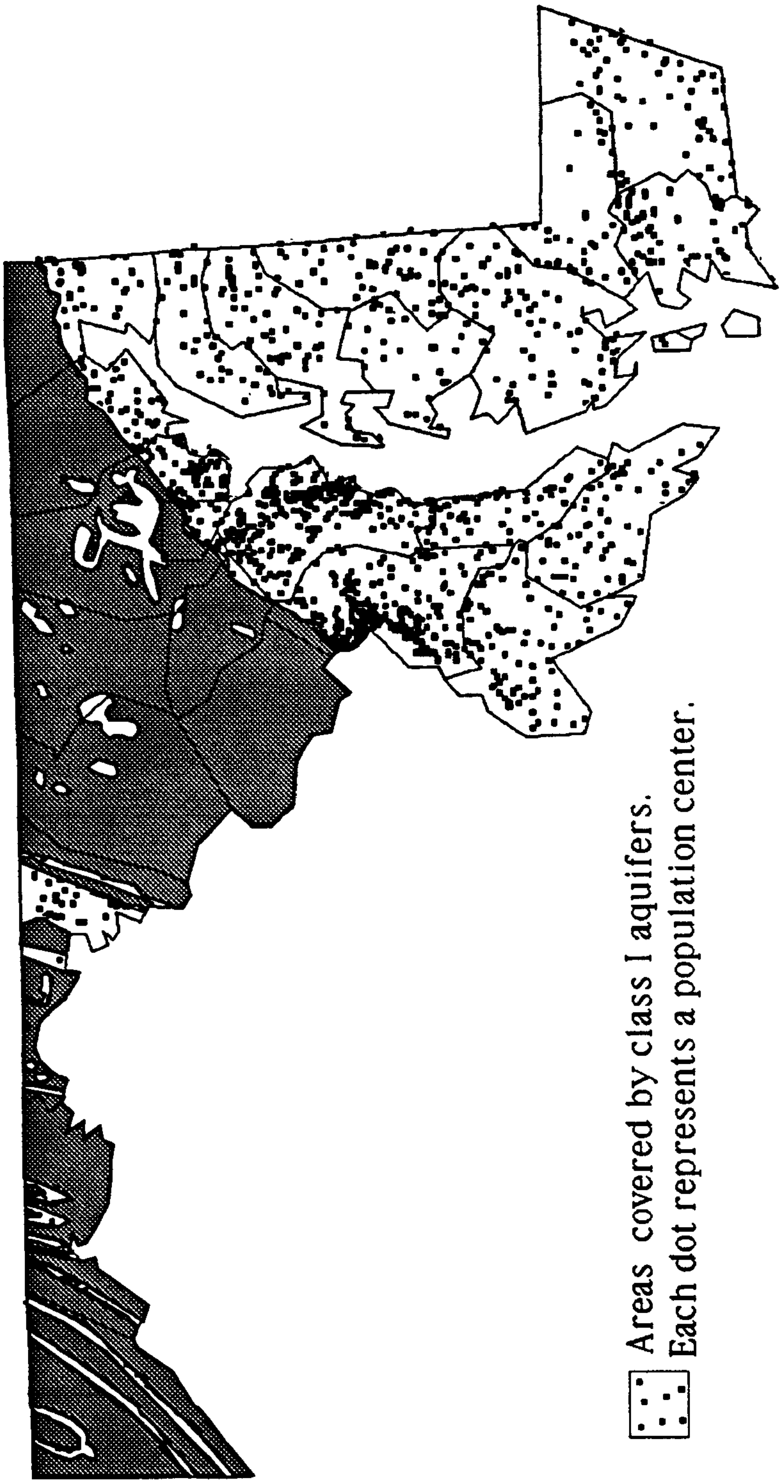
About 63 percent of Maryland is covered by vulnerable Class I deposits. Aquifer sensitivity to ground-water contamination from shallow injection wells is particularly high in the populated areas along the west side of Chesapeake Bay, and to a smaller extent on the east side of the Bay.



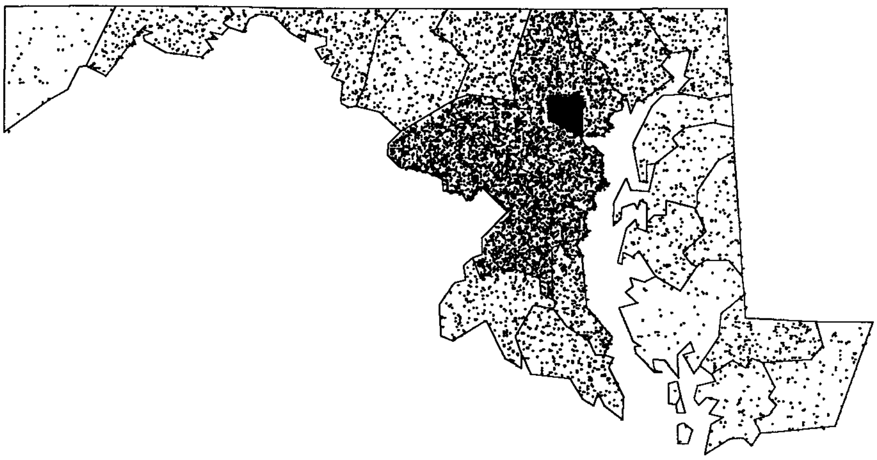
Aquifer Vulnerability Map of Maryland



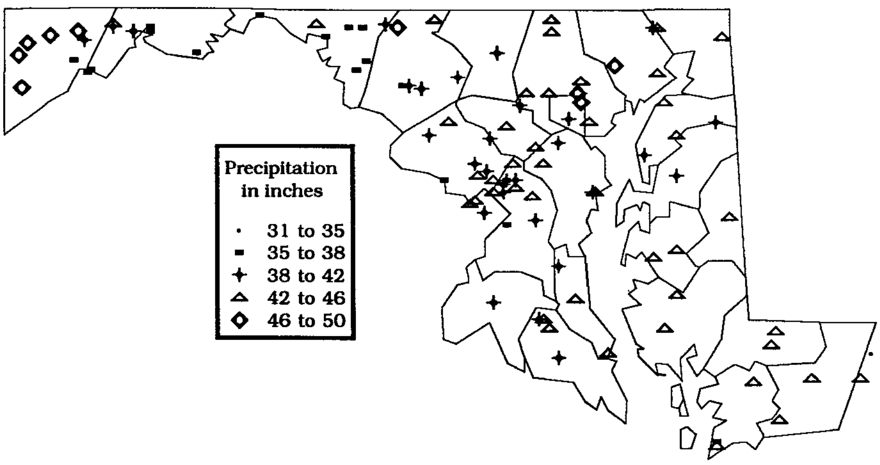
Potential Well Yields in Maryland



Aquifer Sensitivity Map of Maryland



Population Density of Maryland (Dot equals one person per square mile)



Average Annual Precipitation in Maryland

PENNSYLVANIA

General Setting

Pennsylvania contains approximately 45,300 square miles, and lies within four physiographic provinces. The western and northern parts of the state, which are in the Appalachian Plateaus, are underlain by Devonian to Permian age, generally horizontal sedimentary rocks. The Valley and Ridge and Piedmont provinces are characterized by folded and faulted Cambrian to Mississippian age crystalline and sedimentary rock. The Coastal Plain in southeastern Pennsylvania is overlain by unconsolidated Quaternary age deposits. Northwest and northeastern Pennsylvania are mantled by glacial deposits.

Western Pennsylvania is drained largely by the Allegheny River and its tributaries, while the central and eastern parts of the state are drained by Susquehanna and Delaware river systems. Average annual precipitation ranges from 36 inches in the north and west to 48 inches in the east. Pennsylvania's population, about 12 million, is concentrated in the Philadelphia and Pittsburgh areas. The remainder of the state is moderately populated. About 799 million gallons of fresh ground water are used daily in Pennsylvania.

Unconsolidated Aquifers (Class Ia)

Occurring generally along streams in the northern part of Pennsylvania are Quaternary age unconsolidated aquifers. These alluvial and stratified glacial deposits consist of sand and gravel with varying amounts of silt and clay. Well yields generally range from 100 to 1,000 gpm, and may exceed 2,300 gpm. About 8.5 percent of the state is covered by unconsolidated aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Northeast-southwest trending bands of Cambrian and Ordovician age karst carbonate rocks occur in central and southeastern parts of the state. These aquifers consist largely of limestone and dolomite, although there are some units of shale and sandstone. Where present, solutional features contribute to the lateral and vertical permeability of the rock. Well yields commonly range from 5 to 500 gpm, and may exceed 2,250 gpm. About 8 percent of the state is occupied by Class Ib aquifers.

Variably Covered Soluble and Fractured Bedrock Aquifers (Class Ib-v)

A small exposure of variably covered Ordovician age carbonate aquifer occurs in east-central Pennsylvania. The bedrock is composed of limestone, dolomite, shale, and sandstone. The vulnerability of this system is a function of the thickness of the overlying glacial till. Well yields commonly range from 5 to 500 gpm, and may exceed 2,250 gpm. About 1 percent of the state is covered by Class Ib-v aquifers.

Lower Bedrock Aquifers (Class IIb)

Underlying the majority of Pennsylvania are Ordovician to Permian age sedimentary rock aquifers that consist of cyclic sequences of sandstone and shale with lesser amounts of limestone. Well yields commonly range from 5 to 60 gpm, but they may exceed 600 gpm. About 55 percent of the state is overlain with lower yield bedrock aquifers.

Variably Covered Low Yield Bedrock Aquifers (Class IIb-v)

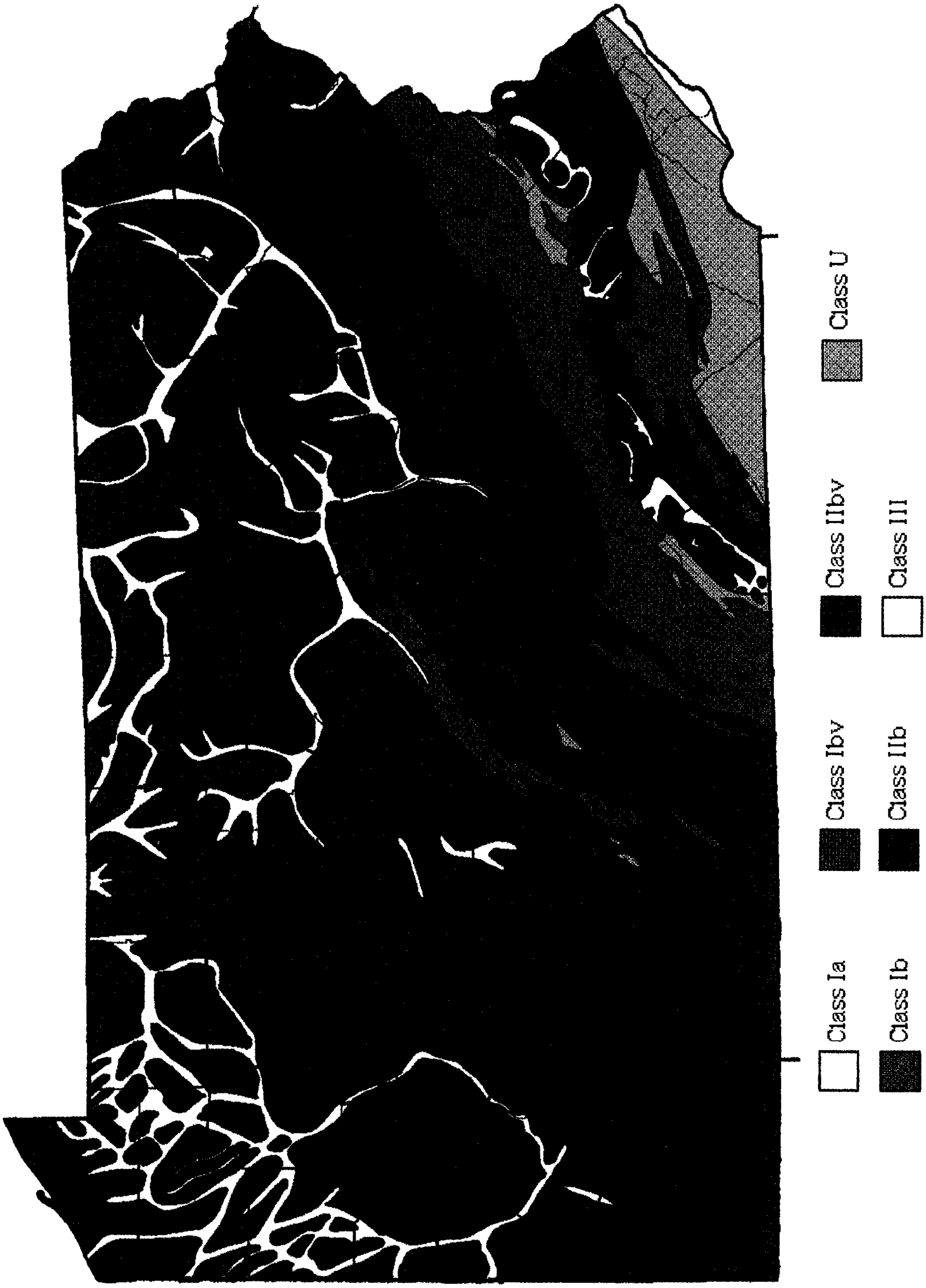
Variably covered lower yield bedrock aquifers occur in the northwest and northeast parts of Pennsylvania. These Devonian to Pennsylvanian age rocks, which consist of sandstone, shale, and limestone, are mantled by a variable thickness of glacial till. Their vulnerability is a function of the thickness and permeability of the overlying till. Well yields commonly range from 5 to 60 gpm, and may exceed 600 gpm. About 22 percent of the state is occupied by Class IIb-v aquifers.

Undifferentiated Aquifers (Class U)

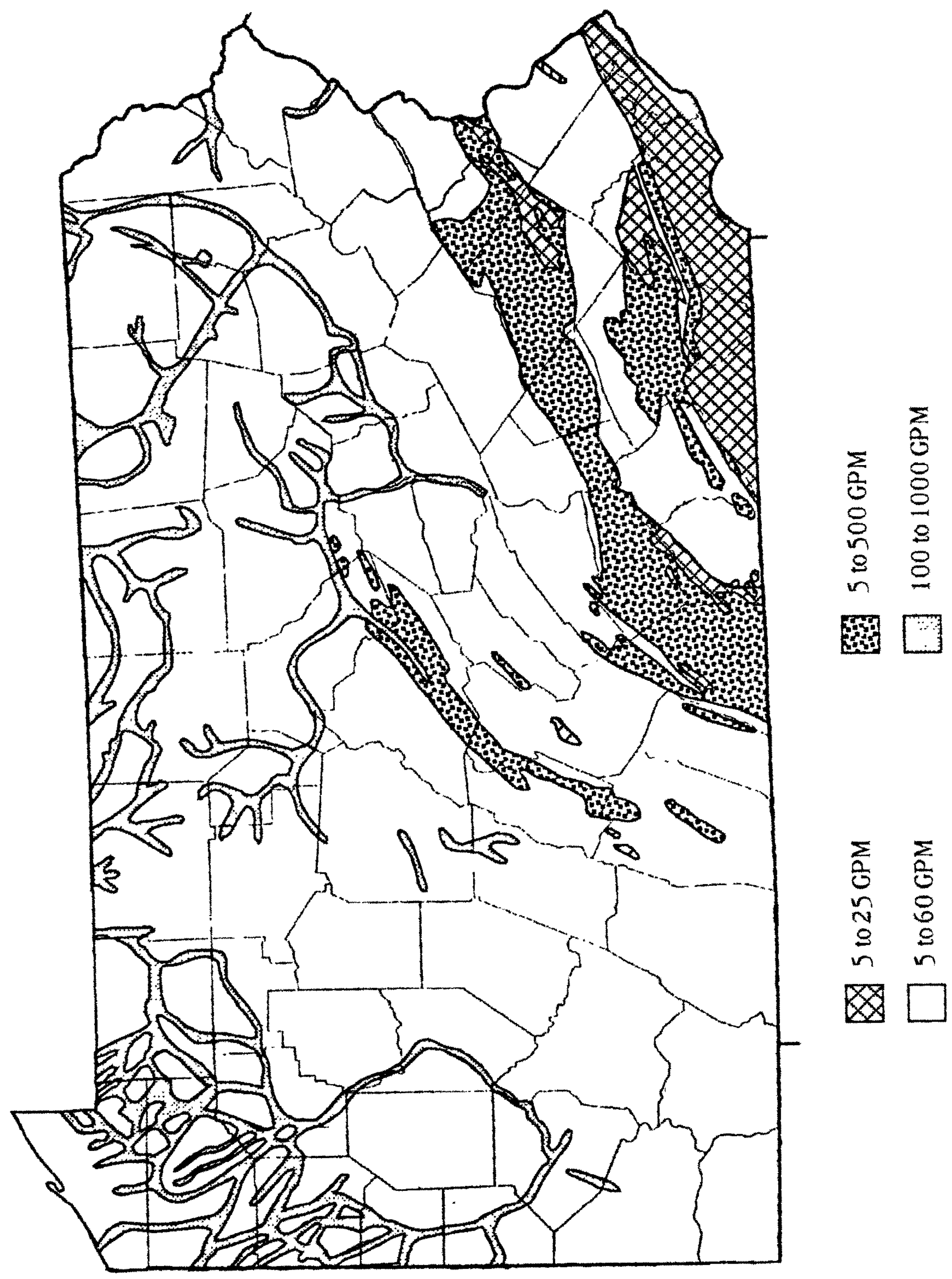
Undifferentiated Precambrian to Ordovician age bedrock aquifers are present in the southeastern part of Pennsylvania. These units consist of crystalline, clastic, and some carbonate rock. Well yields commonly range from 5 to 25 gpm, and may exceed 220 gpm. About 4 percent of the state is occupied by undifferentiated bedrock aquifers.

Sensitivity

Nearly 18 percent of Pennsylvania is covered by vulnerable Class I aquifers. The most sensitive areas lie in the vicinity of Philadelphia, along southwestward-trending belts from Reading to York, Allentown through Harrisburg, and from Williamsport to Altoona. Sensitive reaches also occur along major rivers, such as the Susquehanna and Allegheny rivers, among others.

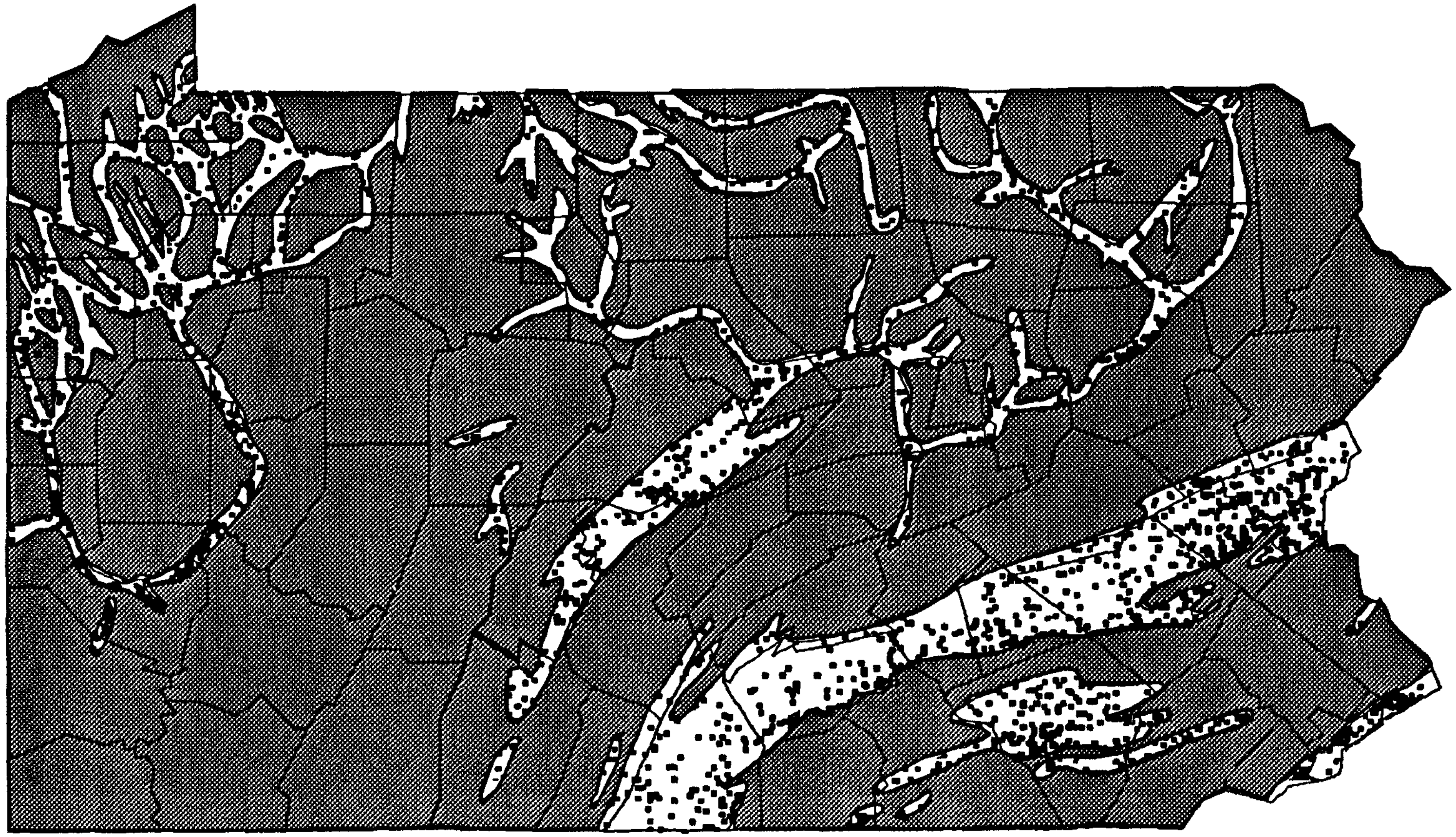


Aquifer Vulnerability Map of Pennsylvania

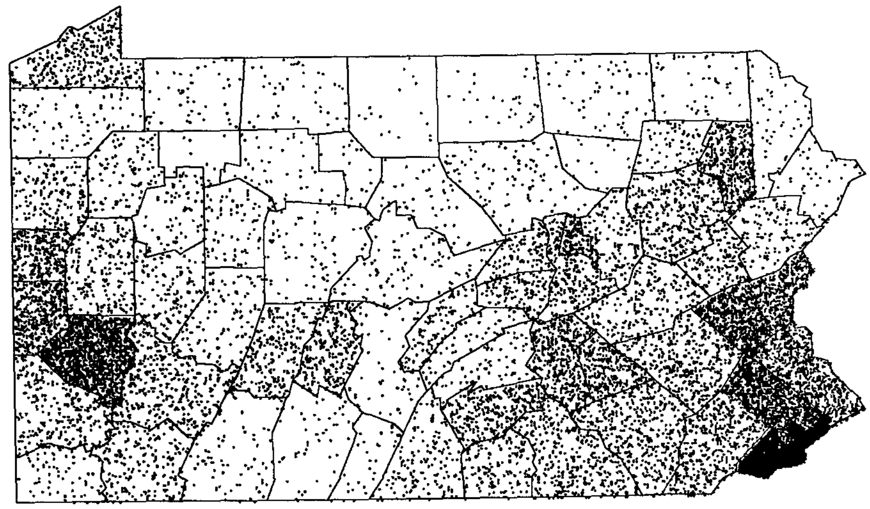


Potential Well Yields in Pennsylvania

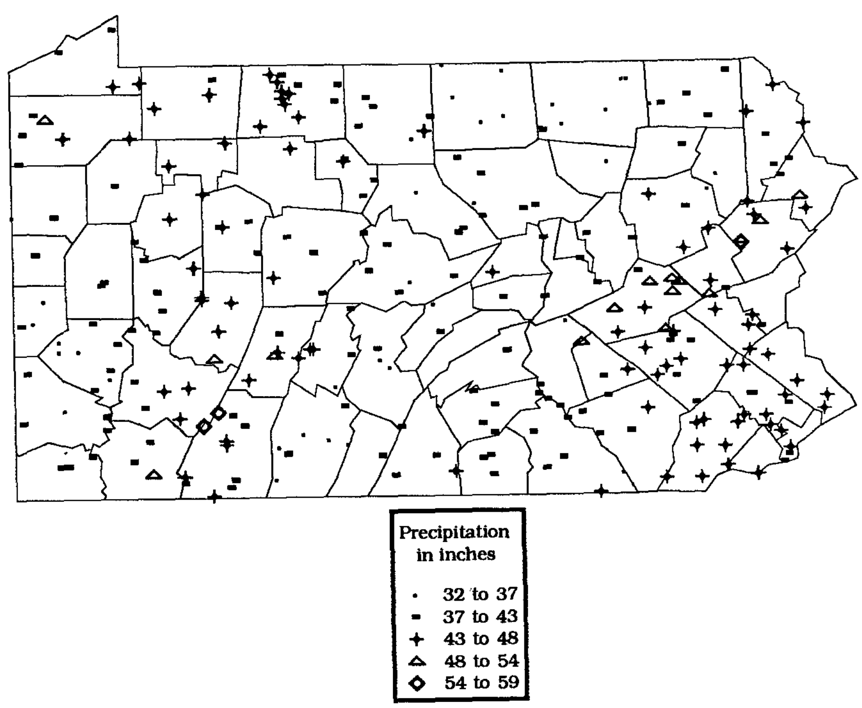
Aquifer Sensitivity Map of Pennsylvania



Areas covered by class I aquifers.
Each dot represents a population center.



Population Density of Pennsylvania (Dot equals one person per square mile)



Average Annual Precipitation in Pennsylvania

VIRGINIA

General Setting

Virginia contains approximately 40,800 square miles. The mountainous western third of the state lies in the Appalachian Plateaus and Valley and Ridge physiographic provinces. Rolling hills and valleys of the Blue Ridge and Piedmont in central Virginia give way to the flat-lying Coastal Plain to the east. The Coastal Plain is underlain by an eastward dipping sequence of Cretaceous to Holocene age unconsolidated, marine-terrace and alluvial deposits. The central part of the state consists of a folded and faulted sequence of Precambrian to Mesozoic age metamorphic, igneous, and sedimentary rocks that are commonly overlain by regolith. A thick sequence of folded and faulted carbonate and clastic sedimentary rocks of Paleozoic age underlie the western part of Virginia.

Western Virginia is drained by several southwest-flowing rivers. The remainder of the state is drained by a network of east-southeast flowing water courses. Annual precipitation ranges from 50 inches in the southeast and southwest to 36 inches along the western part of the state. Precipitation is distributed fairly evenly throughout the year. The majority of Virginia's population, approximately 6 million, is concentrated in the eastern part of the state. The remainder of the state is only moderately populated. Daily use of fresh and saline ground water amounts to about 341 and .2 million gallons, respectively.

Unconsolidated Aquifers (Class Ia)

The unconsolidated sediments that make up Virginia's Coastal Plain form vulnerable and productive aquifers. Alluvial, marsh, lagoonal, and beach deposits consist of unconsolidated sand and gravel that commonly is interbedded with silt and clay. Well yields range from 5 to 250 gpm, and may exceed 350 gpm. Marine-terrace deposits consist of unconsolidated, shelly, and moderately glauconitic sand that is interbedded with silt, clay, gravel, and thin indurated shell beds. Well yields commonly range from 5 to 1,500 gpm, and may exceed 2,500 gpm. About 24 percent of the state is covered by unconsolidated deposits.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Karst features are present in limestone and dolomite units in western Virginia. Minor amounts of argellaceous sandstone and shale occur within these units. Where present, karst features contribute to the vertical and lateral permeability of the rock, creating highly productive and vulnerable aquifers. Well yields commonly range from 50 to 500 gpm, and locally may exceed 3,000 gpm. Surface exposures of soluble aquifers occupy about 23 percent of Virginia.

Higher Yield Bedrock Aquifers (Class IIa)

Higher yield bedrock aquifers are exposed locally in the central part of the state. These aquifers consist of arkosic sandstones, shales, and conglomerates that have been intruded in the north. Well yields commonly range from 10 to 100 gpm, and may exceed 1,000 gpm. Surface exposures of higher yield bedrock aquifers occupy about 3.3 percent of Virginia.

Lower Yield Bedrock Aquifer (Class IIb)

Lower yield bedrock aquifers are exposed throughout southwestern Virginia. These Pennsylvanian age aquifers consist of interbedded sandstone, shale, siltstone and coal. Well yields commonly range from 1 to 50 gpm, and may exceed 200 gpm. Surface exposures of lower yield bedrock aquifers occupy about 5 percent of the state.

Undifferentiated Aquifers (Class U)

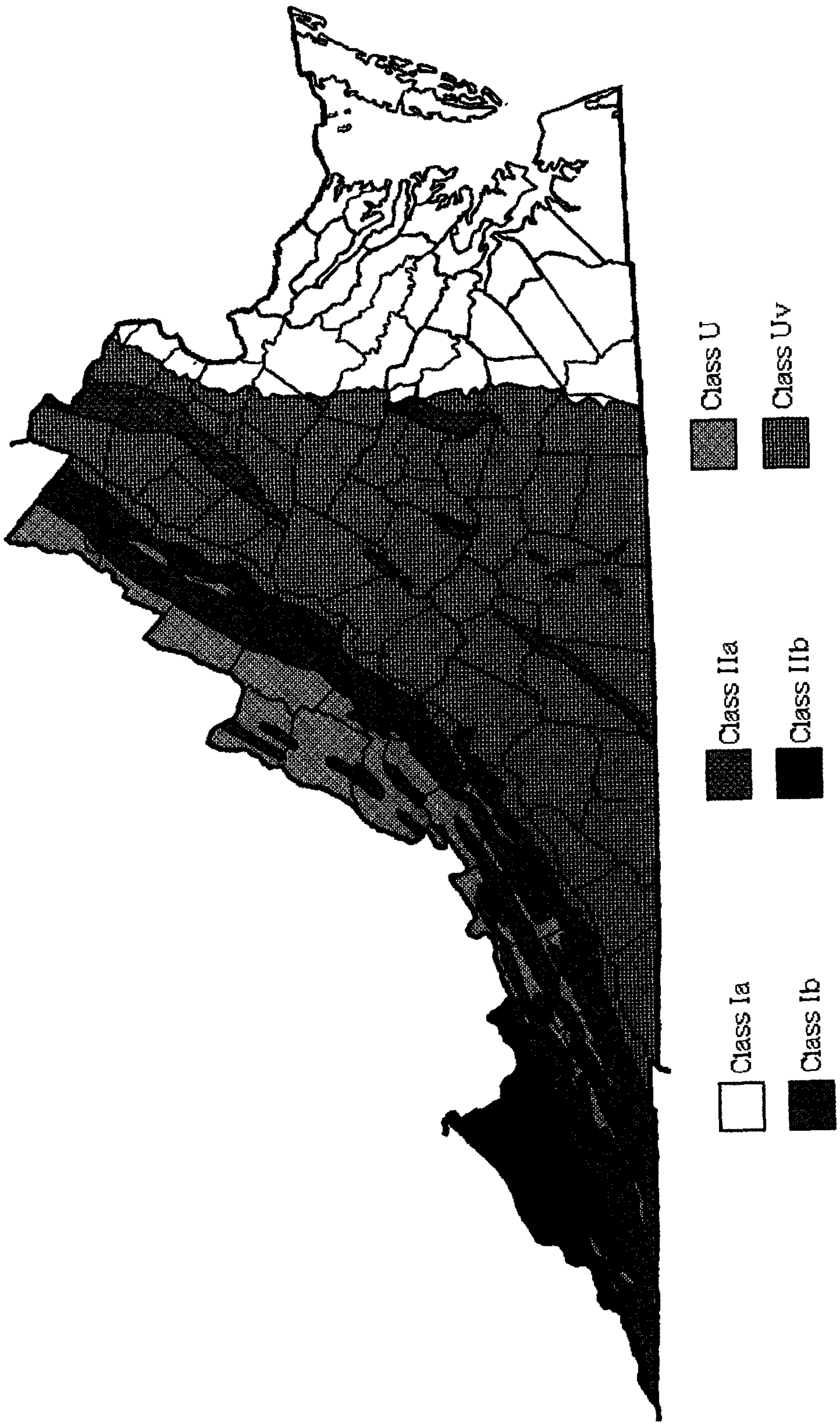
Several undivided and lithologically varied Middle Paleozoic age formations, which crop out along the western margin of Virginia, consist of folded and faulted limestone, dolomite, shale, sandstone, siltstone, and chert. The lithologic and resultant hydrologic variability of these undivided formations have not been delineated. A wide range in aquifer productivity and vulnerability should be expected. Surface exposures of undifferentiated aquifers occupy about .9 percent of the state.

Variably Covered Undifferentiated Aquifers (Class U-v)

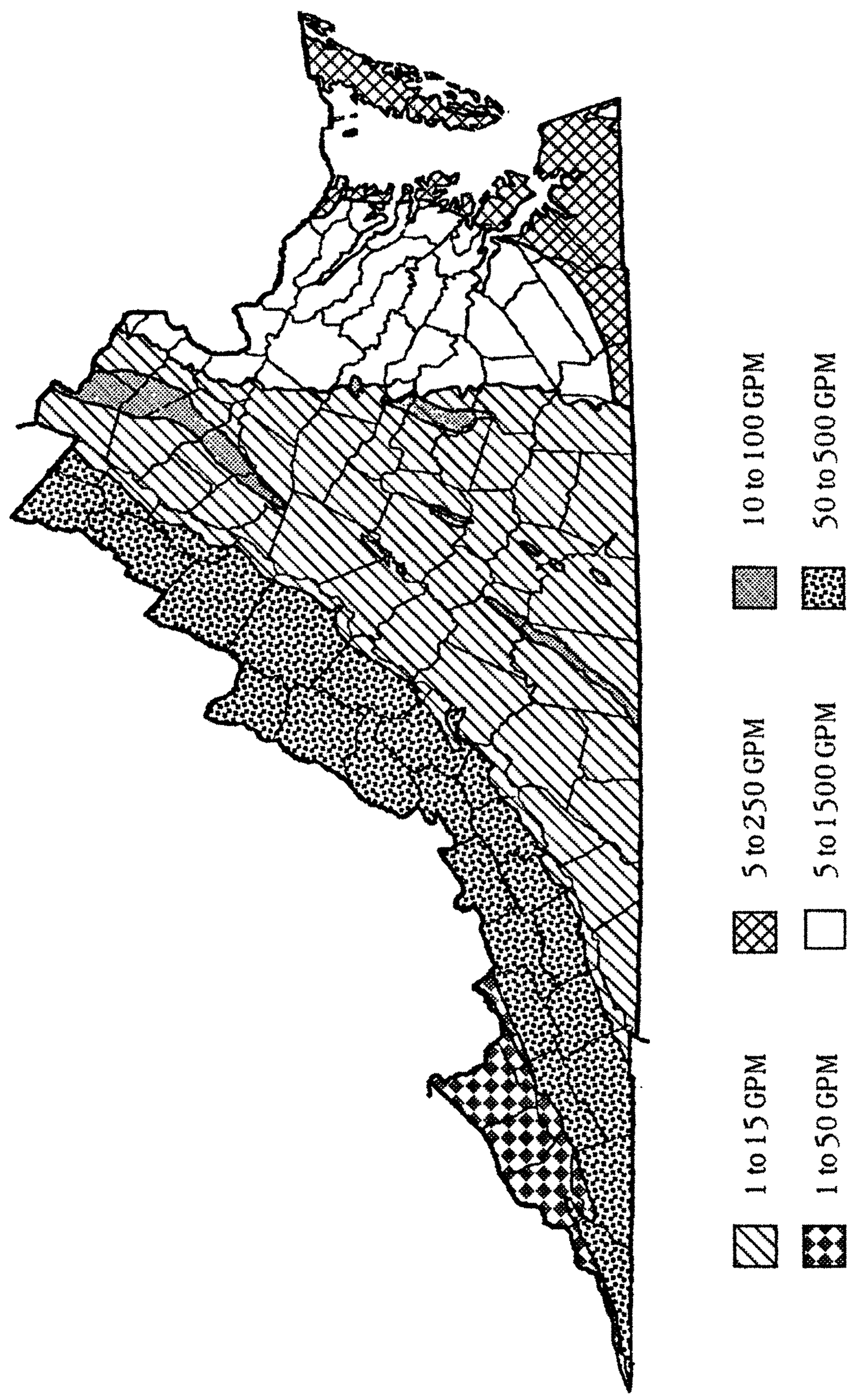
Within the central part of the state, aquifers consist of locally fractured metamorphic and igneous rocks that are commonly overlain by regolith that may exceed 100 feet in thickness. Well yields commonly range from 1 to 15 gpm, and may exceed 200 gpm. Aquifer productivity is dependent on the interception of fractures and vulnerability is related to the thickness of the regolith. The saturated regolith facilitates aquifer recharge. Class U-v aquifers occupy about 43 percent of Virginia.

Sensitivity

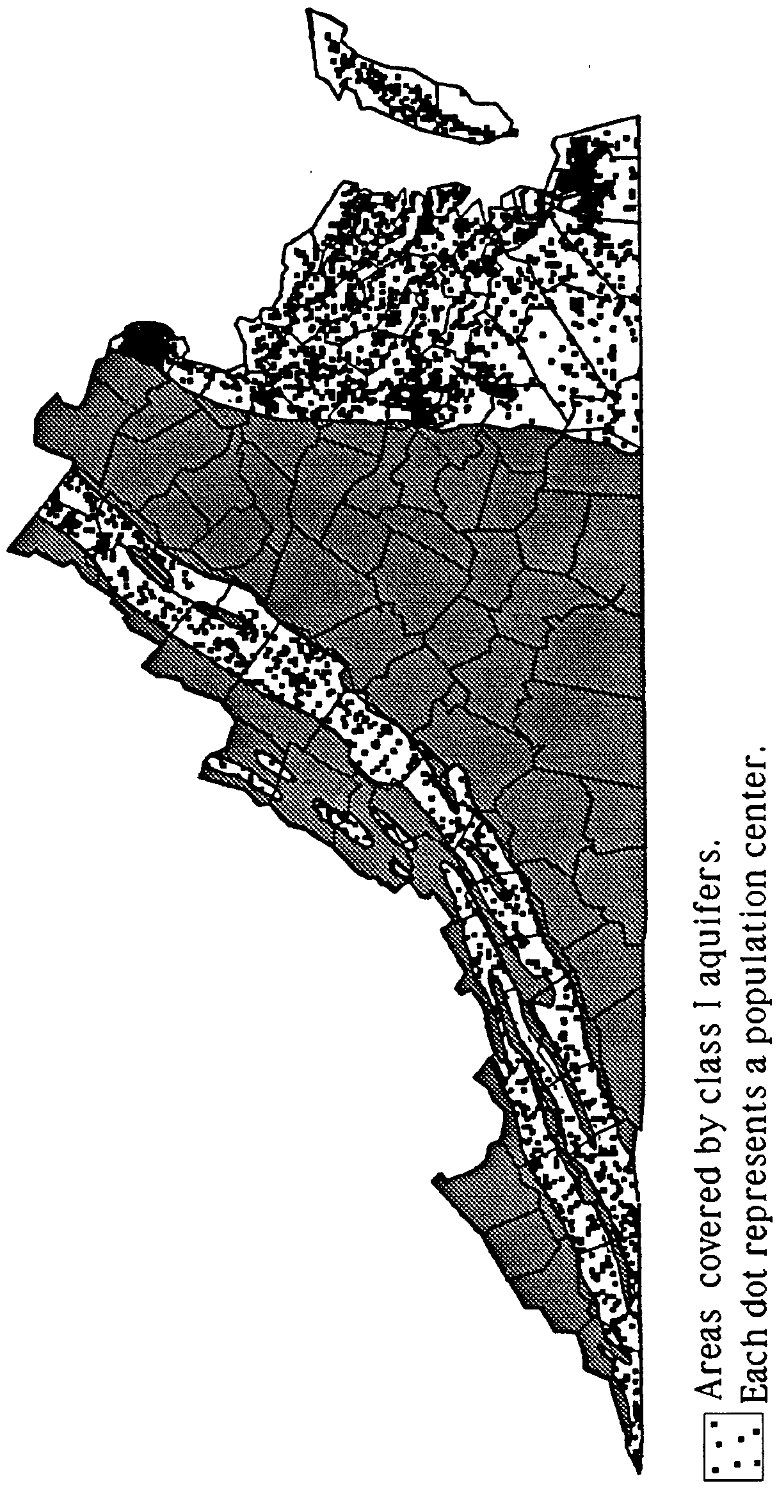
About 47 percent of Virginia is covered by Class I aquifers. Aquifer sensitivity is moderate to high in the eastern quarter of the state and moderate along the western margin where vulnerable aquifers crop out.



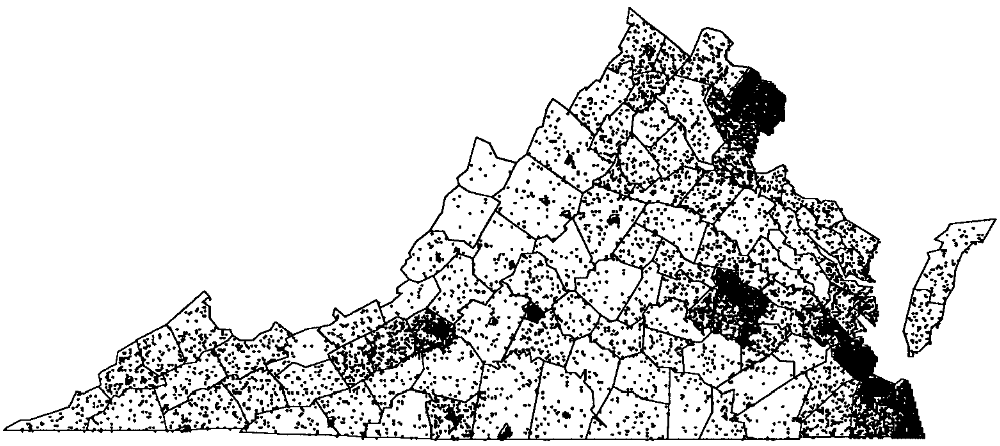
Aquifer Vulnerability Map of Virginia



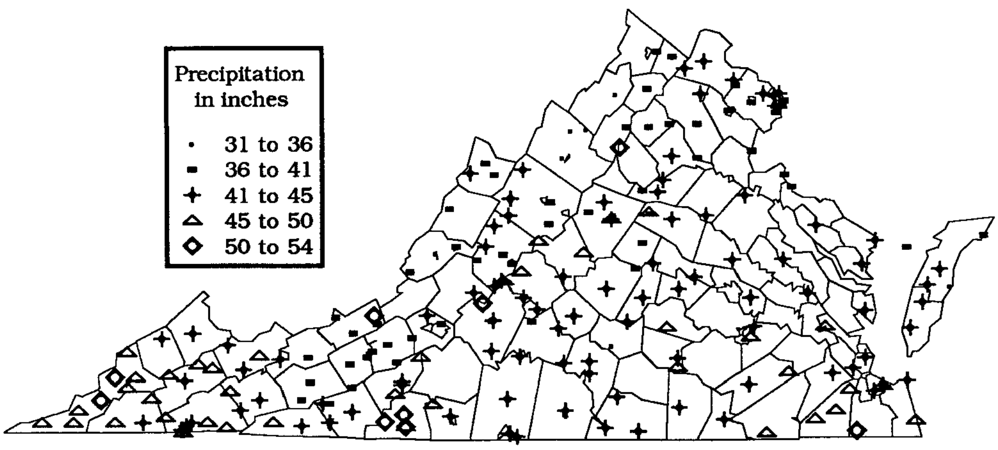
Potential Well Yields in Virginia



Aquifer Sensitivity Map of Virginia



Population Density of Virginia (Dot equals one person per square mile)



Average Annual Precipitation in Virginia

WEST VIRGINIA

General Setting

West Virginia contains approximately 24,200 square miles, and lies in the steep hills and incised valleys and ridges of the Appalachian Plateaus, Valley and Ridge, and Blue Ridge physiographic provinces. Exposures of broadly folded Mississippian to Permian age non-marine and marine cyclic sequences of sandstone, siltstone, shale, limestone, coal, and conglomerate occur throughout western and central West Virginia. Faulted and tightly folded Ordovician to Devonian age marine and non-marine limestone, dolomite, shale, sandstone, conglomerate, and anhydrite occur in the eastern part of the state. Carbonate units, commonly cherty and argillaceous, range from non-fossiliferous to bioclastic. Sandstones commonly are hematitic and calcareous; shales may be fissile.

Except for the eastern part of West Virginia, the entire state is drained by the Ohio River and its northwest flowing tributaries. The eastern part of the state is drained by the Potomac River. Annual precipitation, which is distributed fairly evenly throughout the year, ranges from about 30 inches in the east to about 60 inches in east-central West Virginia. The majority of West Virginia's population, approximately 1.88 million, is located along the Ohio and Kanawha river valleys. The remainder of the state is sparsely to moderately populated. About 227 million gallons of fresh ground water are used daily.

Unconsolidated Aquifers (Class Ia)

Alluvial deposits largely occur along the Ohio, Kanawha, and Little Kanawha river valleys. These generally unconfined systems, which form vulnerable and productive aquifers, consist of unconsolidated sand and gravel that is interbedded with silt and clay. Well yields commonly range from 50 to 1,500 gpm, and may exceed 3,000. About 7.4 percent of the state is covered by Class Ia aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Solutional features are present in the moderately folded Mississippian age limestones that are exposed in southeastern West Virginia. Marine and non-marine shale and minor sandstone units occur within the section. Where present, solutional features contribute to the vertical and lateral permeability of the rock. Well yields commonly range from 1 to 100 gpm, and may exceed 200 gpm. Yields of springs range from 50 to 2,000 gpm. Solutional features also are present in the highly folded Cambrian and Ordovician age carbonate rocks that are exposed in the extreme northeast part of the state. These units primarily consist of limestone, and contain sandstone, shale, and dolomite interbeds. Limestones are commonly argillaceous, siliceous, and fossiliferous, and well yields from them commonly range from 2 to 400 gpm, although yields may exceed 600 gpm. Discharge from springs range from 50 to 5,000 gpm. Surface exposures of soluble aquifers occupy nearly 3 percent of the state.

Higher Yield Bedrock Aquifers (Class IIa)

Higher yield Mississippian and Pennsylvanian age aquifers, composed chiefly of broadly folded shale, sandstone, siltstone, coal, and minor amounts of limestone, crop out across southwest, east-central, and northeast West Virginia. Well yields range from 1 to 100 gpm, and may exceed 300 gpm. Class IIa aquifers occupy about 39 percent of West Virginia.

Lower Yield Bedrock Aquifers (Class IIb)

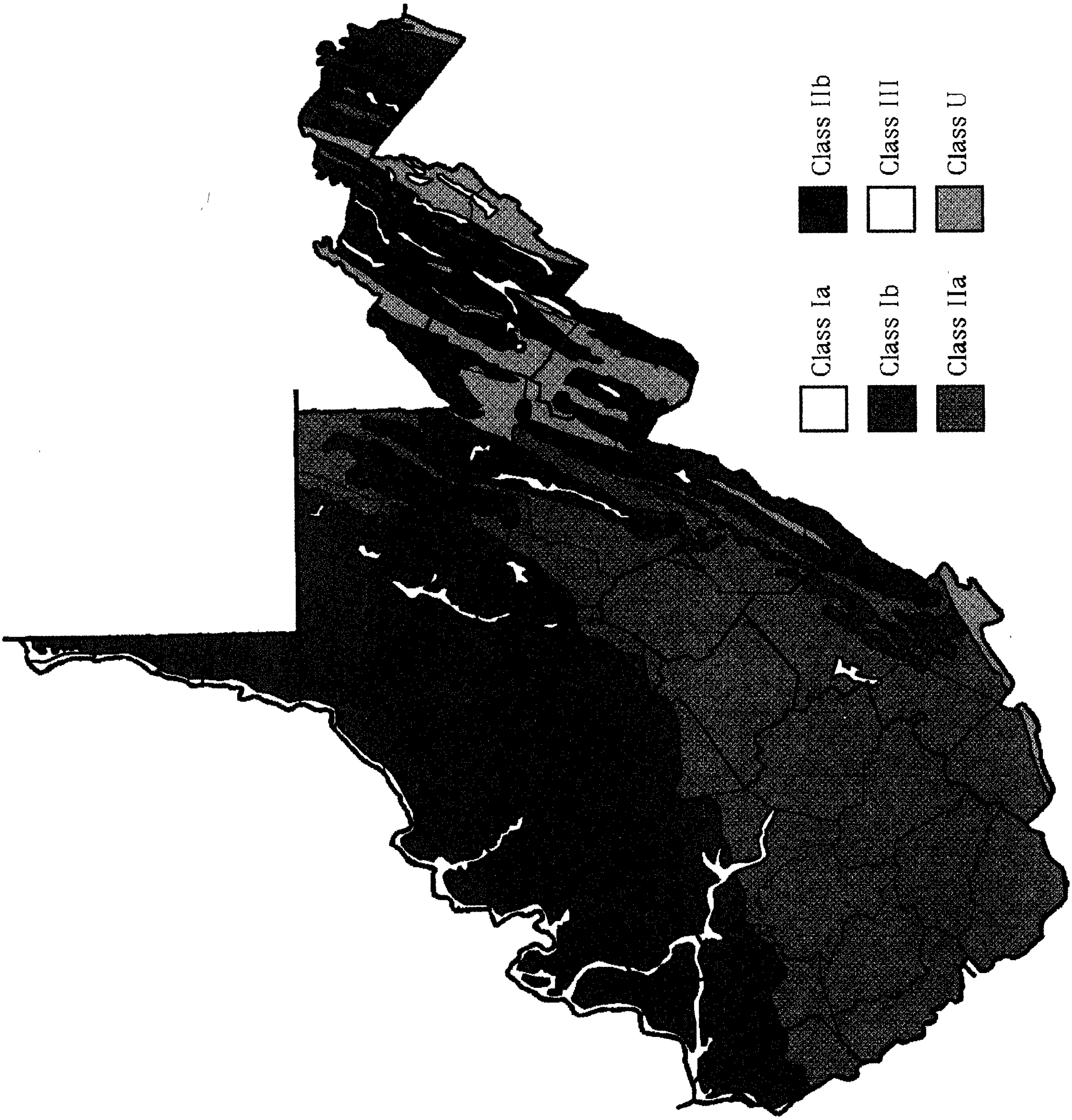
Lower yield Paleozoic age aquifers, composed of nearly horizontal to tightly folded sandstone, shale, siltstone, and minor limestone and coal, crop out across northwestern, eastern, and southeastern West Virginia. Well yields commonly range from 1 to 30 gpm, and may exceed 200 gpm. Class IIb aquifers occupy about 7.4 percent of the state.

Undifferentiated Aquifers (Class U)

Several undivided and lithologically varied Paleozoic age formations crop out in the eastern and southeastern parts of the state. These strata largely consist of folded, interbedded sandstone, shale, limestone, dolomite, and siltstone, with a minor amount of chert. The lithologic and hydrologic variability of these undivided formations have not been delineated. A wide range in aquifer yield and vulnerability should be expected in these areas. Undifferentiated aquifers occupy about 43 percent of West Virginia.

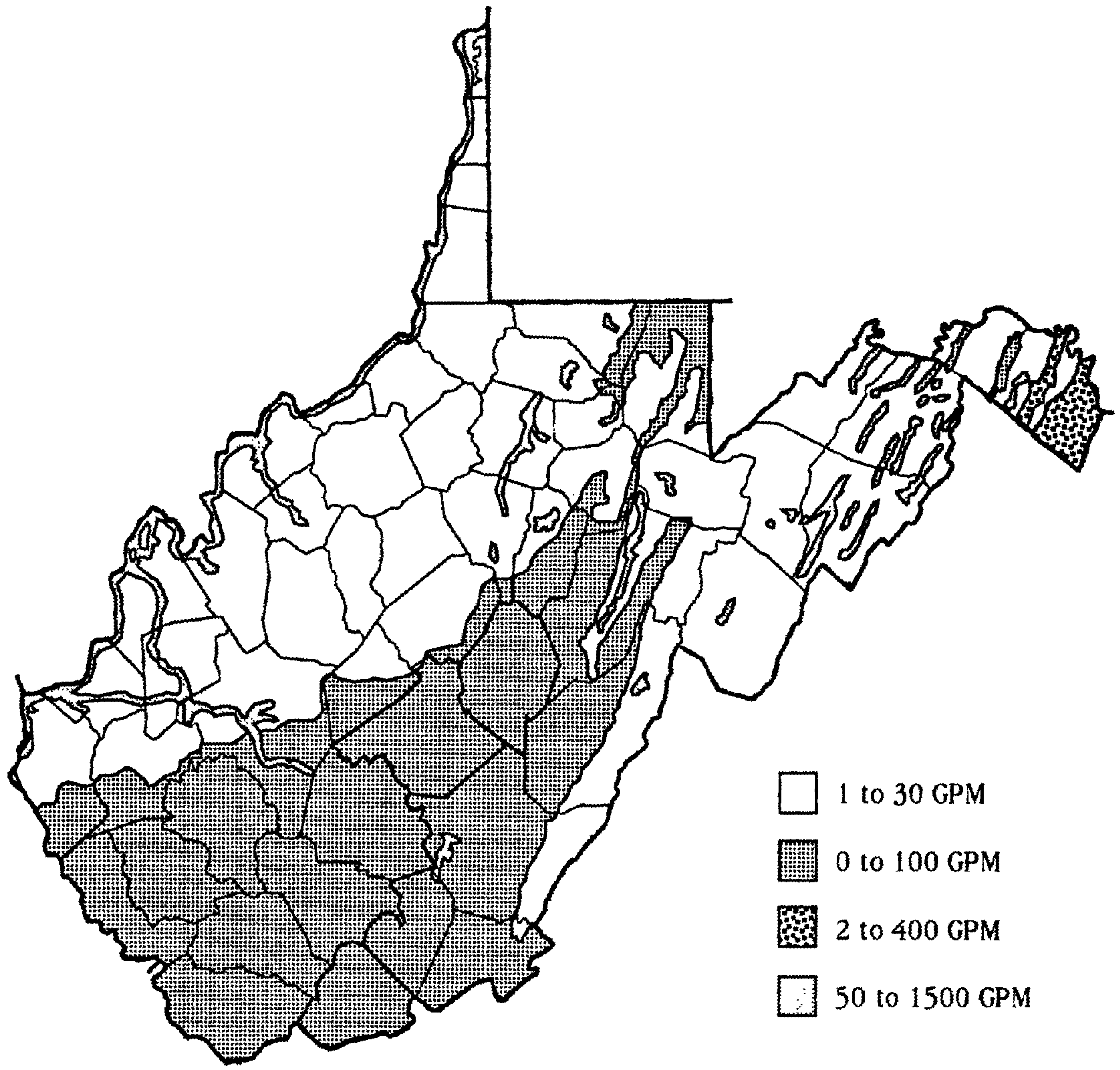
Sensitivity

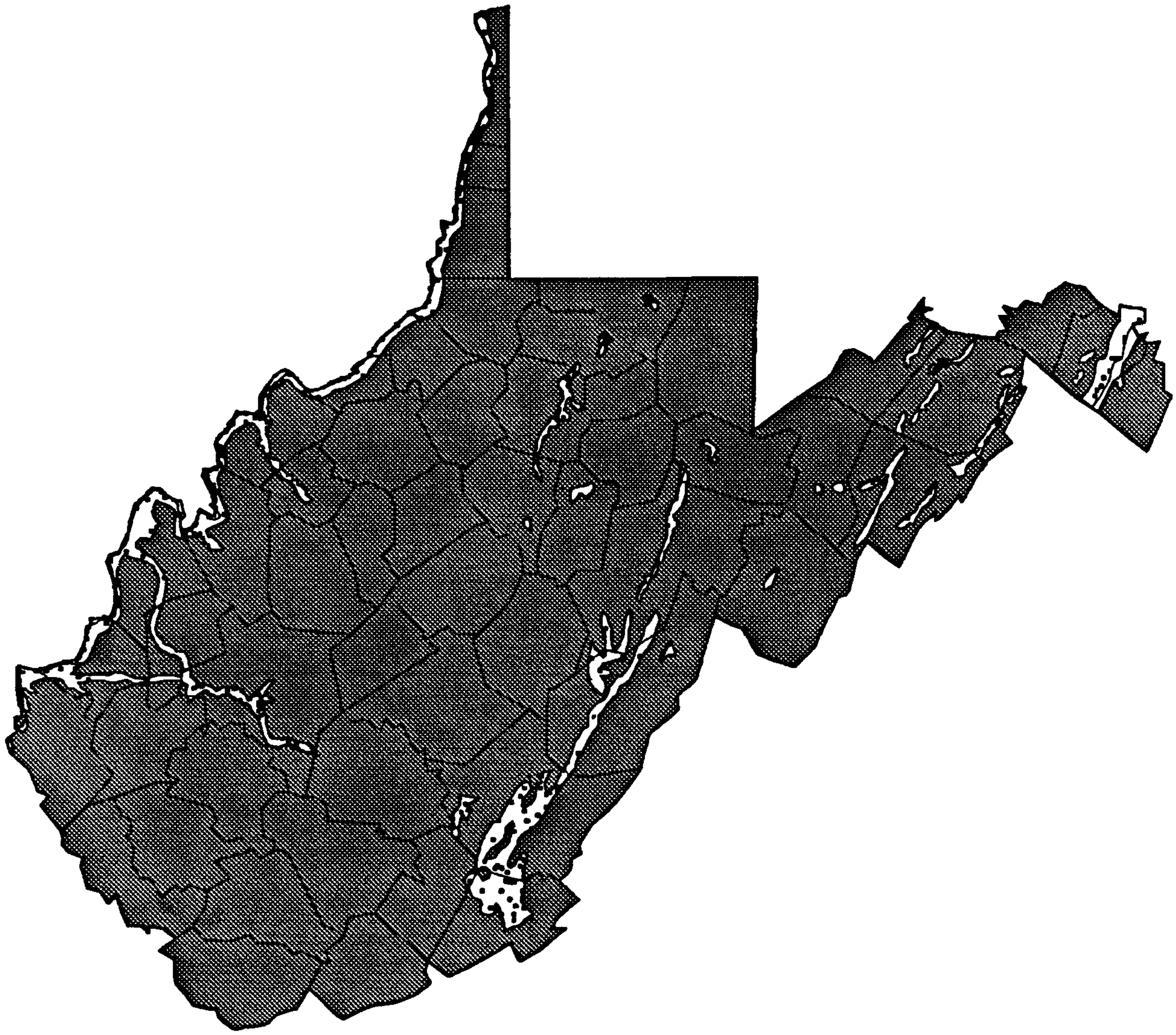
About 10 percent of West Virginia is covered by Class I aquifers. The potential for ground-water contamination from shallow injection wells is small owing to West Virginia's low population density. The most sensitive areas lie along major river valleys, particularly the Ohio River valley where there is a considerable number of population centers and industry.



Aquifer Vulnerability Map of West Virginia

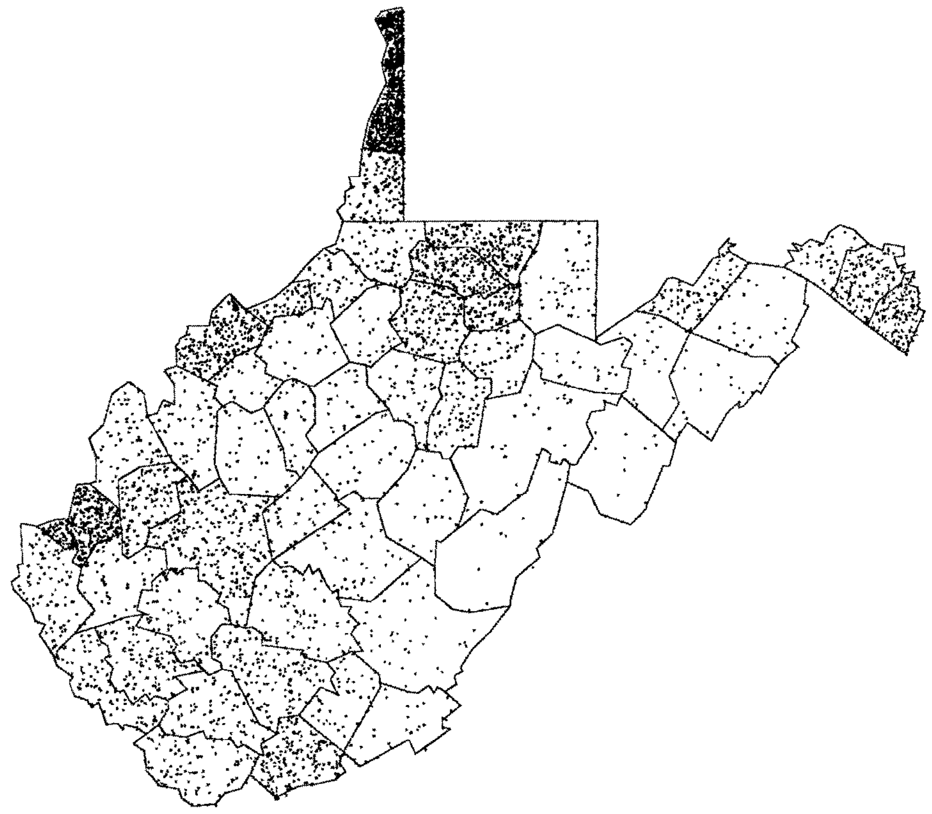
Potential Well Yields in West Virginia



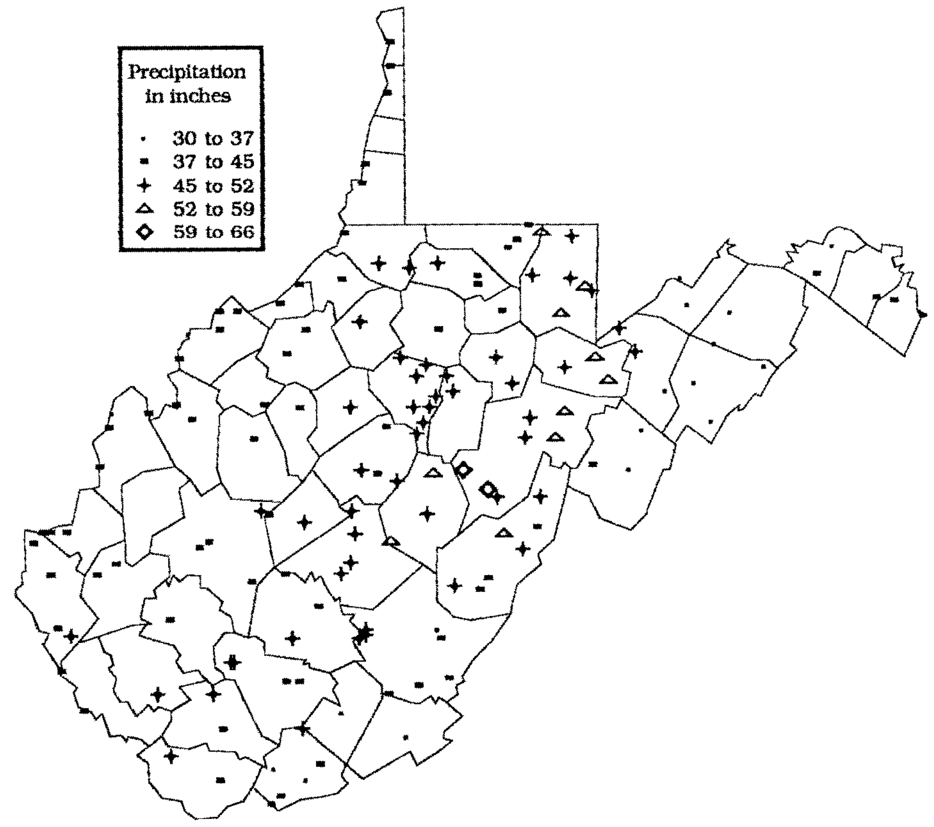


Areas covered by class I aquifers.
Each dot represents a population center.

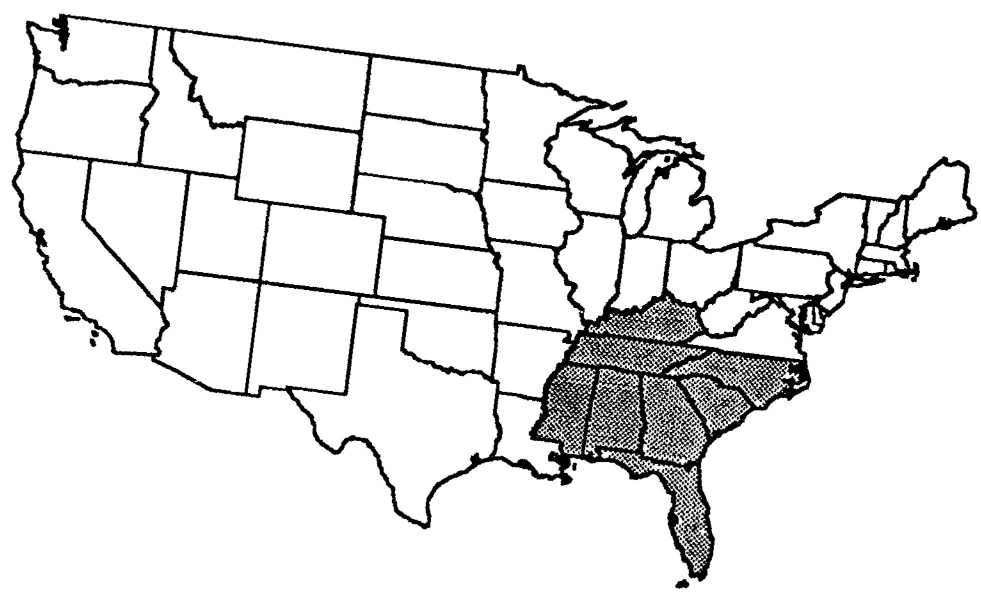
Aquifer Sensitivity Map of West Virginia



Population Density of West Virginia (Dot equals one person per square mile)



Average Annual Precipitation in West Virginia



REGION 4

Alabama
Florida
Georgia
Kentucky
Mississippi
North Carolina
South Carolina
Tennessee

ALABAMA

General Setting

Alabama contains approximately 51,700 square miles. The southwestern three-fifths of the state is in the low lying coast and moderate relief uplands of the Coastal Plain physiographic province. The northeastern two-fifths lies in the mountains and hilly plains of the Piedmont, Valley and Ridge, Appalachian Plateaus, and Interior Low Plateaus provinces. Alabama's Coastal Plain is underlain by a south to southwest dipping sequence of Cretaceous to Quaternary age, semiconsolidated to unconsolidated, sand, clay, gravel, lignite, marl, and limestone. These sediments locally are overlain by alluvial and coastal deposits. Folded and faulted Precambrian to Paleozoic age metamorphic, igneous, and sedimentary rocks underlie the remainder of the state.

Northern Alabama is drained by the west-flowing Tennessee River, while the remainder of the state is drained by the south to southwest flowing Tombigbee, Alabama, and Chattahoochee rivers. Annual precipitation ranges from 49 inches in the north to 66 inches in the south. The majority of Alabama's population, approximately 4.1 million, is distributed among several mid-sized cities across the state. The remainder of the state is sparsely populated. About 343 and 3.4 million gallons of fresh and saline ground water, respectively, are used daily in Alabama.

Unconsolidated Aquifers (Class Ia)

Alluvial and coastal deposits occur throughout the southern half of the state, and form productive and vulnerable aquifers. These generally unconfined systems consist of interbedded and unconsolidated deposits of sand, gravel, clay, and silt. Where saturated sand and gravel deposits are of sufficient thickness, well yields range from 10 to 350 gpm, and may exceed 700 gpm (Hinkle, 1984). About 11.3 percent of Alabama is covered by unconsolidated deposits.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Solutional features are present in bioclastic limestone and dolomite deposits of Paleozoic age, which are exposed across northern Alabama and within the Valley and Ridge province. Fractured chert and fissile shale interbeds occur within this system. Where present, karst features contribute to the vertical and lateral permeability of the rock, creating highly productive and vulnerable aquifers. Well yields range from 100 to 500 gpm, and may exceed 1,000. Springs discharging from limestone and dolomite units yield as much as 1,000 and 4,800 gpm, respectively (Causey, 1965). Solutional features also are present in sandy, glauconitic, fossiliferous limestone and coquina, which is exposed across southern Alabama. Locally these deposits are overlain by residuum. Marl and sand interbeds also occur within this Late Eocene to Oligocene age system. Well yields commonly range from 100 to 500 gpm, and may exceed 700 gpm. Surface exposures of soluble aquifers occupy nearly 11 percent of Alabama.

Semiconsolidated Aquifers (Class Ic)

Exposures of semiconsolidated sediments occur throughout Alabama's Coastal Plain, and consist of partially to poorly indurated, Cretaceous to Miocene age sand that is interbedded with clay, gravel, marl, and sandy limestone. Clastic sediments are commonly calcareous, glauconitic, fossiliferous, and micaceous. Well yields commonly range from 300 to 1,000 gpm, and may exceed 1,400 gpm. Surface exposures of Class Ic aquifers occupy nearly 36 percent of the state.

Lower Yield Bedrock Aquifers (Class IIb)

Lower yield bedrock aquifers crop out in north-central and east-central Alabama. In the north, Pennsylvanian age sandstones contain water in openings along fractures, bedding planes, and joints, and within permeable zones. Fissile shale interbeds are present within this system. Aquifer yields commonly range from 1 to 10 gpm, and may exceed 100 gpm. Surface exposures of lower yield bedrock aquifers occupy about 14 percent of the state.

Undifferentiated Aquifers (Class U)

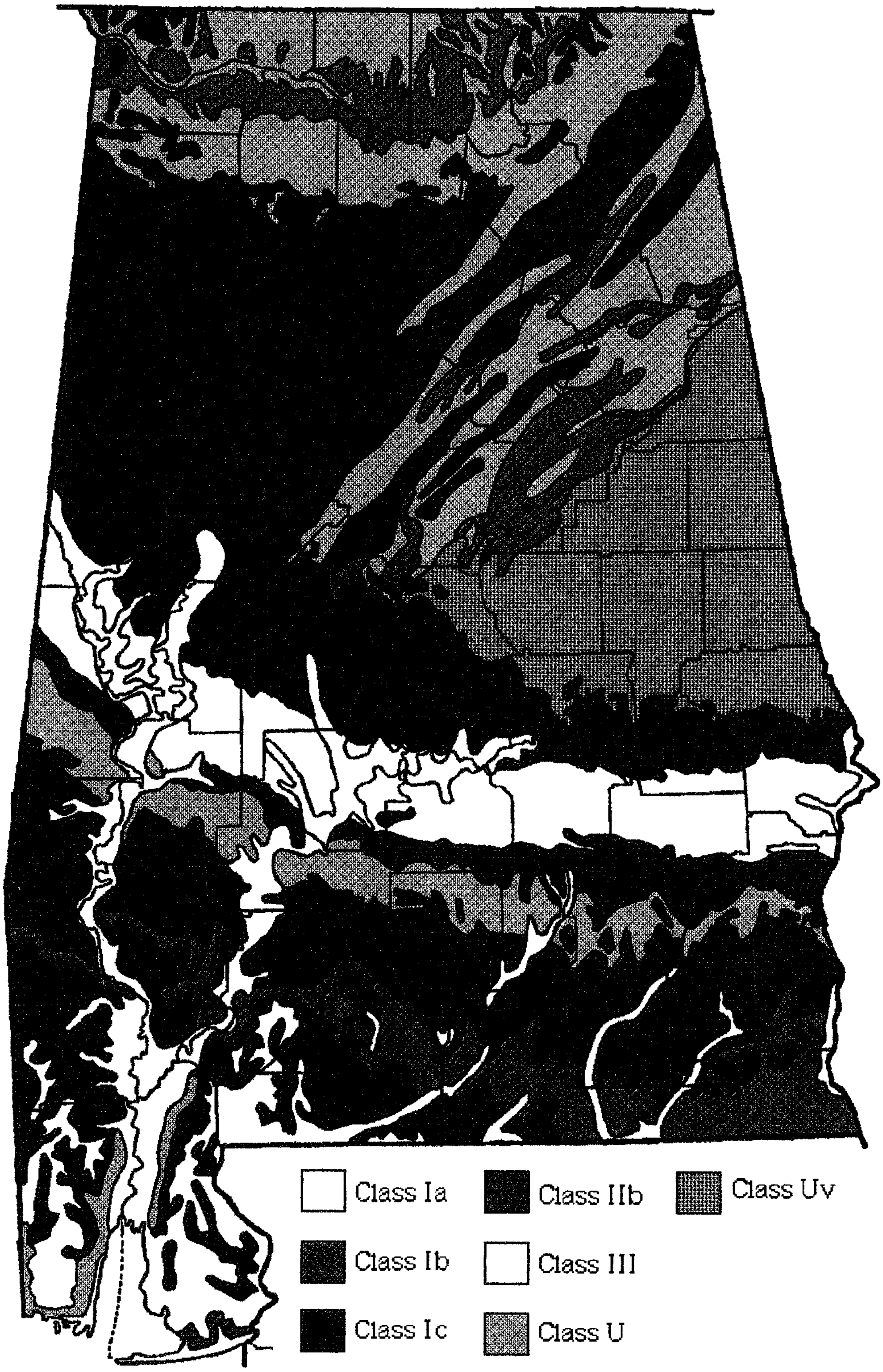
Several undivided and lithologically varied Paleozoic age formations crop out across northern Alabama and within the Valley and Ridge province. These formations consist of folded and faulted, argillaceous and cherty limestone, sandy dolomite, calcareous shale, sandstone, siltstone, and mudstone. Mississippian age limestones are commonly bioclastic and oolitic. The lithologic and resultant hydrologic variability of these undivided formations have not been delineated. Undivided and lithologically varied Early Cenozoic age formations crop out across the southern part of the state, and consist of interbedded sandy and fossiliferous limestone, massive clay, marl, sand, and calcareous silt. Lithologically variable Quaternary age sediments, which occur along coastal and adjacent inland portions of southwestern Alabama, consist of interbedded, unconsolidated sand, clay, and gravel. Owing to the variable nature of these deposits there is a wide range in aquifer yield and vulnerability.Surface exposures of undifferentiated aquifers occupy about 18 percent of the state.

Variably Covered Undifferentiated Aquifers (Class U-v)

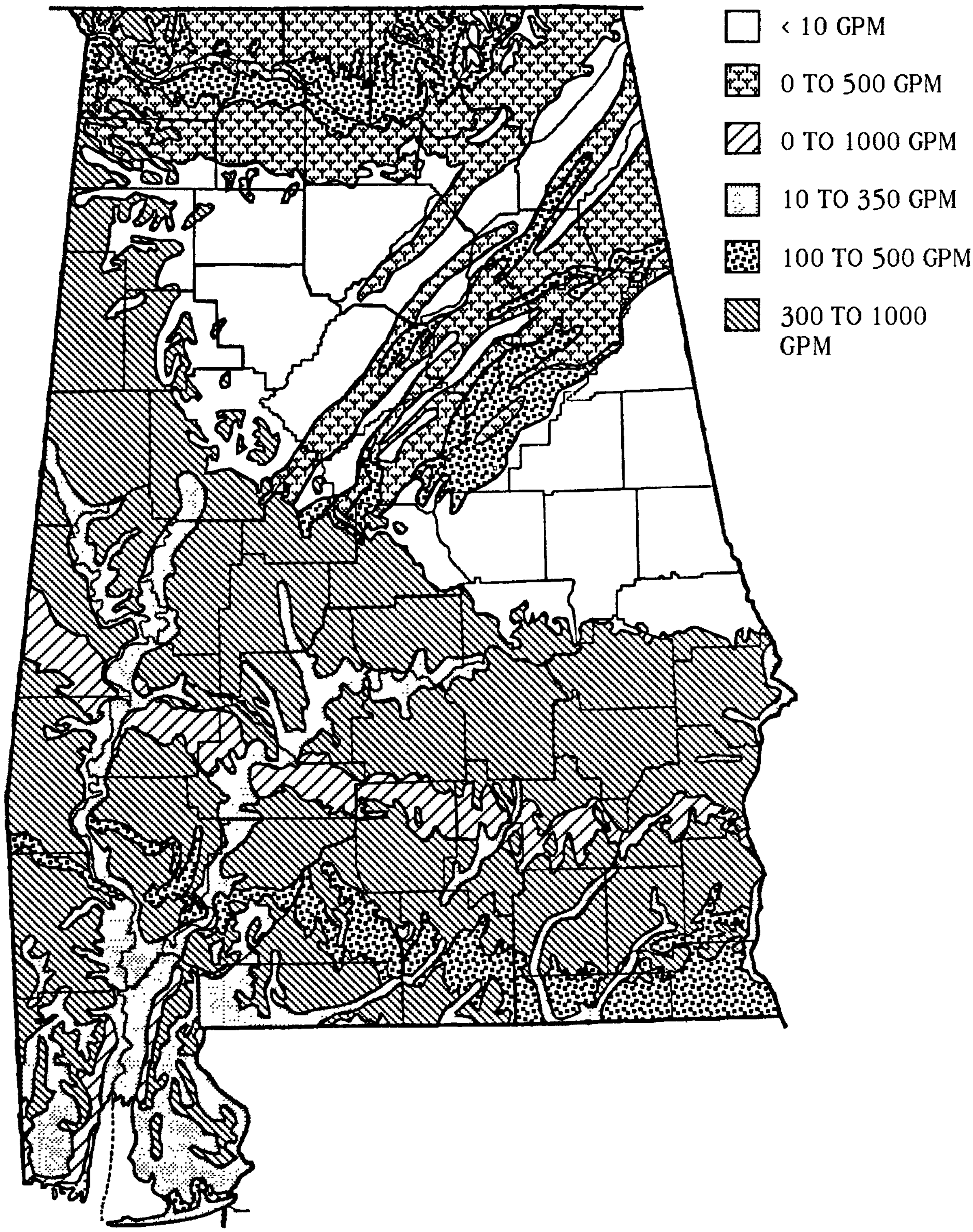
Occurring in the eastern part of Alabama are Precambrian to Paleozoic age folded, faulted metamorphic and granitic rocks that are covered by clay-saprolite of variable thickness. Well yields commonly range from 1 to 10 gpm, and may exceed 100 gpm. Well yields are related to the number of fractures encountered by the well bore, and vulnerability is related to the thickness and permeability of the saprolite. Class U-v aquifers incorporate nearly 10 percent of Alabama.

Sensitivity

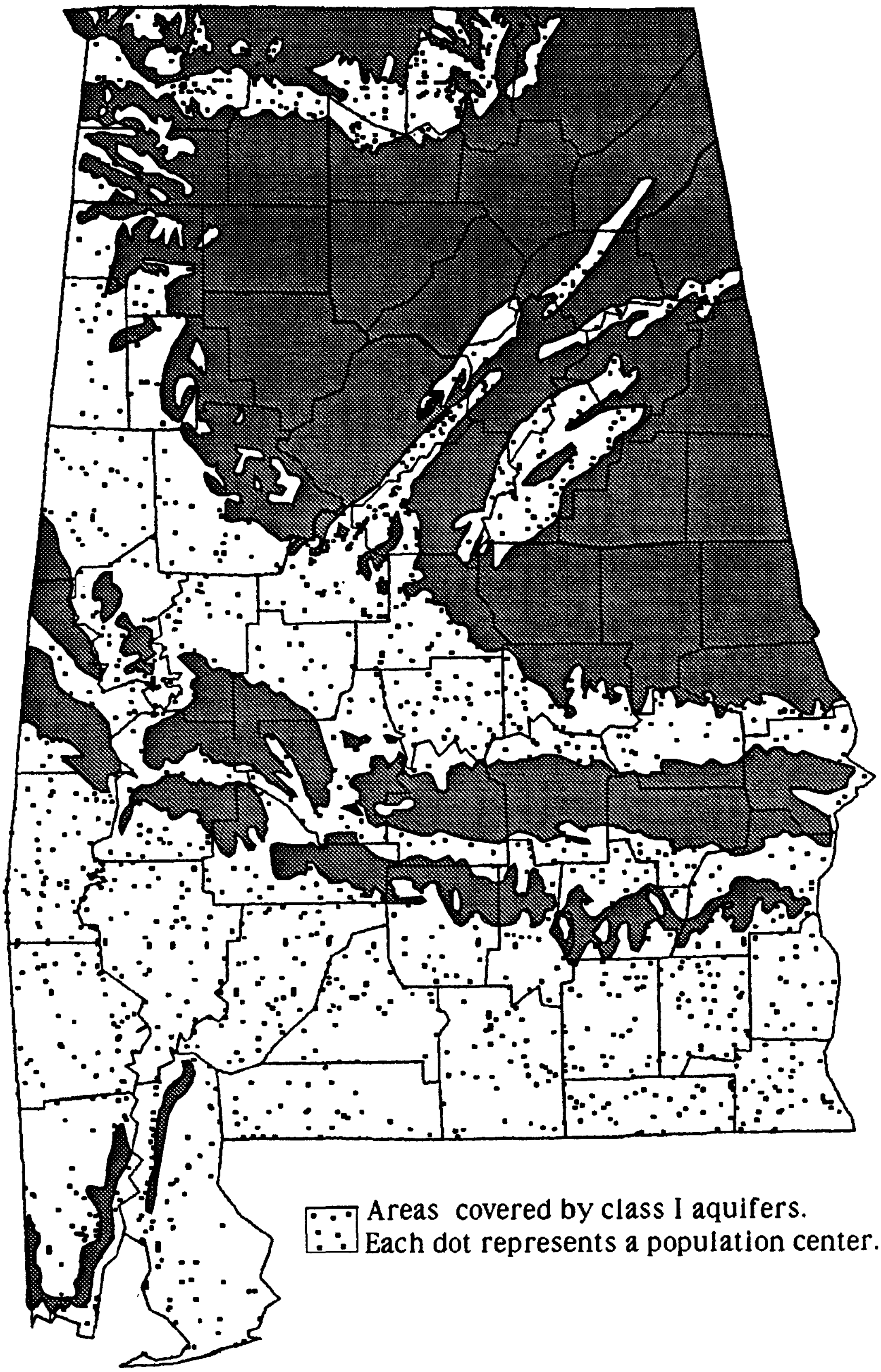
About 57 percent of Alabama is covered by Class I aquifers, and these generally occur in broad belts that arc across the southwestern part of the state. The potential for ground-water contamination from shallow injection wells in these areas is moderate owing to the rather evenly distributed population centers.



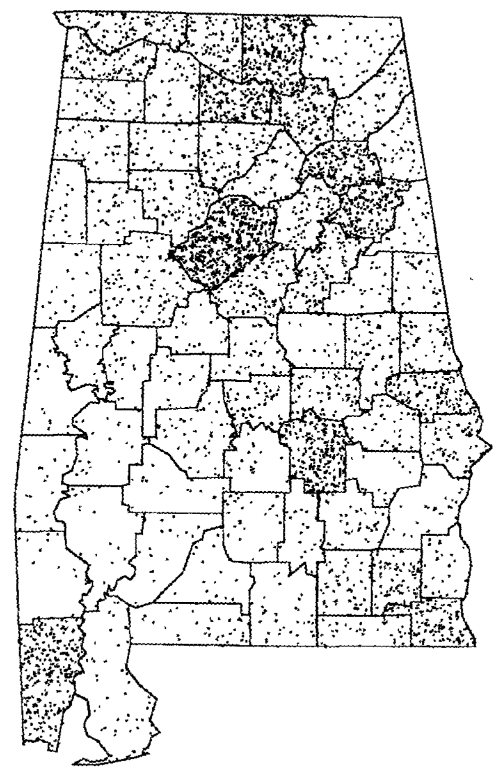
Aquifer Vulnerability Map of Alabama



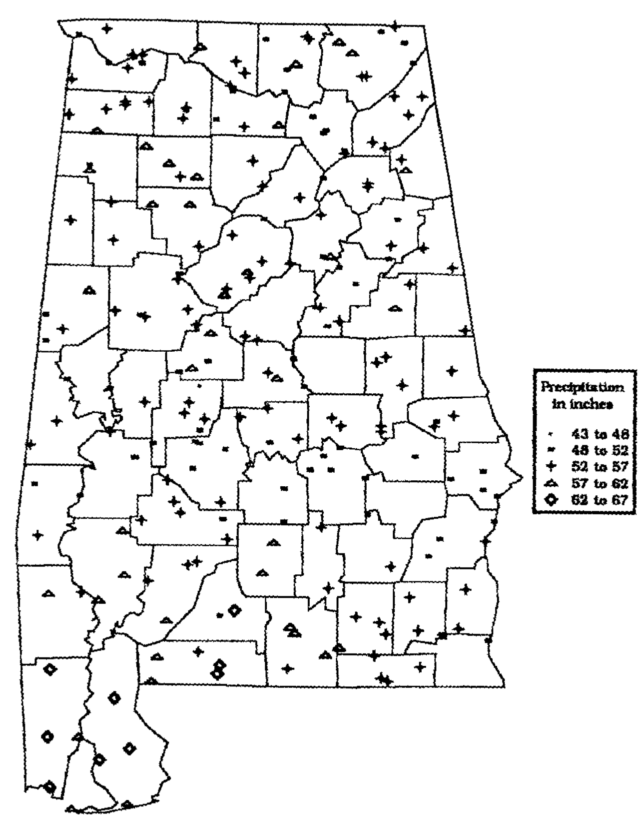
Potential Well Yields in Alabama



Aquifer Sensitivity Map of Alabama



Population Density of Alabama (Dot equals one person per square mile)



Average Annual Precipitation in Alabama

FLORIDA

General Setting

Florida, which contains 58,664 square miles, lies entirely in the low relief coastal beaches, marshes, and inland hills and swamps of the Coastal Plain physiographic province. The Florida Peninsula is underlain by a south-southeastward trending, elongate ridge of Tertiary age limestone and dolomite, which unconformably overlies Precambrian and Paleozoic age rock. Interbedded clastic and carbonate sediments of Quaternary and Tertiary age flank the ridge and cover most of the state.

Florida contains a variety of surface-water features including north-, south-, east-, and west-flowing rivers and canals, as well as numerous swamps, marshes, ponds, and lakes. Closed basins occur in association with karst features. Annual precipitation exceeds 50 inches over most of the state. The majority of Florida's population, approximately 12.34 million, occupies the coastal region of the Florida Peninsula and a few inland cities. The remainder of the state is sparsely populated. Daily use of fresh ground water amounts to about 4050 million gallons.

Unconsolidated Aquifers (Class Ia)

Alluvial, marsh, coastal, and marine deposits occur throughout the state, forming both productive and vulnerable aquifers. These sediments consist of Pliocene to Holocene age quartz sand and clay, interbedded with lenses of gravel, limonite, occasional shell layers, and minor limestone beds. Sands are commonly phosphatic, ferrugenous, and, locally, micaceous and clay rich. The presence of discontinuous, poorly indurated sand layers that contain small quantities of clay, limonite, and hematite cement, result in locally confined conditions. Unconsolidated sediments, which are commonly 5 to 50 feet thick, are as much as 700 feet thick in the northwest corner of the state. Well yields from unconsolidated aquifers vary widely throughout the state. In northwest Florida, yields commonly range from 5 to 1,000 gpm, and may exceed 2,000 gpm (Pascale, 1974). Surficial sediments in the Florida Panhandle commonly yield less than 100 gpm, but locally may exceed 1,000 gpm. About 40 percent of the state is covered by Class Ia aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Solutional features are present in Late Eocene to Pleistocene age carbonate units that are exposed across Florida's Panhandle, and in the northwestern and southern Florida Peninsula. Tertiary age carbonates, associated with the Floridan aquifer system, consist of finely crystalline to granular, fossiliferous to bioclastic, sandy to argillaceous limestone. Dolomite beds and lenses of clay, marl, and shale occur within this system. Well yields range from 500 to 1,000 gpm, and may exceed 20,000 gpm (Pascale, 1974). Pleistocene age carbonates, associated with the Biscayne aquifer system, crop out in southern Florida and consist of oolitic, fossiliferous, pure to sandy limestone, and interbedded sand, and calcareous sandstone. This north and westward thinning system reaches a maximum thickness of 200 feet along the coast. Well yields commonly range from 500 to 1,000 gpm, and may exceed 7,000 gpm. Surface exposures of soluble aquifers occupy about 25 percent of Florida.

Semiconsolidated Aquifers (Class Ic)

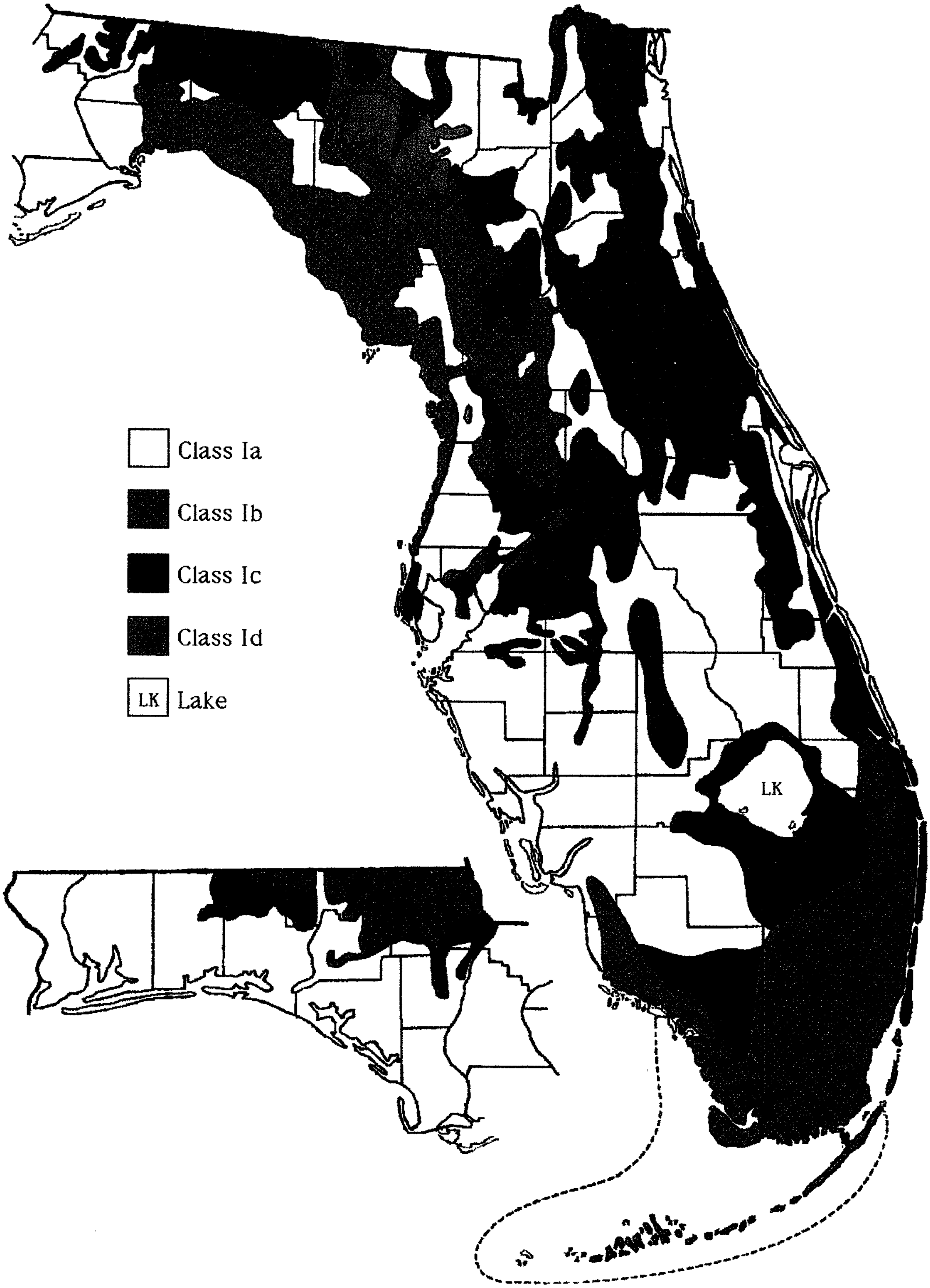
Exposures of semiconsolidated sediments occur throughout Florida and consist of poorly to well indurated, Miocene to Pleistocene age clastic and carbonate units. Miocene age sediments in the Florida Panhandle consist of quartz sand and gravel, interbedded with lesser amounts of clay and shell material, and minor phosphate, glauconite, and limestone beds. Clay, and less commonly micrite, act as cementing agents. Miocene and Pleistocene age sediments, which are exposed throughout the northern and western half of the Florida Peninsula, consist of poorly indurated, clayey sand, interbedded with lenses and laminae of dolomite and sandy limestone. Phosphatic grain coatings and laminae are common within this system. Semiconsolidated sediments exposed in southeastern Florida consist of coarse sand and shell fragments, locally cemented with calcium carbonate and shell marl. Grain size and degree of induration decrease to the west. Semiconsolidated sediments commonly yield less than 100 gpm, but may exceed 1,000 gpm. Surface exposures of semiconsolidated aquifers occupy nearly 31 percent of the state.

Covered Aquifers (Class Id)

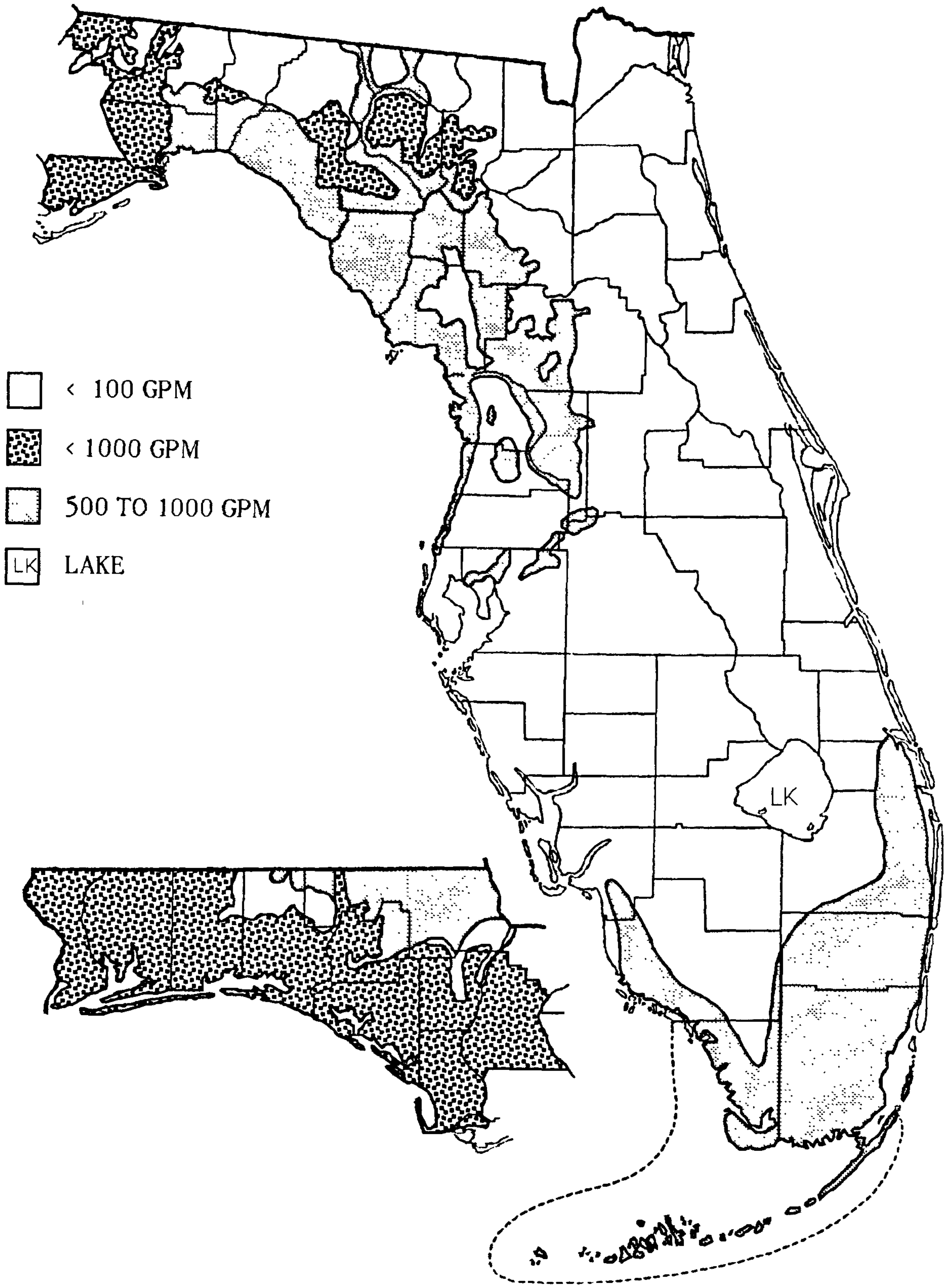
Semiconsolidated and carbonate aquifers, overlain by less than 50 feet of fine-grained, argillaceous sand, occur in the northwestern corner of the Florida Peninsula. Well yields range from a few gallons to 1000 gpm. The reduced vulnerability of these covered systems is a function of the thickness and permeability of the overlying material. Class Id aquifers occupy about 1 percent of the state.

Sensitivity

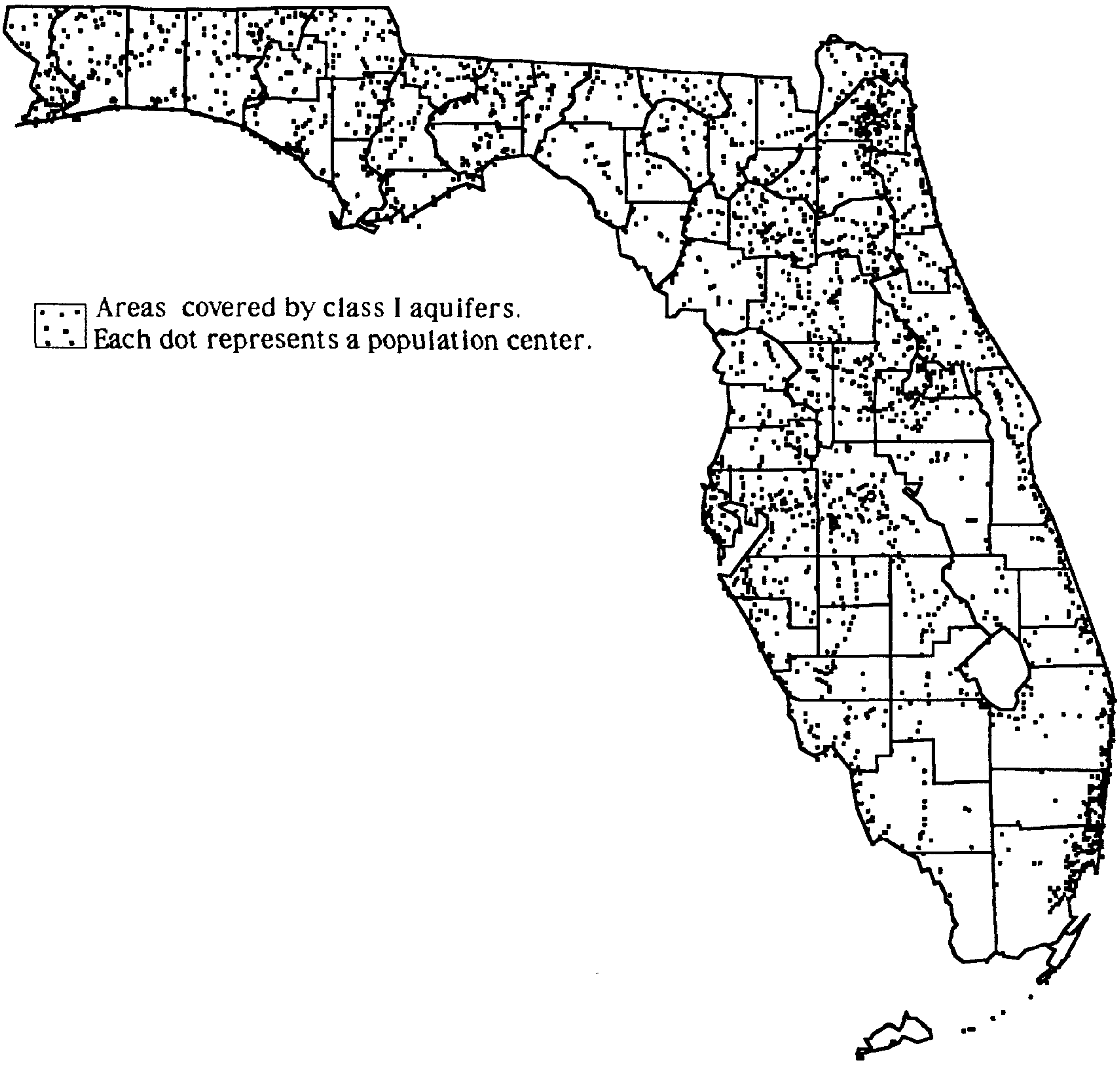
The potential for shallow ground-water contamination from shallow injection wells is very high in Florida. Nearly the entire state consists of Class I aquifers and many major urban and industrial centers lie above highly vulnerable aquifers.



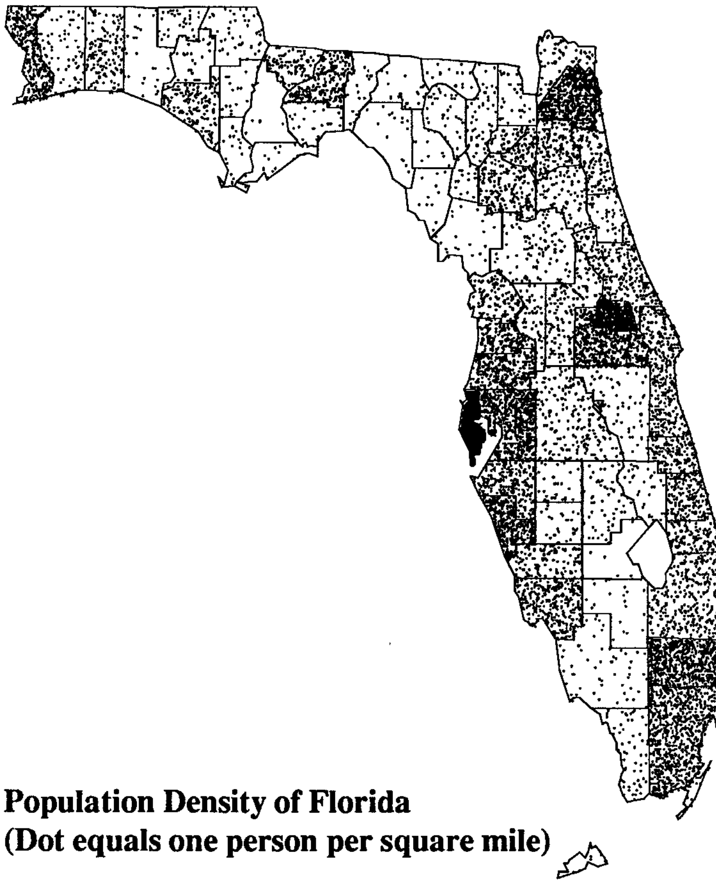
Aquifer Vulnerability Map of Florida



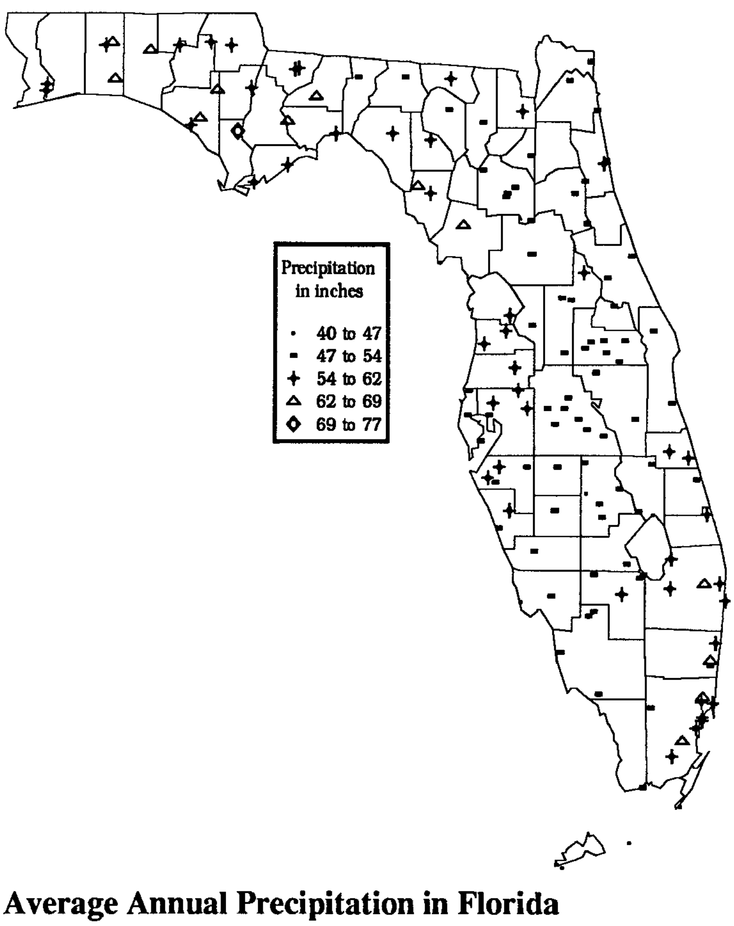
Potential Well Yields in Florida



Aquifer Sensitivity Map of Florida



Population Density of Florida
(Dot equals one person per square mile)



Average Annual Precipitation in Florida

GEORGIA

General Setting

Georgia, which contains approximately 59,000 square miles, lies primarily in the low lying to hilly, Coastal Plain and Piedmont provinces. The northern part of the state is in the mountainous Blue Ridge, Valley and Ridge, and Appalachian Plateaus provinces. The southern half of Georgia is underlain by a southeast dipping and thickening sequence of Cretaceous to Holocene age consolidated to unconsolidated, marine, beach, and alluvial deposits. The north-central and northeastern parts of the state are underlain by folded and faulted Precambrian to Mesozoic age igneous and metamorphic rocks. Folded and faulted Paleozoic age carbonate and clastic sedimentary rocks underlie the northwestern corner of Georgia. Unconsolidated weathered material locally overlies bedrock outcrops throughout the state.

Streams in northern and northwestern Georgia flow to the north and southwest. The remainder of the state is drained by a network of south- to southeast-flowing rivers. Annual precipitation ranges from less than 44 inches in east-central Georgia to more than 76 inches in the north. Precipitation is distributed fairly evenly throughout the year. The majority of Georgia's population, approximately 6.3 million, is located in and around metropolitan Atlanta, and several smaller cities adjacent to major rivers. The remainder of the state is moderately populated. Daily use of fresh ground water amounts to about 1000 million gallons.

Unconsolidated Aquifers (Class Ia)

Alluvial, marsh, and beach deposits, which occur along major rivers and across coastal Georgia, form productive and vulnerable aquifers that have yet to be heavily used. These generally unconfined systems consist of interbedded, unconsolidated sand, gravel, and clay. Expectable well yields range from 100 to 500 gpm (L. Gorday, Georgia Geological Survey, oral communication, 1990). About 13 percent of the state is covered by unconsolidated deposits.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Karst features are present in interbedded carbonate and clastic units that are exposed in a belt that extends from southwestern to east-central Georgia. Where present, karst features contribute to the vertical and lateral permeability of the rock, creating highly productive and vulnerable aquifers. Well yields in Oligocene age limestone, dolomite, and calcareous sand aquifers, commonly range from 1,000 to 5,000 gpm, and may exceed 11,000 gpm. Well yields, in the more widely exposed Late Eocene age sandy limestone aquifers generally range from 150 to 600 gpm, but they may exceed 1,500 gpm. The amount of clastic material present in Upper Eocene strata increases to the northeast. Karst features also are present in dolomite and limestone units exposed in northwestern Georgia. Well yields commonly range from 1 to 50 gpm, and may exceed 3,500 gpm. Springs discharging from these aquifers may flow as much as 5,000 gpm. Surface exposures of soluble aquifers occupy about 17.5 percent of Georgia.

Semiconsolidated Aquifers (Class Ic)

Exposures of semiconsolidated sediments, which occur throughout Georgia's Coastal Plain, consist of partially to poorly indurated Cretaceous to Miocene age sand that is interbedded with silt, clay, gravel, and minor limestone units in the southwest. Sands vary from glaconitic to calcareous and ferruginous, and are locally phosphatic, fossiliferous, micaceous, and carbonaceous. Well yields commonly range from 50 to 1,200 gpm, and may exceed 3,300 gpm. Surface exposures of semiconsolidated aquifers occupy about 30 percent of the state.

Lower Yield Bedrock Aquifers (Class IIb)

Lower yield bedrock aquifers, composed of fractured sandstone, mudstone, and chert, crop out in the northwest corner of the state. Well yields range from

1 to 20 gpm, and may reach 300 gpm (Sonderegger, 1978). Surface exposures of Class IIb aquifers occupy about 1 percent of the state.

Undifferentiated Aquifers (Class U)

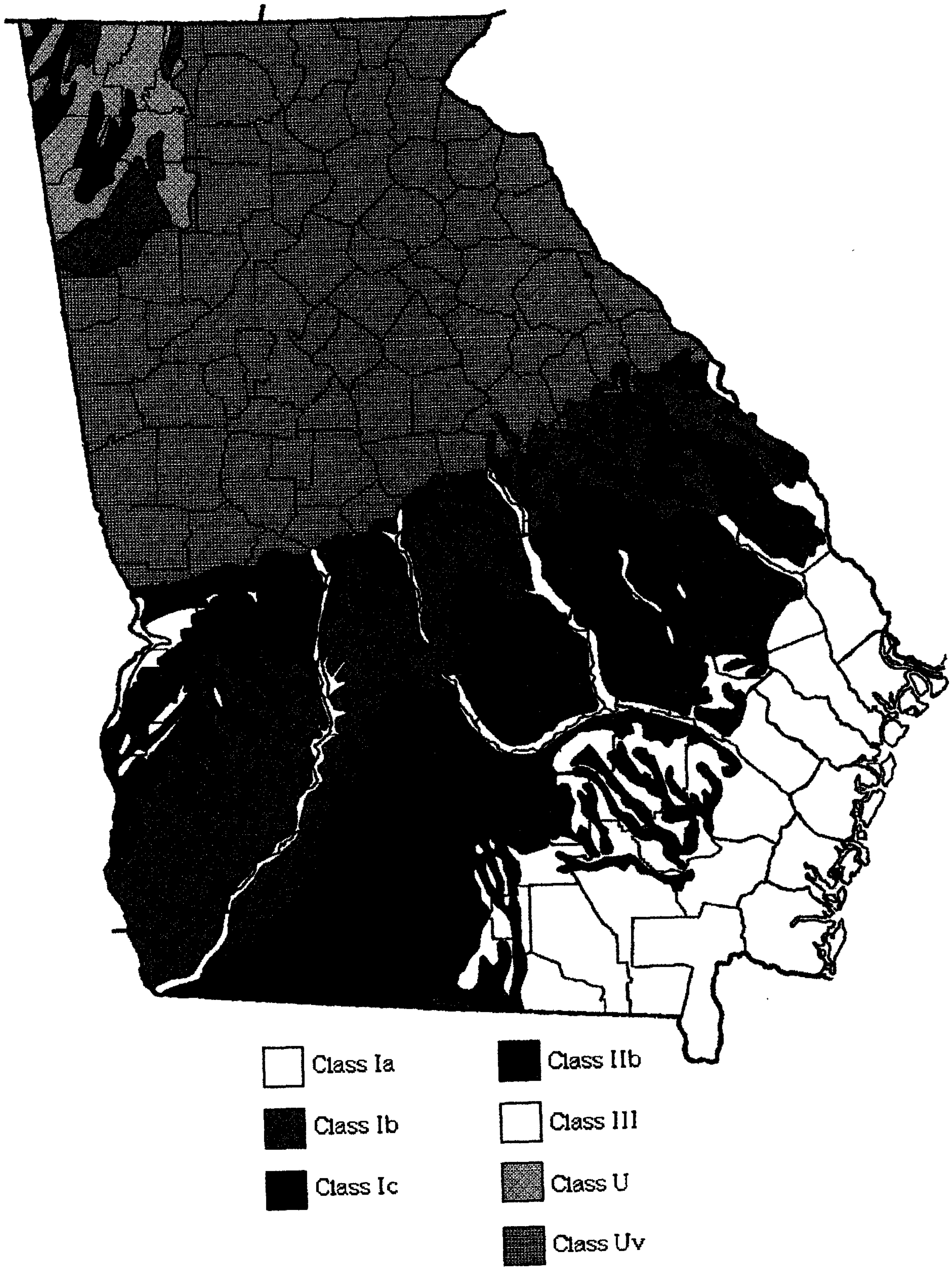
Several undivided and lithologically varied Paleozoic age formations, which crop out in the northwestern corner of Georgia, consist of folded and faulted, limestone, dolomite, sandstone, and mudstone. The lithologic and resultant hydrologic variability of these undivided formations has not been delineated. A wide range in aquifer productivity and vulnerability should be expected in these areas. Surface exposures of undifferentiated aquifers occupy about 3 percent of the state.

Variably Covered Undifferentiated Aquifers (Class U-v)

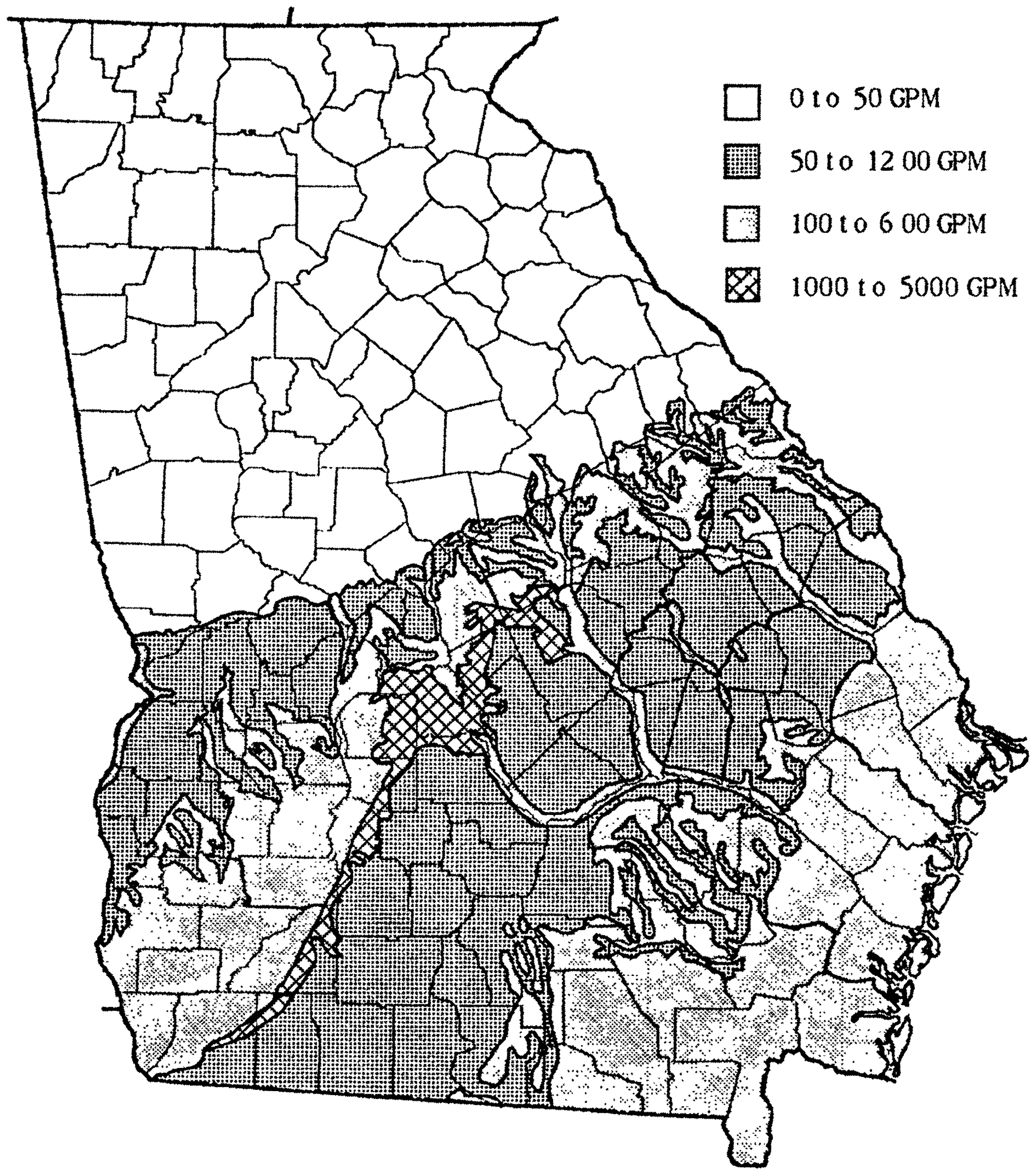
Precambrian to Paleozoic age crystalline rocks occur in northern Georgia. These bedrock aquifers consist of granite, gneiss, schist, quartzite, and marble. The rocks are mantled by saprolite of variable thickness. Aquifer productivity relies on the presence of saturated regolith and fractured bedrock. Well yields commonly range from 1 to 25 gpm, and may exceed 500 gpm. Slightly more than 34 percent of the state is covered by Class U-v aquifers.

Sensitivity

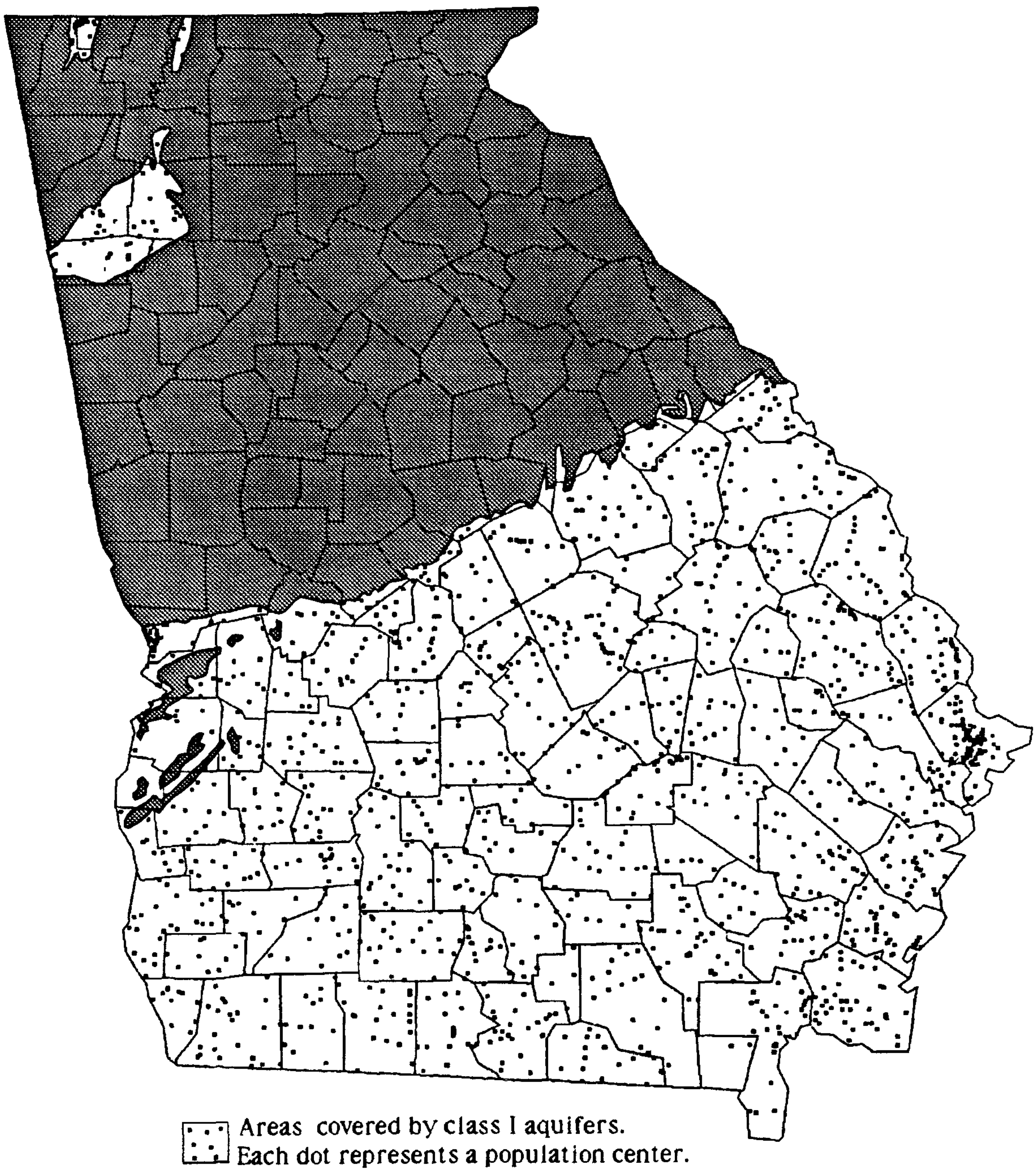
About 60 percent of Georgia is covered by Class I aquifers. The potential for ground-water contamination from shallow injection wells is greatest in the southeastern half of the state owing to the vulnerability of the aquifers and the relatively uniform distribution of population centers.



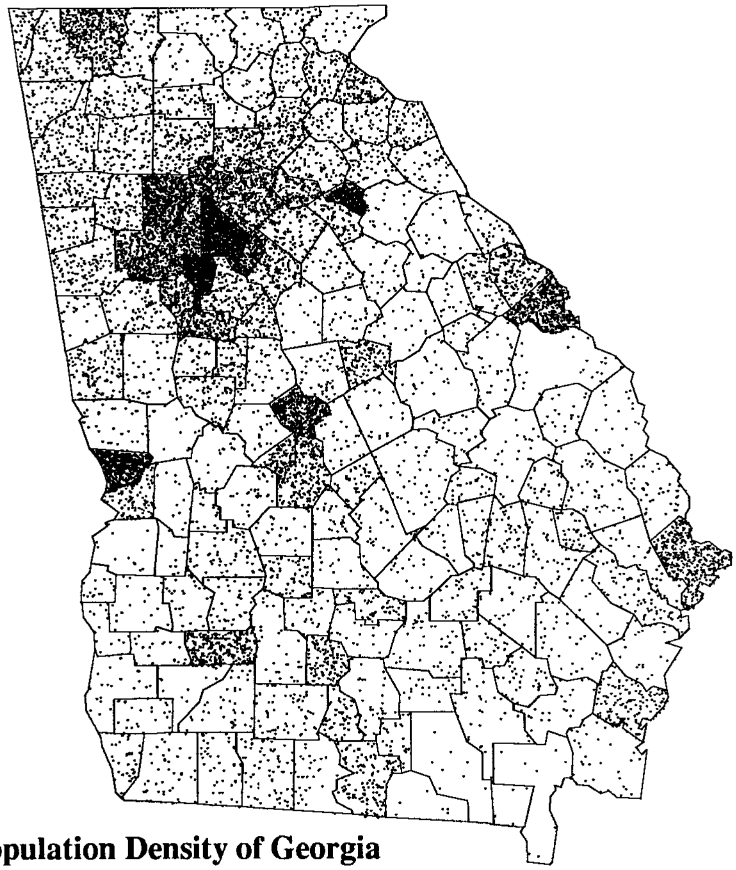
Aquifer Vulnerability Map of Georgia



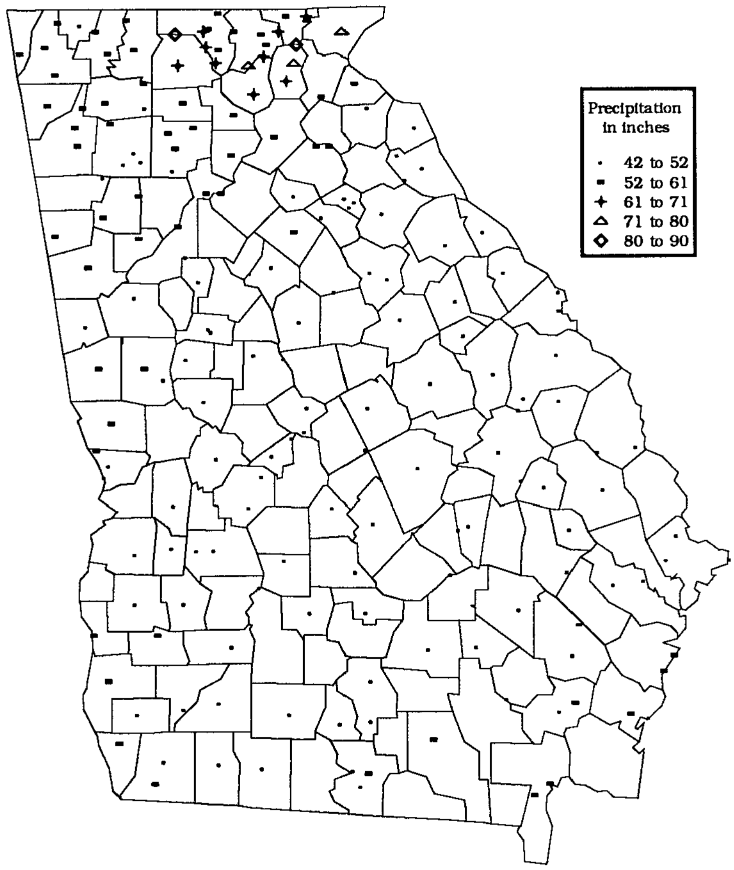
Potential Well Yields In Georgia



Aquifer Sensitivity Map of Georgia



Population Density of Georgia
(Dot equals one person per square mile)



Average Annual Precipitation in Georgia

KENTUCKY

General Setting

Kentucky contains approximately 40,400 square miles, and lies primarily in the gently rolling plateaus and dissected to mountainous terrain of the Interior Low Plateaus and Appalachian Plateaus provinces. The extreme southwestern part of the state lies in the flat lying to gently rolling Coastal Plain. The Appalachian Plateaus province in eastern Kentucky is underlain by synclinally folded Pennsylvanian age sandstone, siltstone, and shale. The eastern part of Interior Low Plateaus province, in east-central Kentucky, is underlain by anticlinally folded Ordovician age limestone, dolomite, shale, and sandstone. To the west, synclinally folded interbedded, Mississippian age limestone, sandstone, and shale, flank a core of Pennsylvanian age clastics. Western Kentucky is underlain by westward dipping, semiconsolidated to unconsolidated Cretaceous and Tertiary age sand, silt, and clay. Alluvial and eolian deposits occur throughout western Kentucky and along the Ohio River.

Except for the southeastern part, the entire state is drained by the Ohio and Mississippi rivers and their numerous northwest flowing tributaries. The southwest flowing Cumberland River drains southeastern Kentucky. Annual precipitation ranges from about 40 inches in the north to about 52 inches in the southeast. Kentucky's population, approximately 3.7 million, is distributed among many municipalities across the state. Jefferson, and Fayette are the most densely populated counties. About 205 million gallons of fresh ground water are used daily in Kentucky.

Unconsolidated Aquifers (Class Ia)

Alluvial and coastal deposits occur throughout southwestern Kentucky, and along the major rivers in the western and northern parts of the state. These generally unconfined systems, which form vulnerable and productive aquifers, consist of Tertiary and Quaternary age unconsolidated sand, gravel, silt, and clay. Well yields commonly range from 5 to 500 gpm, and may exceed 5,000 gpm. About 10 percent of the state is covered by Class Ia aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Solutional features are present in Mississippian age chert and shale bearing limestone units that are exposed across west-central Kentucky, and in Ordovician age limestone and dolomite units in the north-central part. Where present, karst features contribute to the vertical and lateral permeability of the rock. Well yields commonly range from 2 to 10 gpm, and may exceed 500 gpm. Surface exposures of Class Ib aquifers occupy about 13 percent of the state.

Semiconsolidated Aquifers (Class Ic)

Semiconsolidated sediments, which crop out in southwestern Kentucky, consist of Cretaceous age sand, silt, clay, and gravel. Well yields commonly range from 5 to 25 gpm, and may exceed 1,100 gpm. Surface exposures of Class Ic aquifers occupy about 1.3 percent of the state.

Covered Aquifers (Class Id)

Unconsolidated alluvial and coastal deposits that are overlain by less than 50 feet of low permeability materials, occur throughout the extreme southwestern part of Kentucky. The reduced vulnerability of these covered systems is a function of the thickness of the overlying fine-grained material. Covered alluvial and coastal aquifers occupy about 1 percent of the state.

Lower Yield Bedrock Aquifers (Class IIb)

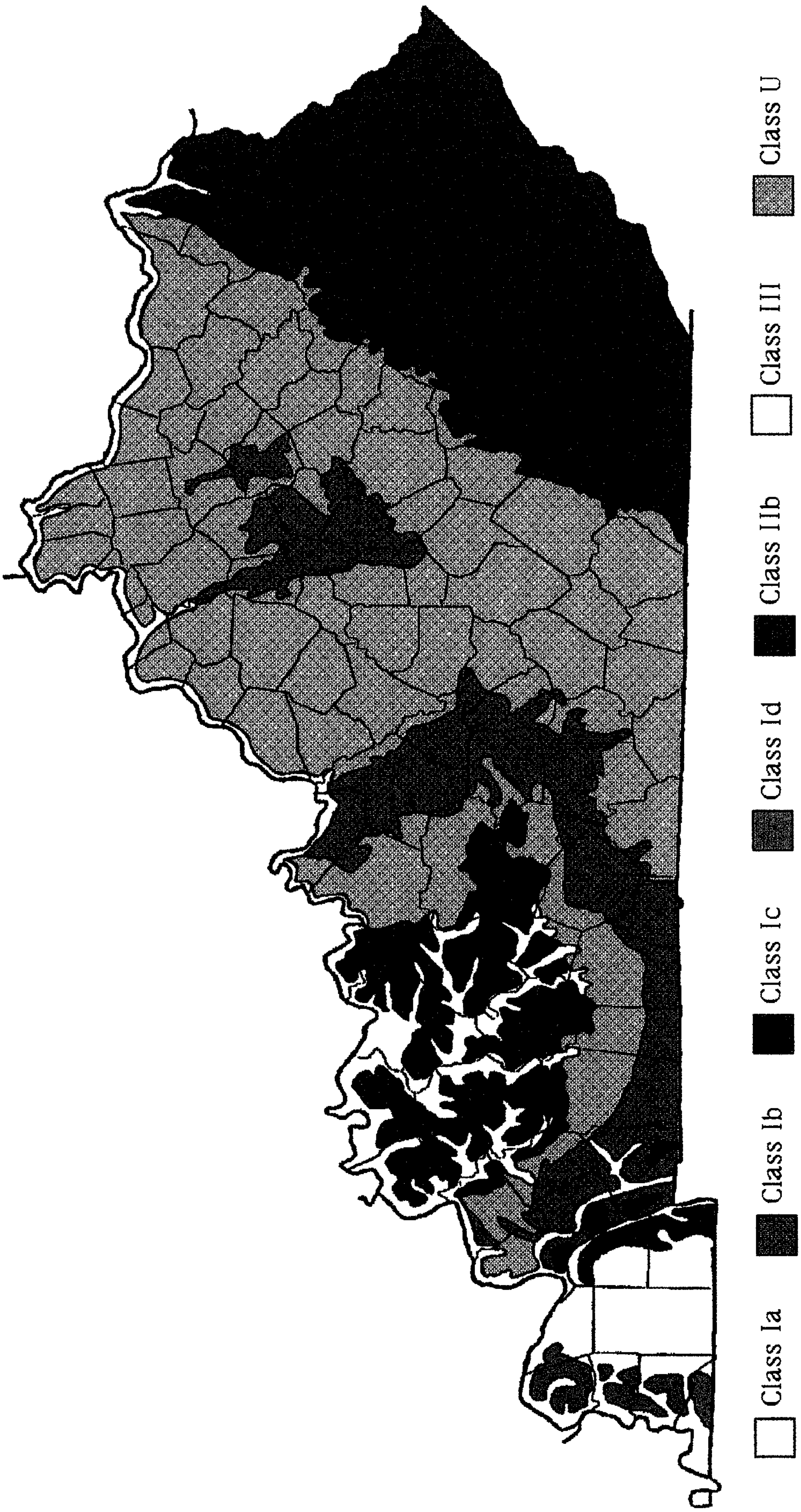
Lower yield Pennsylvanian age bedrock aquifers, composed of interbedded sandstone, shale, siltstone, and coal, crop out throughout eastern and parts of western Kentucky. Well yields commonly range from 1 to 5 gpm, and may exceed 200 gpm. Surface exposures of lower yield bedrock aquifers occupy about 32.4 percent of the state.

Undifferentiated Aquifers (Class U)

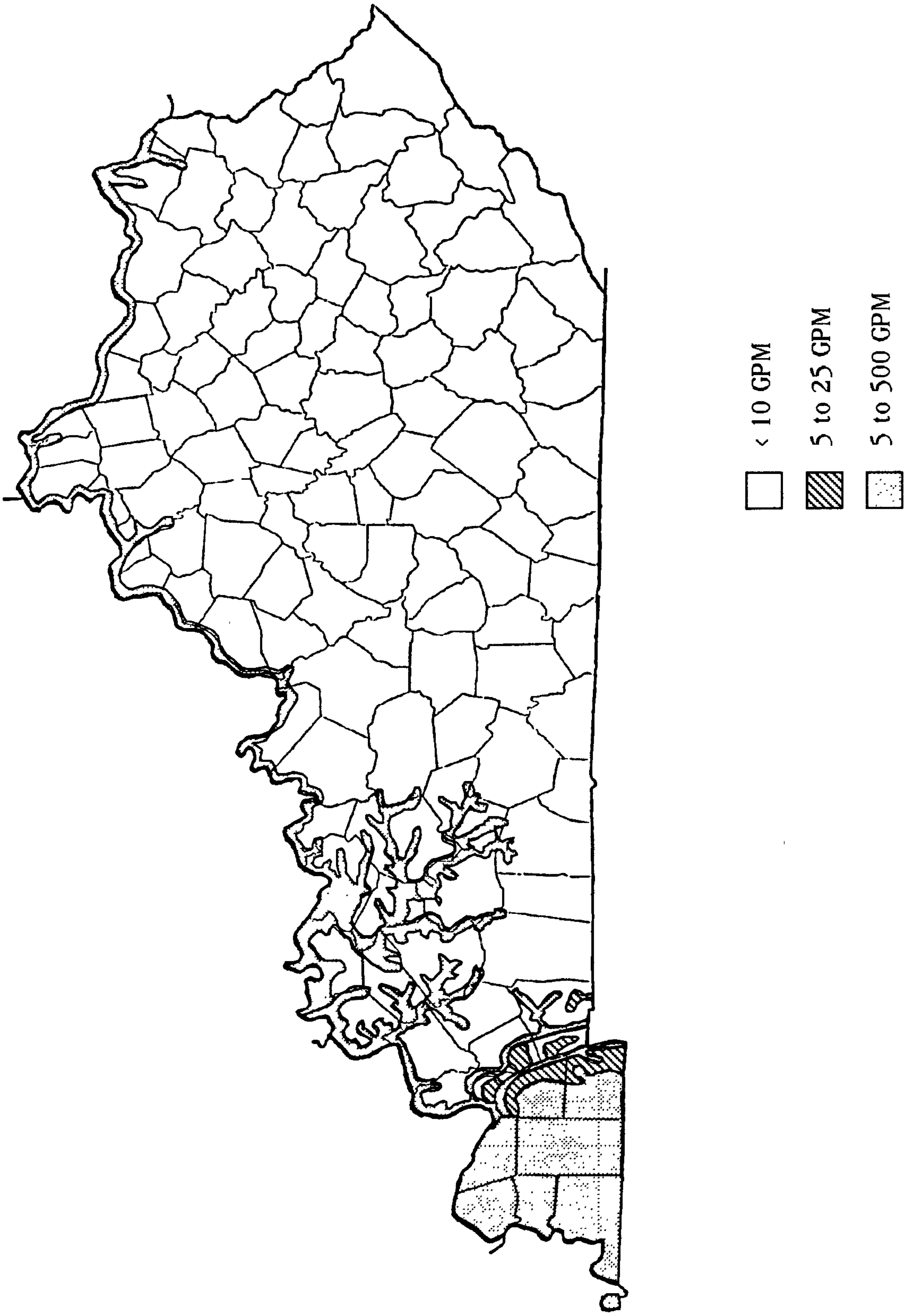
Several undivided and lithologically varied Paleozoic age formations crop out across central Kentucky, and consist of interbedded limestone, shale, and sandstone. The lithologic and resultant hydrologic variability of these undivided formations has not been delineated. A wide range in aquifer productivity and vulnerability should be expected. Surface exposures of undifferentiated aquifers occupy about 42.3 percent of the state.

Sensitivity

About 25 percent of Kentucky is covered by Class I aquifers. The potential for ground-water contamination from shallow injection wells is moderately low. Sensitivity is high both in karst areas and locally along the Ohio River where there is an abundance of industry.

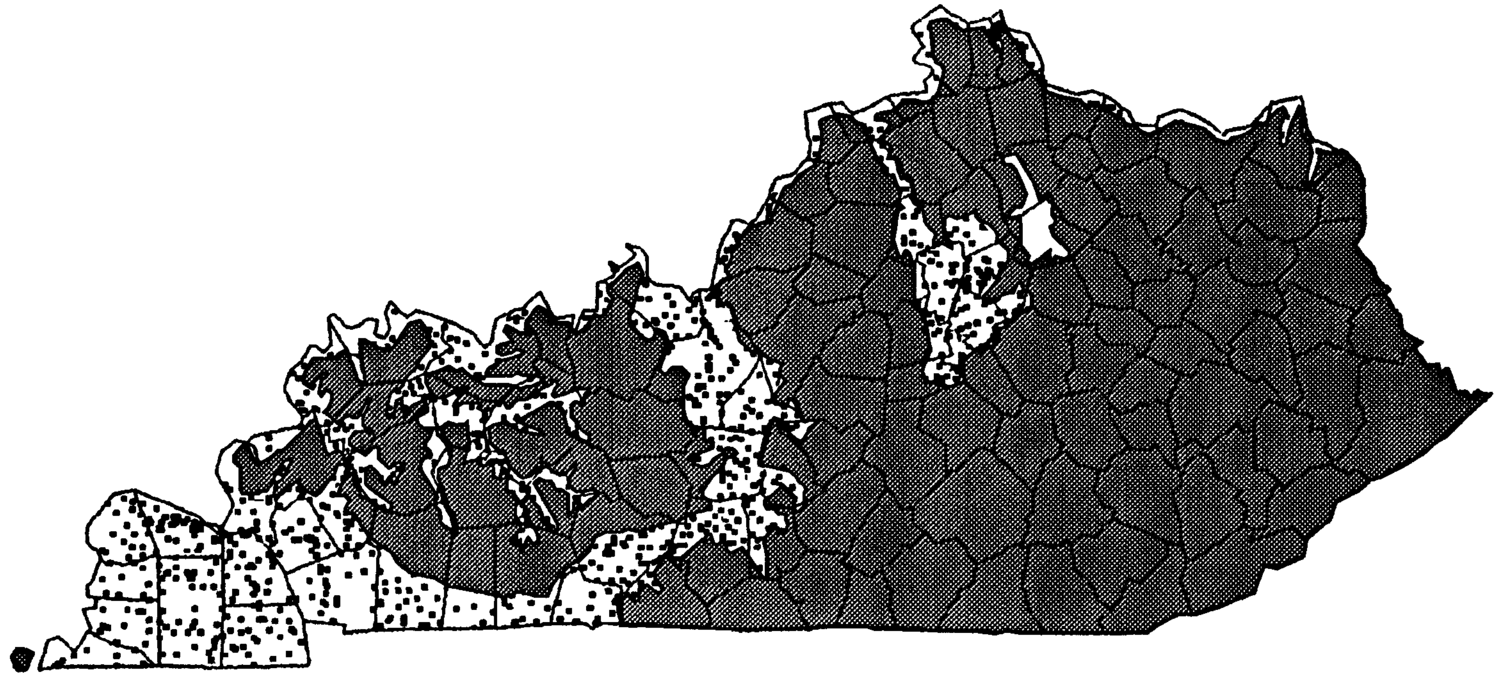


Aquifer Vulnerability Map of Kentucky



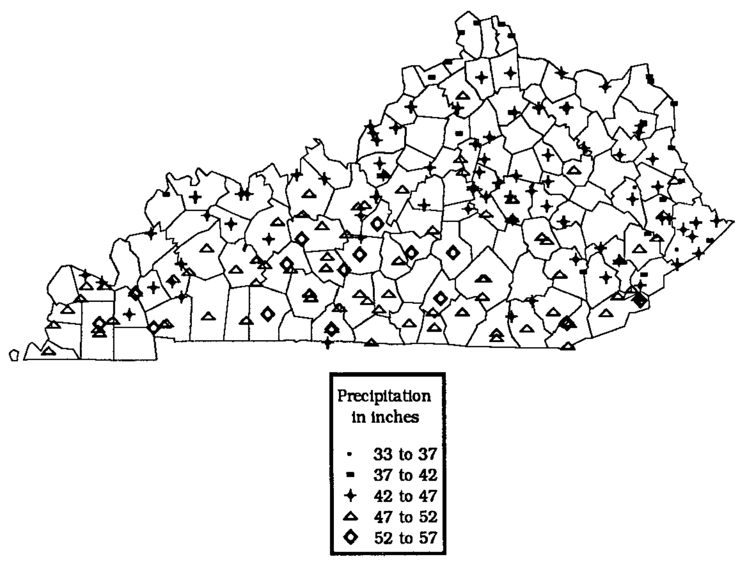
Potential Well Yields in Kentucky

Aquifer Sensitivity Map of Kentucky



Areas covered by class I aquifers.
Each dot represents a population center.

Population Density of Kentucky
(Dot equals one person per square mile)



Average Annual Precipitation in Kentucky

MISSISSIPPI

General Setting

Mississippi contains nearly 48,000 square miles, and lies largely in the relatively flat lying Coastal Plain physiographic province. The extreme northeastern corner of the state is in the Central Lowland province. The Coastal Plain is underlain by a south- to southwest-dipping sequence of Cretaceous to Tertiary age semiconsolidated to unconsolidated sand, silt, clay, gravel, marl, and limestone. These sediments are mantled by unconsolidated Mississippi River alluvium and loess deposits in the west and, locally, by river alluvium and coastal deposits. Devonian and Mississippian age carbonate and clastic rocks crop out in the extreme northeast corner of the state.

The Mississippi River and its southwest-flowing tributaries drain western Mississippi. The remainder of the state is drained by a network of south-flowing rivers. Annual precipitation ranges from about 46 inches in the north to 65 inches in the south. The late winter and spring months generally have the highest precipitation. Evapotranspiration is high due to the state's flat topography and warm climate. The majority of Mississippi's population, about 2.6 million, is located in and around metropolitan Jackson, and along the Gulf Coast. The remainder of the state is rural, and sparsely populated. About 1580 million gallons of fresh ground water are used daily in the state.

Unconsolidated Aquifers (Class Ia)

Alluvial and coastal deposits occur throughout the state, and form productive and vulnerable aquifers. These semiconfined to unconfined systems consist of unconsolidated sand, gravel, silt, clay, and loam. Alluvium in the Mississippi River flood plain average about 140 feet in thickness, and well yields range from 500 to 3,000 gpm, and may exceed 5,000 gpm. Yields from other alluvial and coastal aquifers range from 50 to 300 gpm, and may exceed 500 gpm. Nearly 40 percent of the state is covered by Class Ia aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Solutional features are present in Mississippian age limestone units exposed in the extreme northeast corner of the state. Chert, sandstone, and shale interbeds occur within this system. Where present, solutional features contribute to the vertical and lateral permeability of the rock, creating highly productive and vulnerable aquifers. Well yields range from 100 to 900 gpm, and may exceed 1,000 gpm. Karst features are present in Oligocene age limestones exposed across the southern mid-section of the state. Marl, clay, and sand interbeds occur within this system. Well yields range from 10 to 150 gpm, and may exceed 400 gpm. Surface exposures of karst carbonate aquifers occupy about 1.3 percent of Mississippi.

Semiconsolidated Aquifers (Class Ic)

Exposures of semiconsolidated sediments occur throughout Mississippi. This thick sequence consists of partially to poorly indurated, Cretaceous to Tertiary age calcareous and glauconitic sand with interbedded clay, gravel, marl, and limestone. Well yields range from 10 to 2,000 gpm, and may exceed 5,000 gpm. The presence of numerous intercalated layers of low permeability strata reduces the vulnerability of this system. Surface exposures of semiconsolidated aquifers occupy nearly 36 percent of the state.

Covered Aquifers (Class Id)

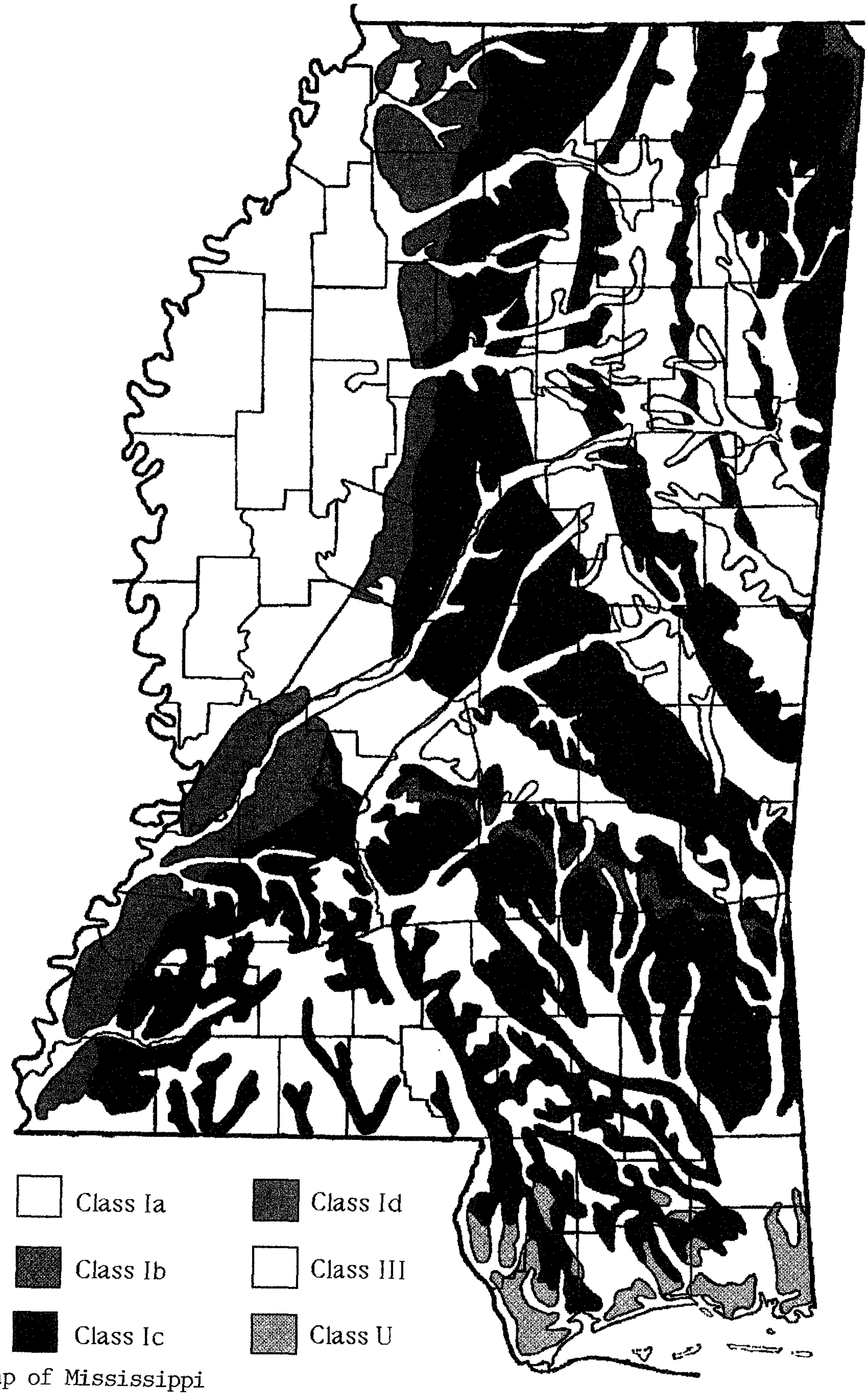
Semiconsolidated and soluble aquifers, overlain by less than 50 feet of loess, occur along the eastern margin of the Mississippi River flood plain. The reduced vulnerability of these covered systems is a function of the thickness of the overlying low permeability material. Covered semiconsolidated and soluble aquifers occupy about 6 percent of the state.

Undifferentiated Aquifers (Class U)

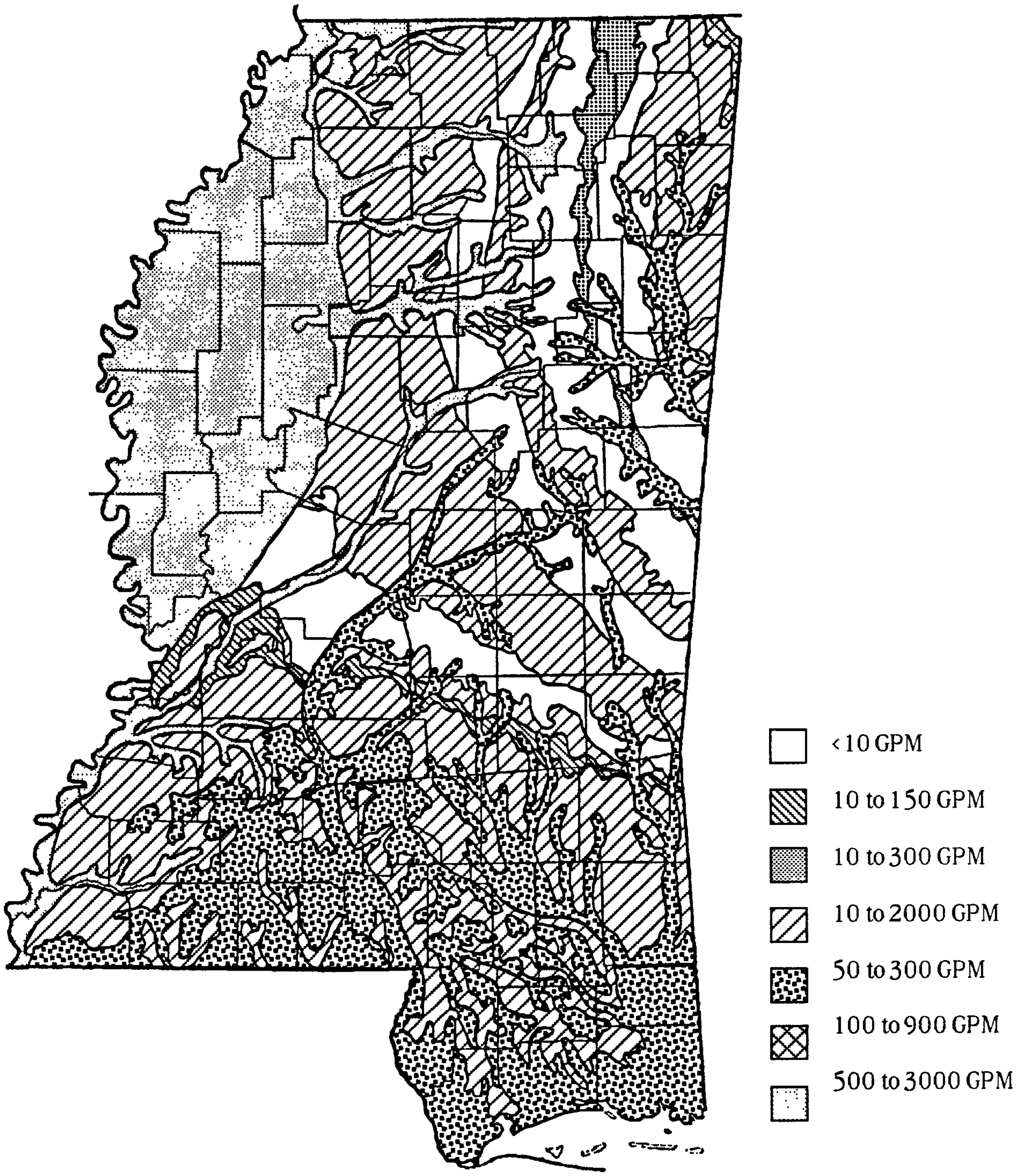
Lithologically varied Quaternary age sediments occur along coastal and adjacent inland parts of southeastern Mississippi, and consist of interbedded unconsolidated clay, silt, sand, and gravel. Due to their textural heterogeneity, a wide range in aquifer productivity and vulnerability should be expected in these areas. About 2 percent of the state is covered by Class U aquifers.

Sensitivity

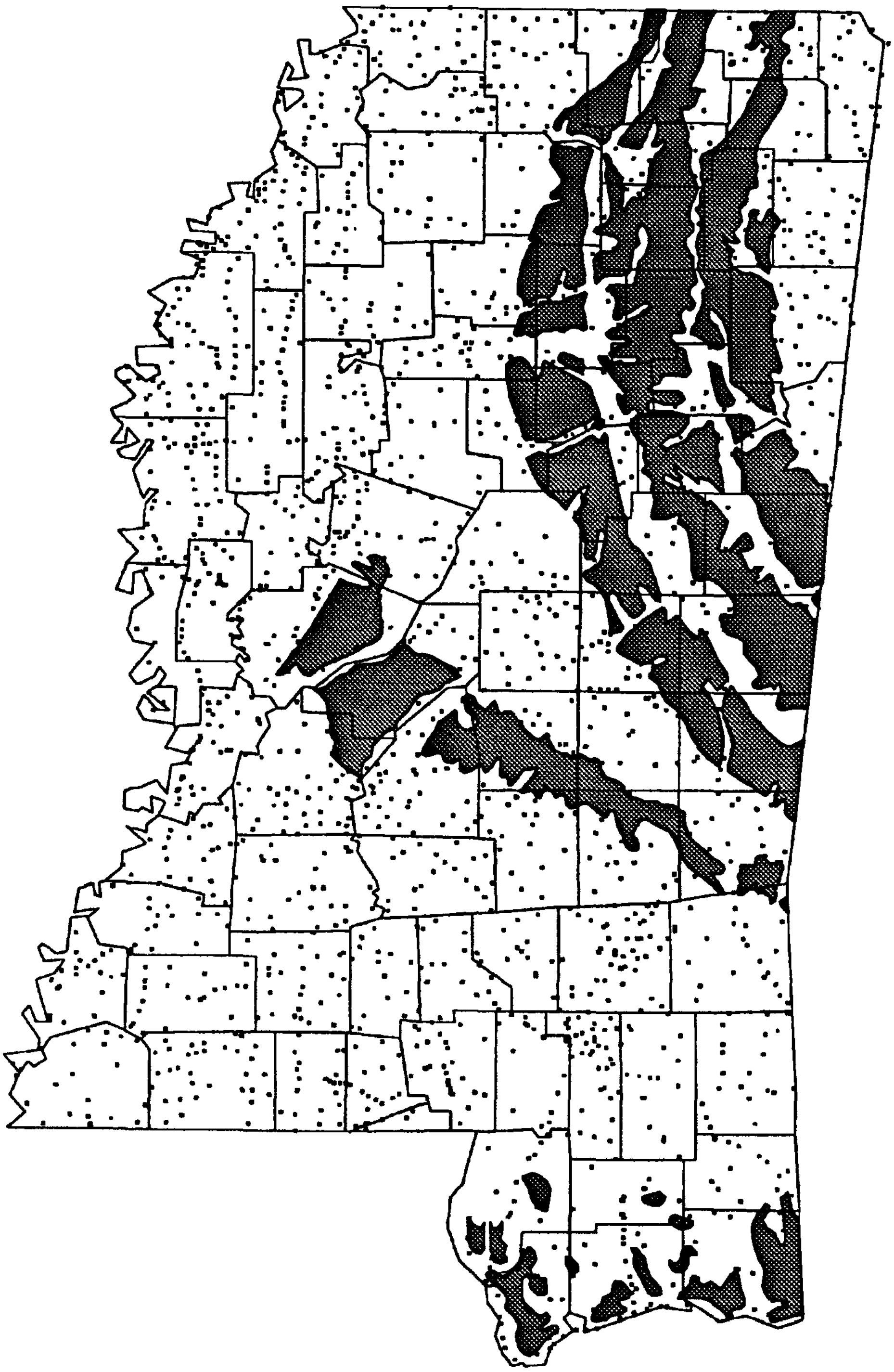
Nearly 83 percent of Mississippi is covered by Class I aquifers. Owing to the high permeability of these systems, the potential for ground-water contamination from shallow injection wells is significant. On the other hand, the population centers, which are rather evenly distributed throughout the state, are generally quite small.



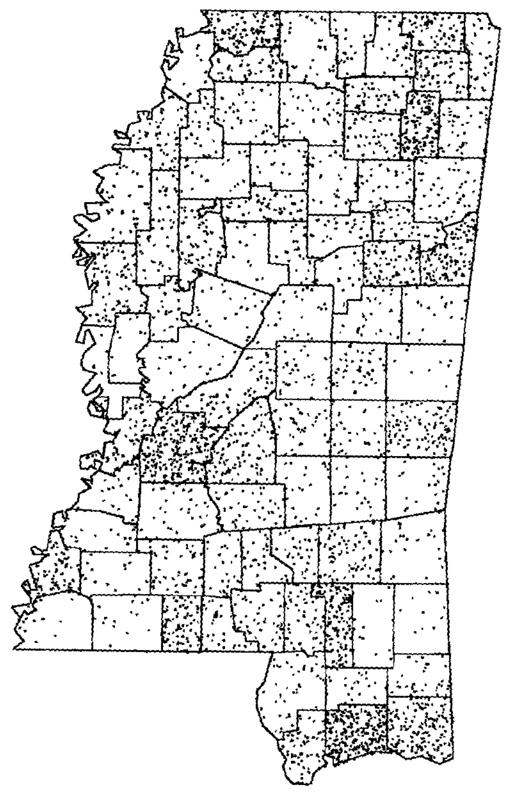
Aquifer Vulnerability Map of Mississippi



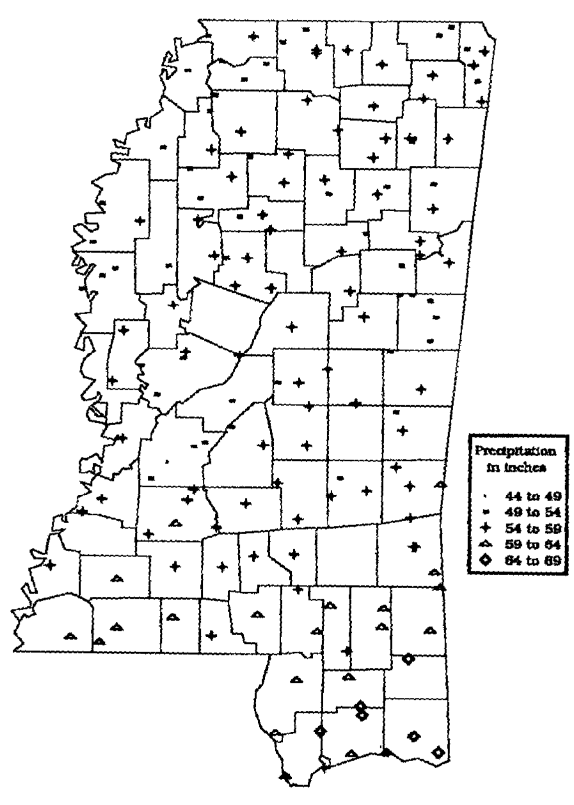
Potential Well Yields In Mississippi



Aquifer Sensitivity Map of Mississippi



Population Density of Mississippi (Dot equals one person per square mile)



Average Annual Precipitation in Mississippi

NORTH CAROLINA

General Setting

North Carolina, which contains approximately 52,700 square miles, lies within four distinct physiographic provinces. The Coastal Plain province occupies the eastern two-fifths of the state, and contains the low lying to flat, poorly drained, outer or tide-water part, and the gently rolling, well drained, inner part (Stuckey and Steel, 1953). The central part of the state lies in the hills of the Piedmont province, while the mountainous western fifth of the state is in the Blue Ridge and Valley and Ridge. The Coastal Plain is underlain by an eastward thickening wedge of Cretaceous to Holocene age consolidated to unconsolidated, marine, marine-terrace, and alluvial deposits. The central and western parts of the state are underlain by faulted and folded Precambrian to Mesozoic age metamorphic, igneous, and sedimentary rocks, which commonly are overlain by regolith.

The western part of North Carolina is drained by several northwest-flowing rivers. The remainder of the state is drained by a network of southeast-flowing rivers. Annual precipitation ranges from 40 to 82 inches in the mountainous Blue Ridge province. Elsewhere annual precipitation ranges from 44 inches in the west to 52 inches in the southeast. The majority of North Carolina's population, nearly 6.5 million, is located in the Piedmont. The remainder of the state is moderately populated. About 435 million gallons of fresh ground water are used daily in North Carolina.

Unconsolidated Aquifers (Class Ia)

The unconsolidated sediments in North Carolina's Coastal Plain form vulnerable and productive aquifers. Alluvial, marsh, lagoonal, and beach deposits consist of unconsolidated sand, silt, gravel, and clay, which locally are overlain by dune sand. Well yields commonly range from 25 to 200 gpm, and may exceed 500 gpm. Marine-terrace deposits consist of unconsolidated sand and clay, sandy shell beds and interbedded marls, and massive marine clays. Well yields commonly range from 15 to 90 gpm, and may exceed 500 gpm. About 38.5 percent of the state is covered by unconsolidated deposits.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Solutional features are present in carbonate rocks, which are locally exposed in stream cuts in the eastern part of the state. Lithologies range from sandy shell limestone and marl to dense silicified limestone with calcareous sand facies. Solutional features contribute to the vertical and lateral permeability of the rock, creating highly productive and vulnerable aquifers. Well yields commonly range from 200 to 500 gpm, and may exceed 2,000 gpm. Surface exposures of soluble aquifers occupy about 1.2 percent of the state.

Semiconsolidated Aquifers (Class Ic)

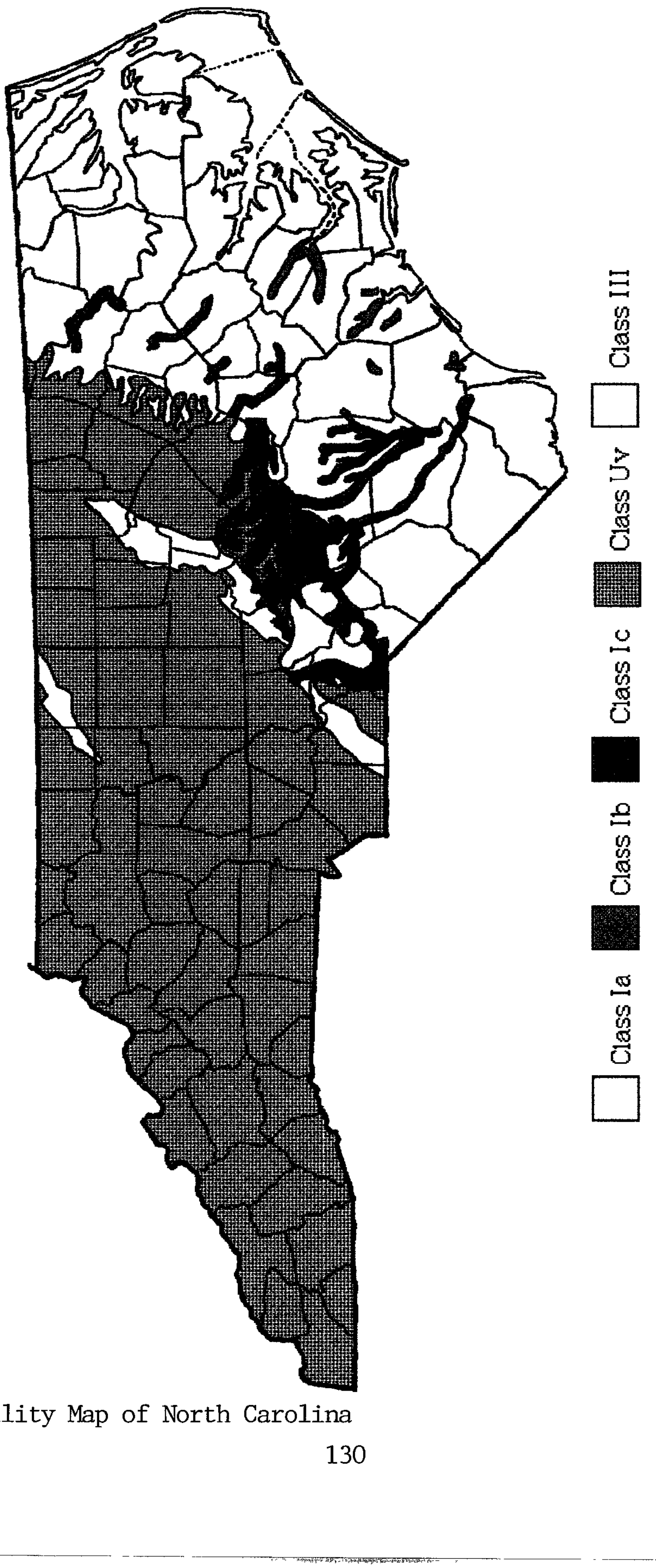
Exposures of semiconsolidated marine sediments occur along a northeasterly trend in south-central North Carolina, and in several stream valleys in the eastern part of the state. These Cretaceous age sediments consist of sand, clayey sand, and clay, and locally contain marls and shell limestones. Well yields commonly range from 200 to 400 gpm, and may exceed 1400 gpm. Surface exposures of Class Ic aquifers occupy about 6 percent of the state.

Variably Covered Undifferentiated Aquifers (Class U-v)

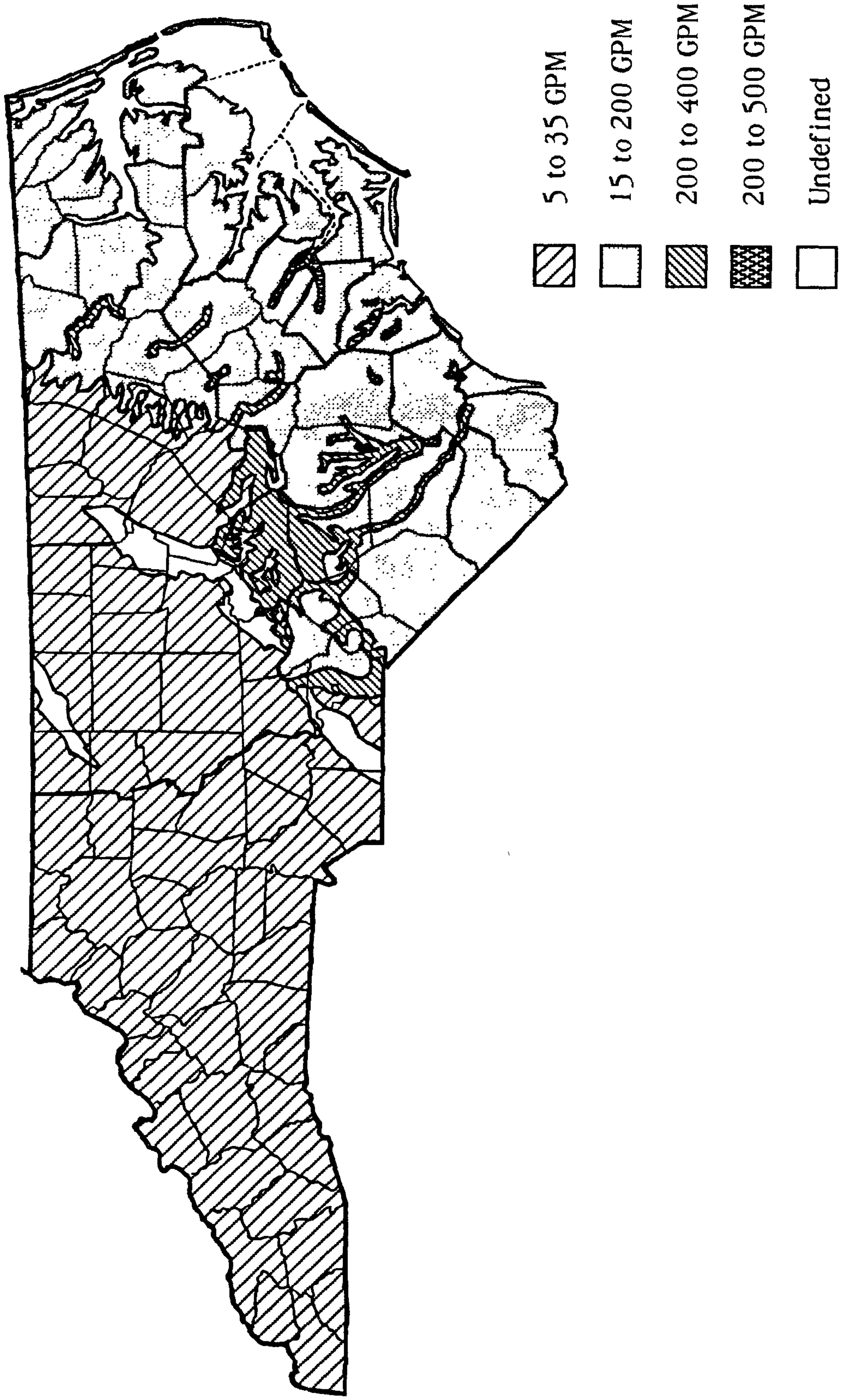
Undifferentiated aquifers are exposed throughout the western two-thirds of North Carolina. These bedrock units consist of fractured, metamorphic and igneous rocks that commonly are overlain by a clay-rich regolith of variable thickness. Well yields normally range from 5 to 35 gpm, and may exceed 200 gpm. Well yields are dependent on the number of fractures penetrated by the well bore. Sustained well yields are related to the thickness of the saturated regolith. Class U-v aquifers occupy about 51 percent of the state.

Sensitivity

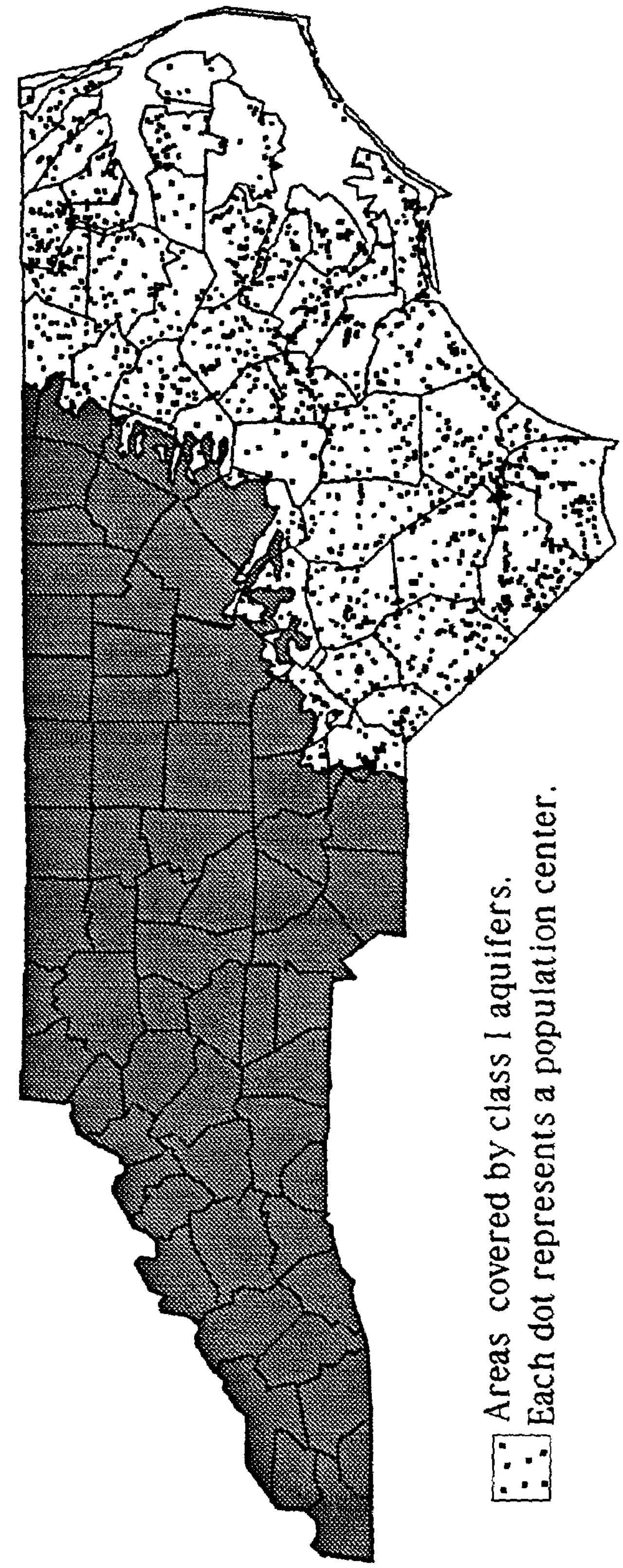
About 46 percent of North Carolina is covered by Class I aquifers. The potential for ground-water contamination from shallow injection wells is highest in the eastern part of the state where population centers are rather evenly distributed.



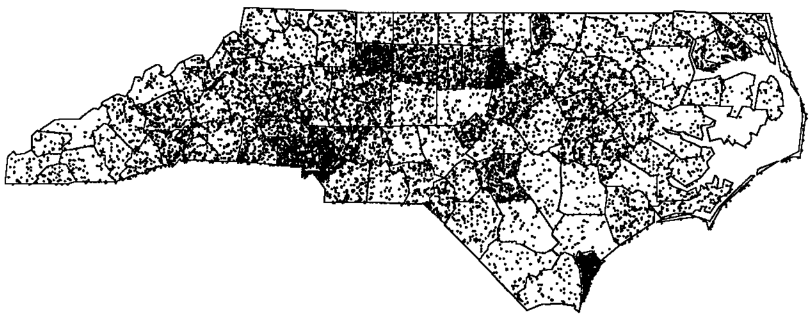
Aquifer Vulnerability Map of North Carolina



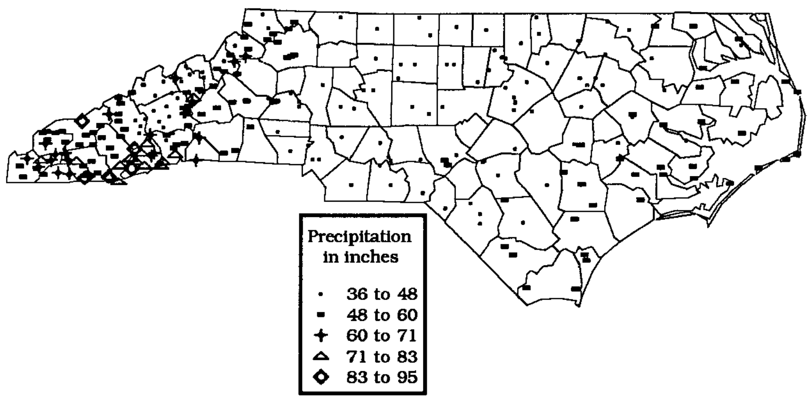
Potential Well Yields in North Carolina



Aquifer Sensitivity Map of North Carolina



Population Density of North Carolina (Dot equals one person per square mile)



Average Annual Precipitation in North Carolina

SOUTH CAROLINA

General Setting

South Carolina, which contains approximately 31,100 square miles, lies primarily in the low relief to hilly Coastal Plain and Piedmont physiographic provinces. The extreme northwestern part of the state includes the mountainous Blue Ridge province. The southeastern two-thirds of the state is underlain by a southeastward thickening wedge of consolidated to unconsolidated marine, marine-terrace, and alluvial deposits that range from Cretaceous to Holocene in age. The northwestern third of the state is underlain by folded and faulted metamorphic and igneous rocks, Precambrian to Mesozoic in age, that commonly are overlain by regolith.

South Carolina is drained by a network of southeast flowing rivers. The Savannah River and its many tributaries drain the western margin of the state. Annual precipitation ranges from less than 48 inches in the southeast to more than 80 inches in the northwest. Precipitation is greatest during the summer and least in the fall. The majority of South Carolina's population, nearly 3.5 million, is divided among several mid-sized cities that are distributed throughout the state. Elsewhere the state is moderately populated. About 214 million gallons per day of fresh ground water are used in the state.

Unconsolidated Aquifers (Class Ia)

The unconsolidated sediments, which form South Carolina's Coastal Plain, are vulnerable and productive aquifers. Alluvial, marsh and beach deposits consist of unconsolidated sand, gravel, and clay. Well yields commonly range from 5 to 10 gpm, and may exceed 500 gpm. Marine-terrace deposits consist of unconsolidated glauconitic, quartzose sand, interbedded with clay, marl, and coquina. Well yields from these deposits commonly range from 50 to 200 gpm, and may exceed 700 gpm. About 40 percent of the state is covered by Class Ia aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Solutional features are present in fossiliferous limestones and coquina beds that are locally exposed by stream cuts throughout the southwestern half of the Coastal Plain. Karst features create highly productive and vulnerable aquifers. Well yields commonly range from 100 to 300 gpm, and may exceed 2,000 gpm. Surface exposures of soluble aquifers occupy about 8 percent of the state.

Semiconsolidated Aquifers (Class Ic)

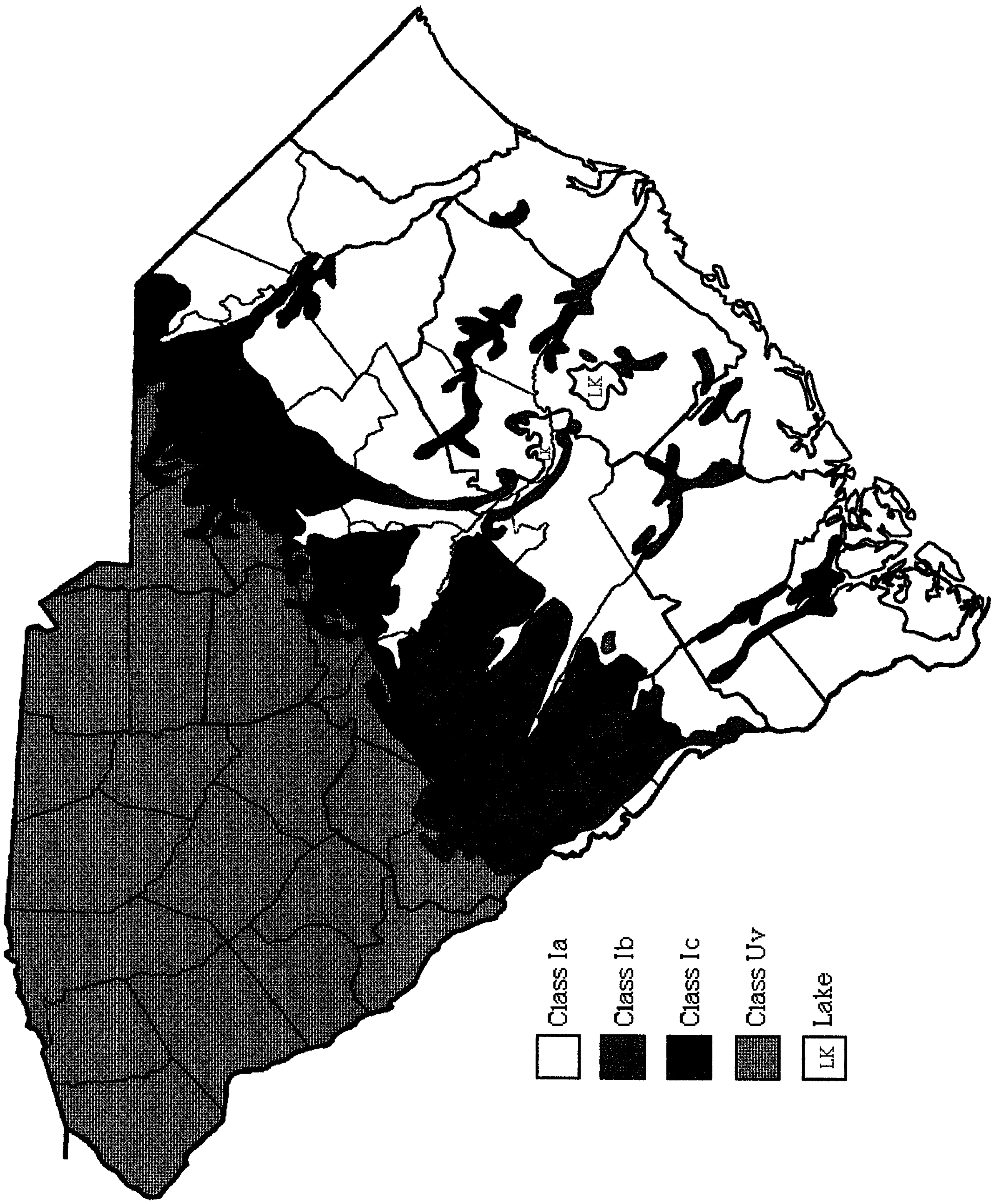
Exposures of semiconsolidated continental and marine sediments occur along a northeastern trend across central South Carolina, and in stream cut valleys throughout the Coastal Plain. These Cretaceous age sediments consist of phosphatic, glauconitic, and calcareous sand, interbedded with clay. Well yields commonly range from 50 to 700 gpm, and may exceed 2,000 gpm. Surface exposures of semiconsolidated aquifers occupy about 15 percent of the state.

Variably Covered Undifferentiated Aquifers (Class U-v)

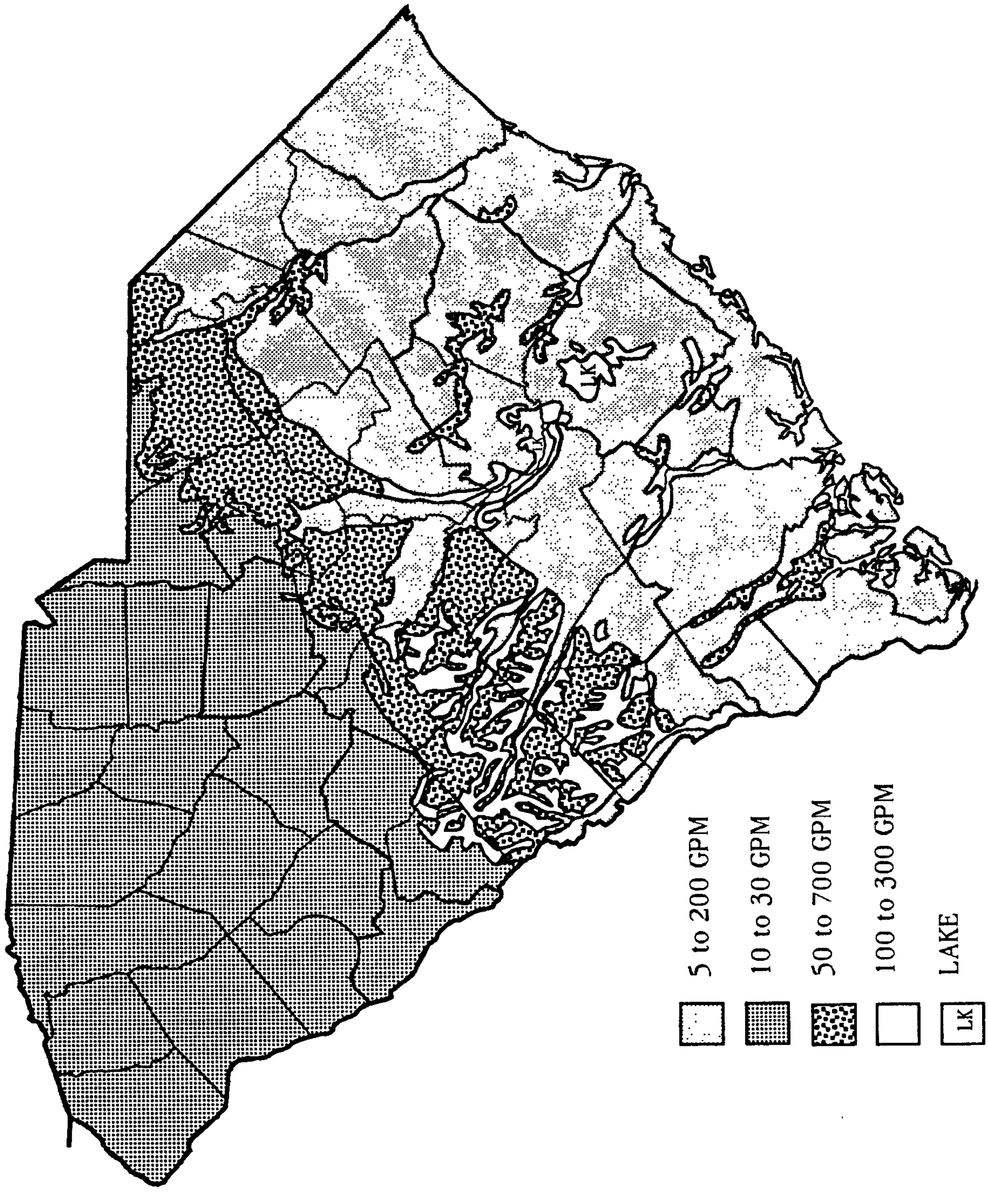
Class U-v aquifers occur throughout the northwestern half of the state. These bedrock aquifers consist of fractured igneous and metamorphic rocks that are commonly covered by a saprolite that ranges from about 30 to 60 feet in thickness. The clay-rich, unconsolidated saprolite stores a large quantity of water, but it has a low permeability. Well yields generally range from 10 to 30 gpm, and may exceed 300 gpm. The occurrence of water bearing fractures decreases with depth. Class U-v aquifers occupy approximately 36 percent of the state.

Sensitivity

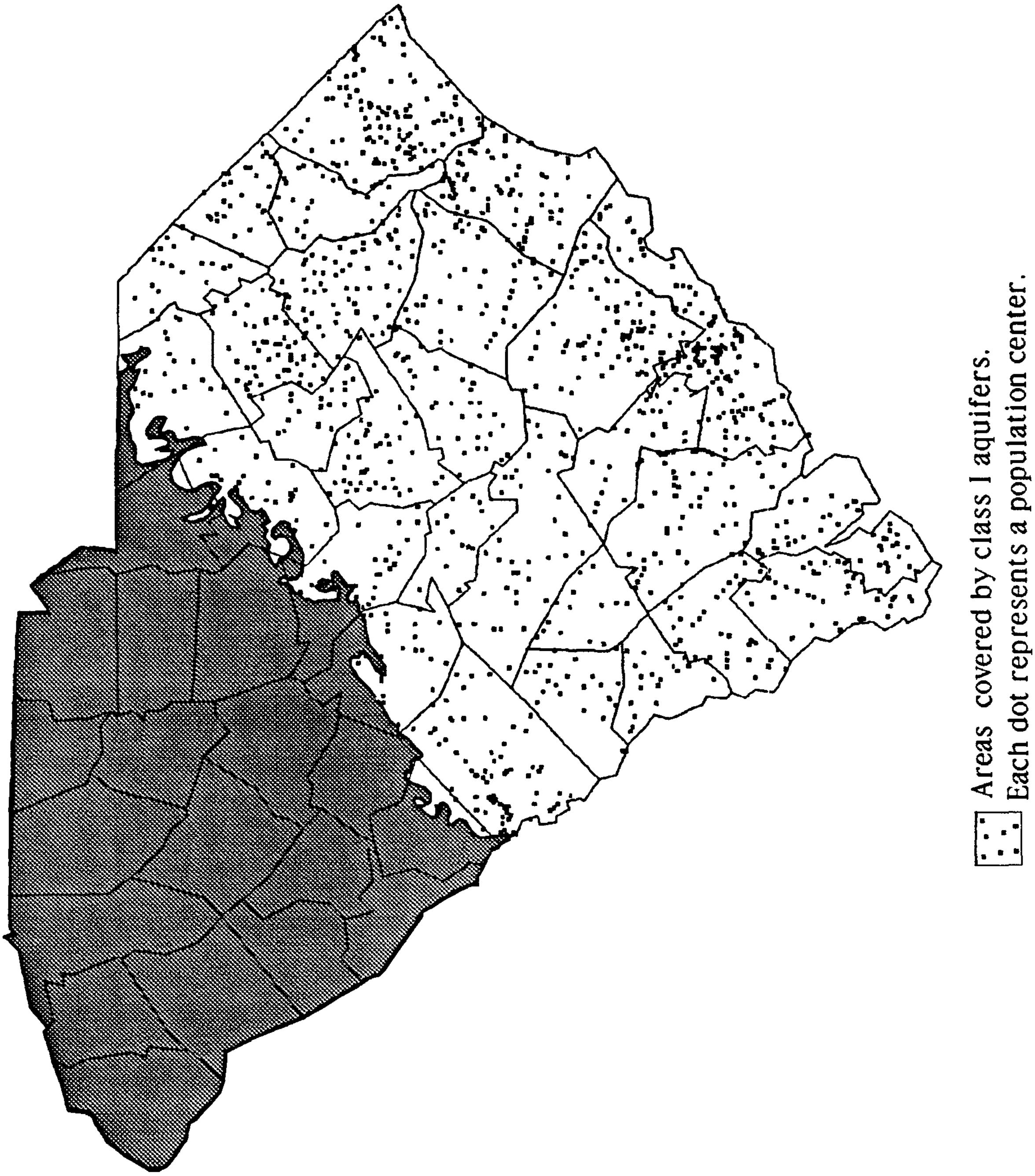
About 63 percent of South Carolina is covered by Class I aquifers. The potential for ground-water contamination from shallow injection wells is low to moderate, particularly in the southeastern half of the state where unconsolidated Coastal Plain deposits crop out.



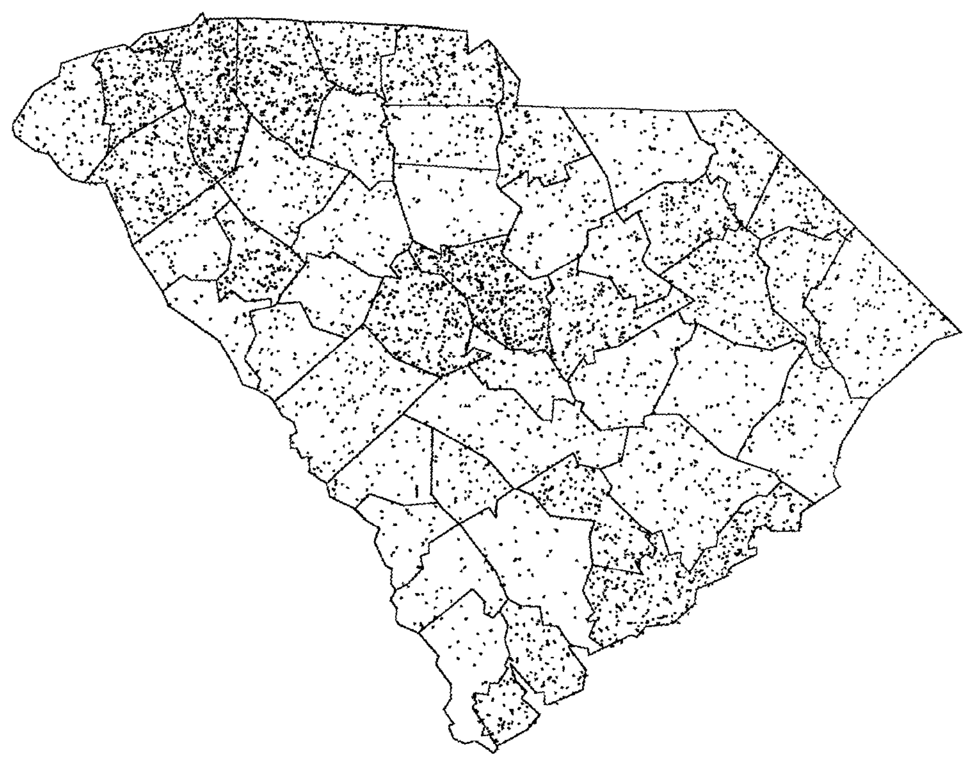
Aquifer Vulnerability Map of South Carolina



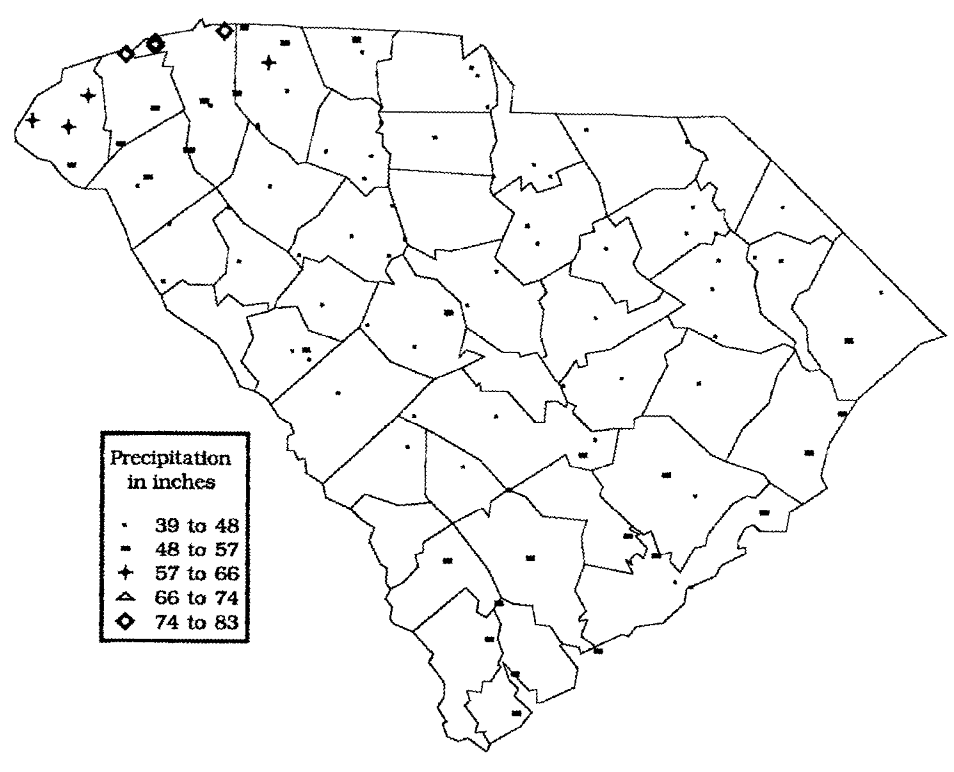
Potential Well Yields in South Carolina



Aquifer Sensitivity Map of South Carolina



Population Density of South Carolina (Dot equals one person per square mile)



Average Annual Precipitation in South Carolina

TENNESSEE

General Setting

Tennessee, which contains approximately 42,150 square miles, is in a physiographically diverse region. The eastern half of the state lies among the mountains, ridges, hills, and incised valleys of the Blue Ridge, Valley and Ridge, and Appalachian Plateaus provinces. West-central Tennessee is in the rolling plains of the Interior Low Plateaus and the surrounding gently rolling to highly dissected plateaus of the Highland Rim. Western Tennessee lies in the north-south trending Western Valley and the westward sloping plains of the Coastal Plain. The eastern third of Tennessee is underlain by faulted and tightly folded Cambrian to Pennsylvanian age carbonate and clastic strata. The central part of the state consists of a broadly folded dome of Ordovician to Mississippian age carbonate and clastic sedimentary rocks. Westward dipping, semiconsolidated to unconsolidated, Cretaceous to Holocene age clastic sediments underlie the western third of the state. Alluvial and eolian deposits occur throughout western Tennessee.

Western Tennessee is drained by the Mississippi River, and the remainder of the state by the west- and north-flowing Tennessee and Cumberland rivers. Annual precipitation ranges from 47 inches in the west to 80 inches in the mountainous east. The majority of Tennessee's population, approximately 4.9 million, is located in Shelby, Davidson, Hamilton, and Knox Counties. Elsewhere the state is moderately populated. Each day Tennessee uses about 444 million gallons of fresh ground water.

Unconsolidated Aquifers (Class Ia)

Alluvial deposits occur throughout western Tennessee, and form vulnerable and productive aquifers. These generally unconfined systems consist of Tertiary to Quaternary age interbedded and unconsolidated sand, gravel, clay, silt, and lignite. Well yields commonly range from 20 to 1,000 gpm, and may exceed 2,000 gpm. About 11.4 percent of the state is covered by Class Ia aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Karst features are present in Mississippian age dolomitic and cherty limestone, which is exposed throughout central Tennessee's Highland Rim. These rocks commonly contain calcareous sandstone and shale in the north and east. Where present, karst features contribute to the vertical and lateral permeability of the rock. Well yields commonly range from 5 to 50 gpm, and may exceed 400 gpm. Extensively faulted and folded, Cambrian to Ordovician age clastic and karstic carbonate rocks crop out across eastern Tennessee. These units consist of highly fractured calcareous shale, sandstone, conglomerate, and limestone with dolomite interbeds. Well yields commonly range from 5 to 200 gpm, and may exceed 2,000 gpm. Class Ib aquifers occupy 24.4 percent of the state.

Semiconsolidated Aquifers (Class Ic)

Semiconsolidated sediments crop out in west-central Tennessee. These Cretaceous age units consist of fine-grained, glauconitic sand that is interbedded with silt, clay, marl, and cherty gravel. Well yields commonly range from 50 to 500 gpm, and may exceed 1000 gpm. Surface exposures of semiconsolidated aquifers occupy about 4 percent of the state.

Covered Aquifers (Class Id)

Unconsolidated alluvial aquifers that are overlain by less than 50 feet of low permeability deposits occur throughout western Tennessee's Coastal Plain. The reduced vulnerability of these covered systems is a function of the thickness of the overlying material. Covered alluvial aquifers occupy about 10 percent of the state.

Lower Yield Bedrock Aquifers (Class IIb)

Lower yield Pennsylvanian age bedrock aquifers, composed of sandstone and conglomerate that is interbedded with shale, siltstone, and coal, crop out throughout eastern Tennessee's Cumberland Plateau. Well yields commonly range from 5 to 50 gpm, and may exceed 200 gpm. Class IIb aquifers cover 11 percent of the state.

Undifferentiated Aquifers (Class U)

Several undivided and lithologically varied Paleozoic age formations crop out across the eastern three-fourths of the state, and consist of interbedded limestone, shale, dolomite and sandstone. Lithologically varied Tertiary age sediments extend across the eastern margin of the Coastal Plain in western Tennessee, and consist of interbedded clay, glauconitic sand, and a basal limestone unit. The lithologic and resultant hydrologic variability of these undivided formations has not been delineated, but a wide range in aquifer productivity and vulnerability should be expected. Surface exposures of undifferentiated aquifers occupy about 33 percent of the state.

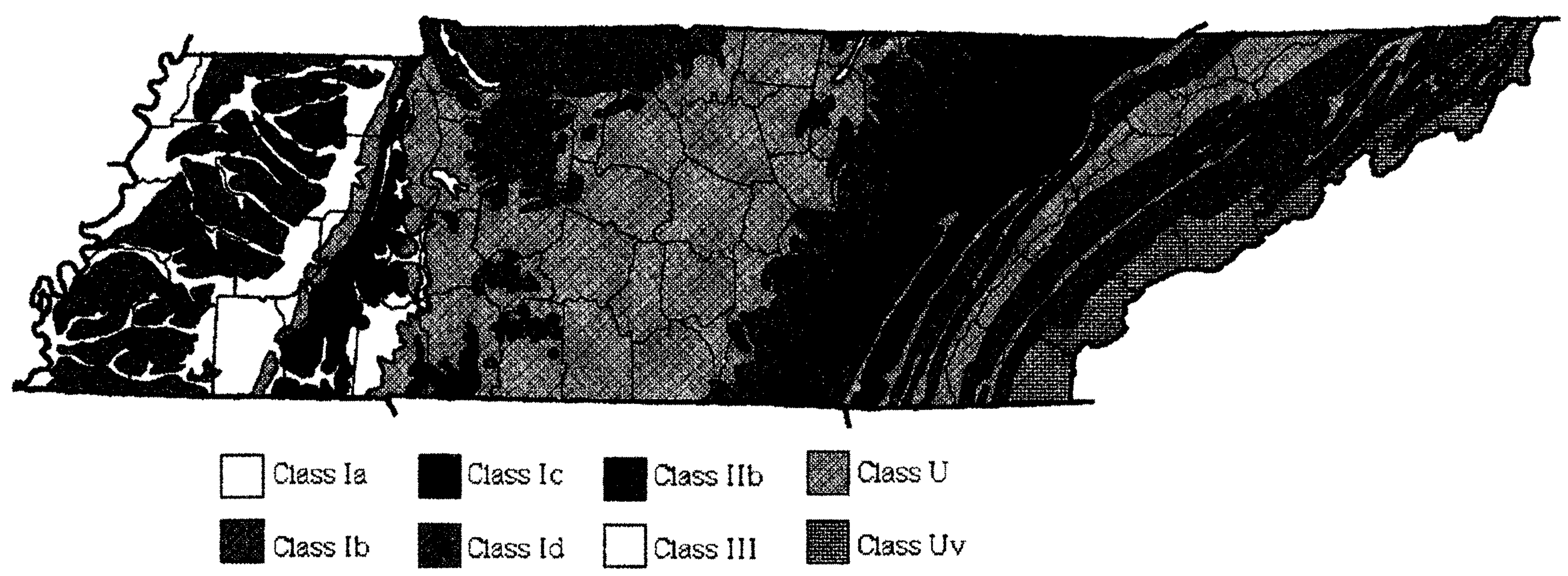
Undifferentiated Aquifers (Class U-v)

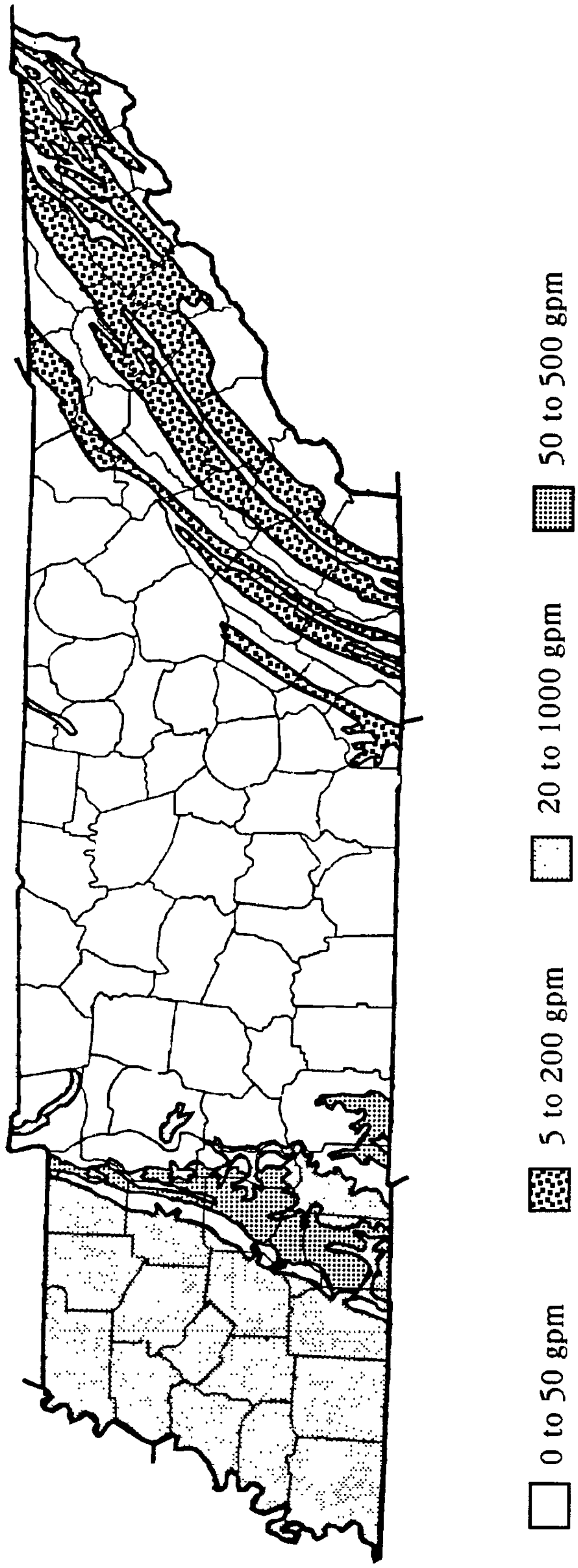
Undifferentiated bedrock aquifers crop out across eastern Tennessee's Blue Ridge. These units consist of Precambrian age igneous, metamorphic, and metasedimentary rocks that are mantled by regolith of variable thickness. Aquifer productivity relies on the presence of saturated regolith and fractured bedrock. Well yields commonly range from 5 to 50 gpm, and may exceed 1,000 gpm. Class U-v aquifers occupy about 5 percent of the state.

Sensitivity

About 50 percent of Tennessee is covered by Class I aquifers. The potential for ground-water contamination from shallow injection wells is relatively low owing to the moderate population density. The most sensitive areas lie in southwest-trending belts in the eastern part of the state where the density of population centers is rather high. Elsewhere in vulnerable areas, population centers are rather evenly distributed.

Aquifer Vulnerability Map of Tennessee

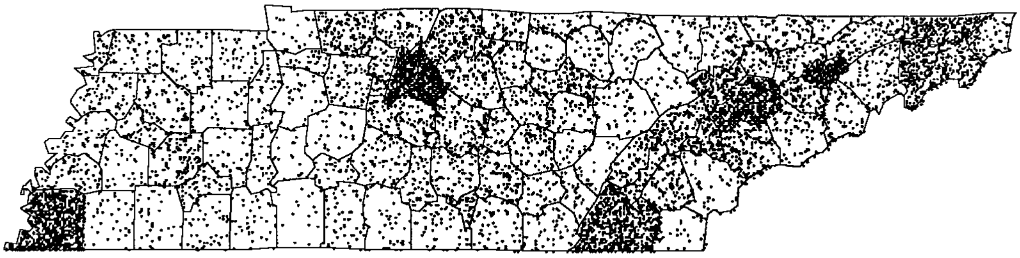




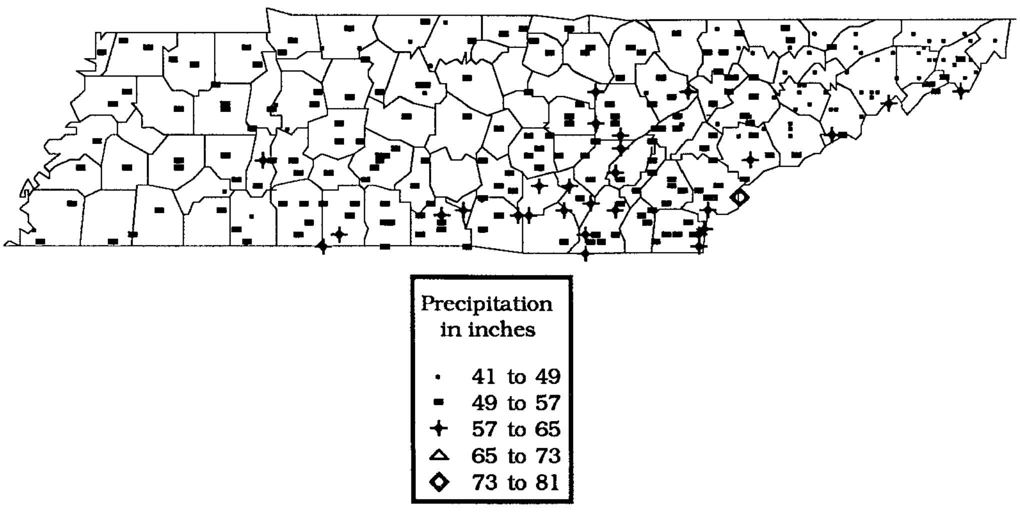
Potential Well Yields in Tennessee

Aquifer Sensitivity Map of Tennessee

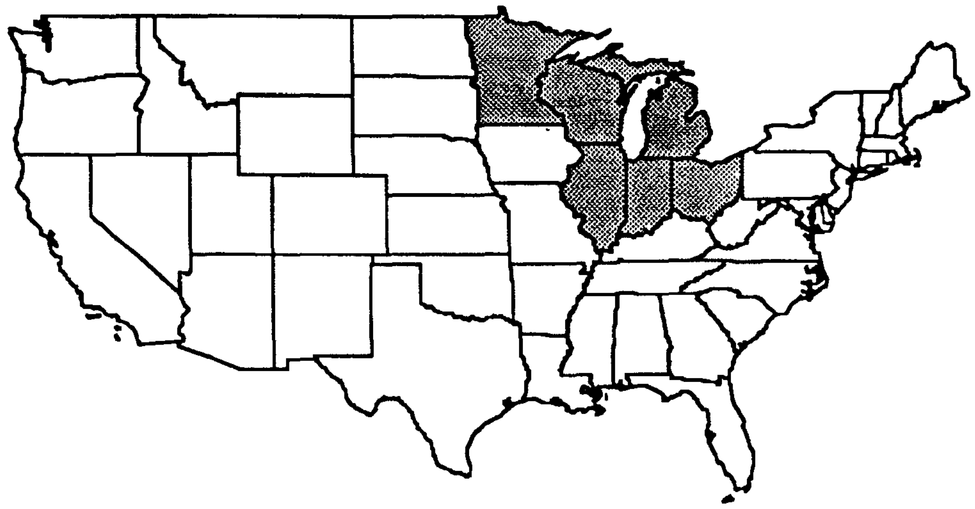
Areas covered by class I aquifers.
Each dot represents a population center.



Population Density of Tennessee (Dot equals one person per square mile)



Average Annual Precipitation in Tennessee



REGION 5

Illinois
Indiana
Michigan
Minnesota
Ohio
Wisconsin

ILLINOIS

General Setting

Illinois contains approximately 56,400 square miles, and mainly lies in the Central Lowland physiographic province. Small areas in the southwestern and southern parts of the state lie within the Ozark Plateaus province. The topography varies from flat-lying to gently rolling. The state is underlain by gently dipping Paleozoic age sediments that are mantled by a variable thickness of glacial material. Glacial deposits, which range from 0 to 600 feet in thickness, are absent in extreme northwest and southern Illinois.

The southern part of the state is drained by several rivers that empty into the Ohio River. The southwesterly-flowing Illinois and Rock rivers drain central and northern Illinois, respectively. Annual average precipitation ranges from 36 inches in the north to about 46 inches in the southern part of the state. The majority of Illinois' population, approximately 11.6 million, is concentrated in the Chicago metropolitan area. The remainder of the state is moderately populated. Ground-water usage amounts to about 930 million gallons of fresh and 38 million gallons of saline ground water each day.

Unconsolidated Aquifers (Class Ia)

Exposed intermittently throughout the state are unconsolidated alluvial and glaciofluvial aquifers. These aquifers consist of sand and gravel with variable amounts of silt and clay. Well yields commonly range from 10 to 1,000 gpm, and may exceed 3,000 gpm. Approximately 14 percent of the state is covered by permeable unconsolidated aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Local exposures of Ordovician to Mississippian age carbonate rocks occur in northeastern, western, and far southern Illinois. These rocks consist of dolomite, limestone, chert, and shale. Where present, solutional features contribute to the vertical and lateral permeability of the rock. Well yields commonly range from 5 to 1,000 gpm, and may exceed 1,500 gpm. About .6 percent of Illinois is covered by Class Ib aquifers.

Semiconsolidated aquifers (Class Ic)

In the south and west-central parts of Illinois are local exposures of Cretaceous age semiconsolidated deposits. These consist of sand, silt, and clay. Well yields commonly range from 10 to 1,000 gpm, and may exceed 3,000 gpm. About .8 percent of the state is occupied by semiconsolidated aquifers.

Covered Aquifers (Class Id)

Soluble strata that are overlain by less than 50 feet of low permeability sediments occur in northern, western, and southern Illinois. These Ordovician to Mississippian age units consist of dolomite, limestone, chert, and shale. Well yields commonly range from 5 to 1,000 gpm, and may exceed 1,500 gpm. Class Id aquifers occupy about 4 percent of the state.

Lower Yield Bedrock Aquifers (Class IIb)

Local exposures of lower yield sedimentary rock aquifers occur in southern Illinois. These Pennsylvanian age strata are predominantly sandstone with minor amounts of shale, coal, and limestone. Well yields commonly range from 5 to 25 gpm, and may exceed 1,000 gpm. Class IIb aquifers are exposed in about 1.3 percent of Illinois

Covered Aquifers (Class IIc)

Exposed intermittently throughout Illinois are low yield aquifers that are overlain by less than 50 feet of low permeability sediments. These Pennsylvanian age rocks consist of sandstone, shale, and chert with minor amounts of limestone and coal. Well yields commonly range from 5 to 25 gpm, and may exceed 1,000 gpm. About 25 percent of Illinois is occupied by Class IIc aquifers.

Undifferentiated Aquifers (Class U)

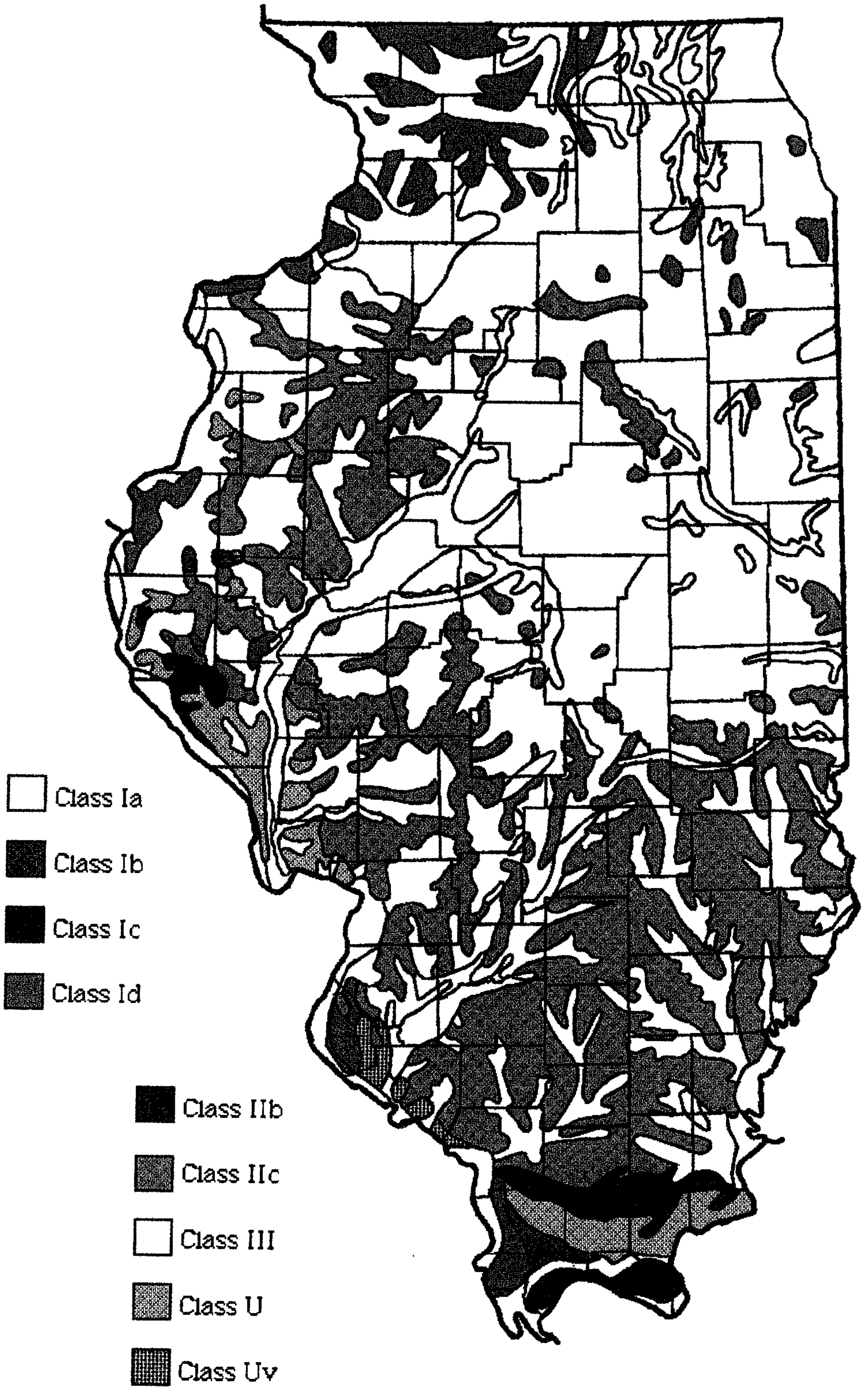
Exposed locally in western and southern Illinois are undifferentiated Upper Mississippian rocks that consist of shale, sandstone, and limestone. Well yields commonly range from 5 to 25 gpm, and may exceed 1,000 gpm. About 2 percent of the state is occupied by undifferentiated aquifers.

Covered Undifferentiated Aquifers (Class U-v)

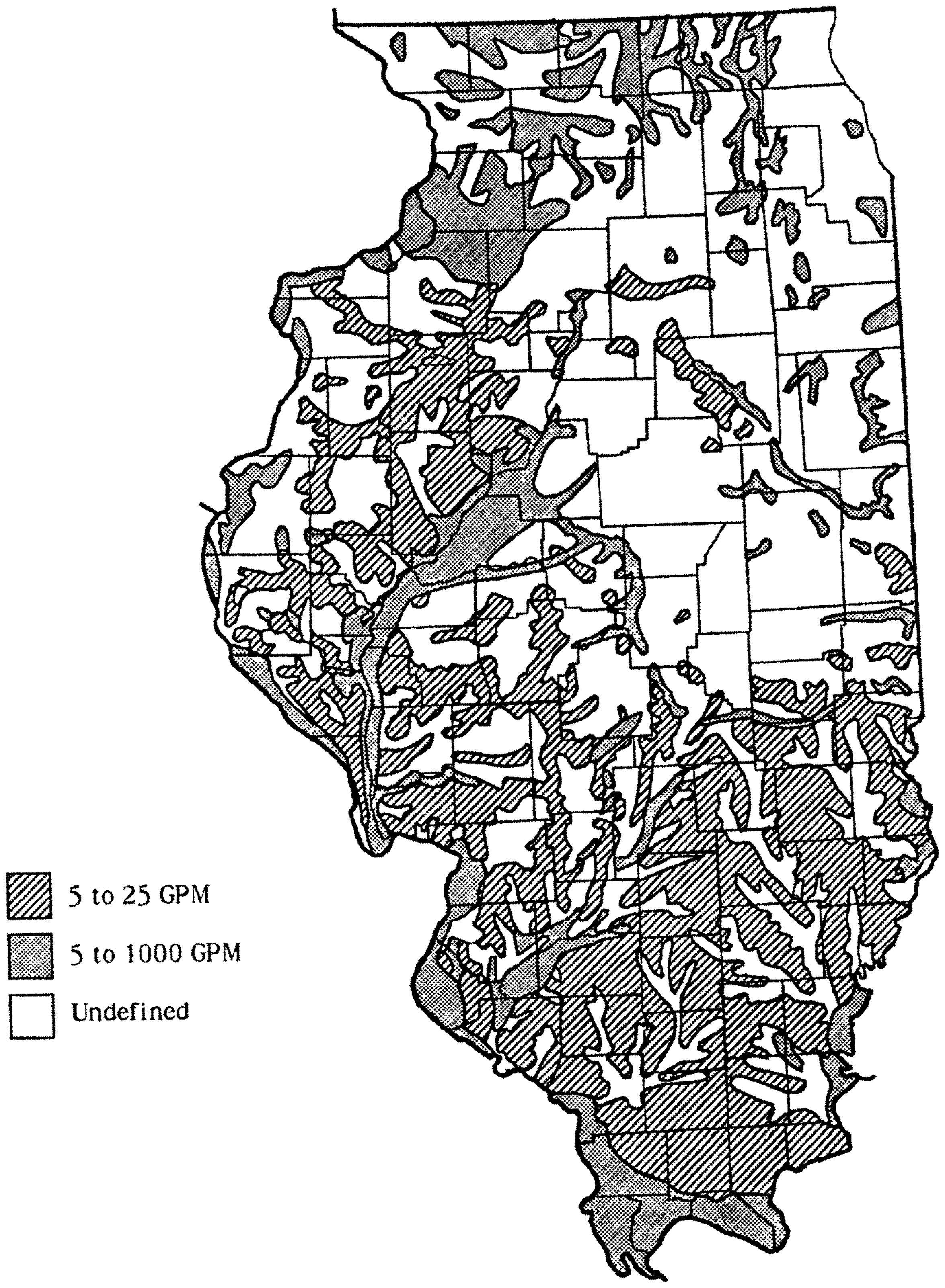
Occurring in southwestern Illinois are undifferentiated Mississippian age clastic and carbonate rocks that are overlain by a variable thickness of low permeability sediments. Well yields commonly range from 5 - 25 gpm, and may exceed 100 gpm. About 1 percent of Illinois is occupied by Class U-v aquifers.

Sensitivity

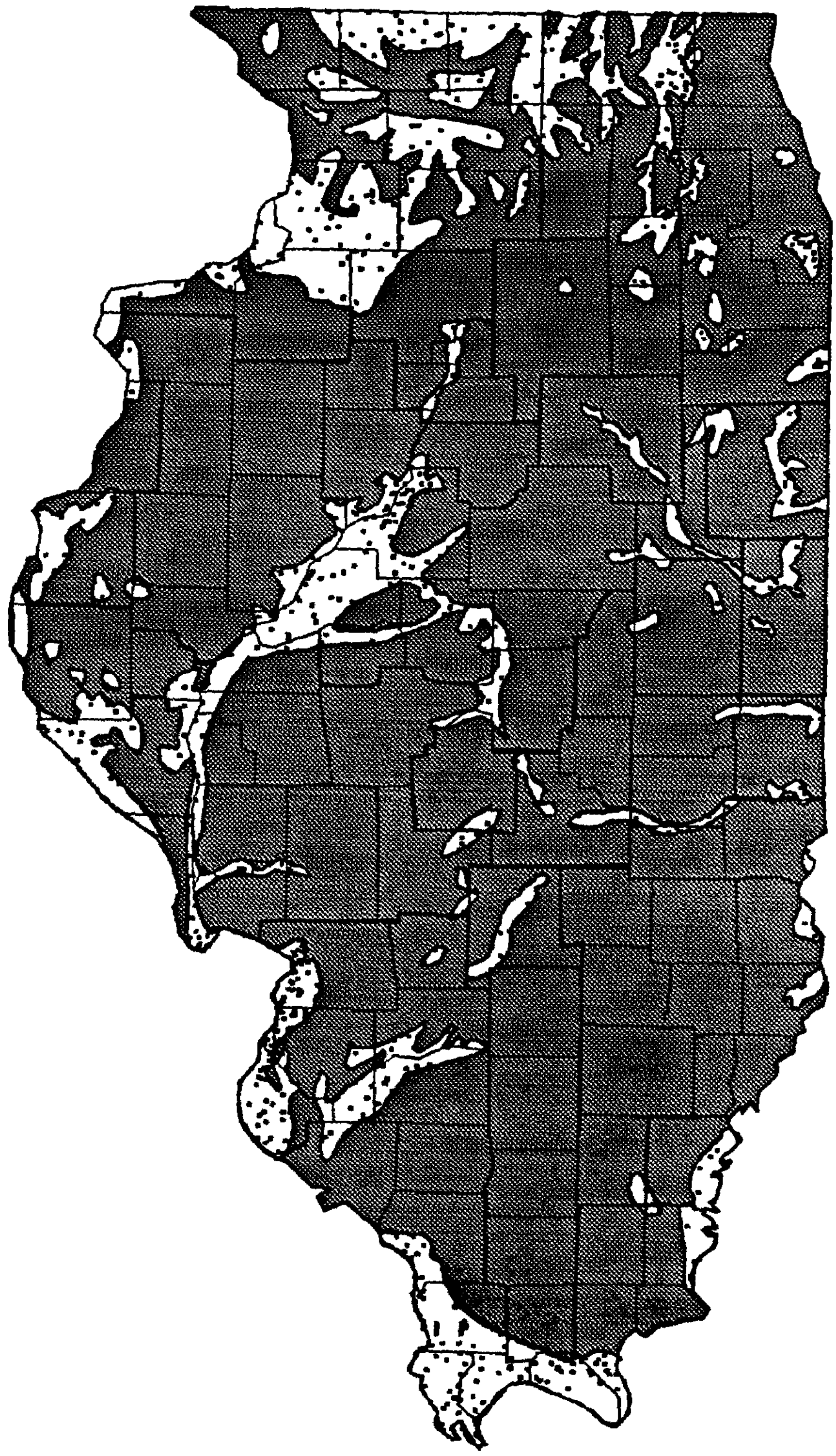
Nearly 15 percent of Illinois is covered by Class I aquifers. Most of the areas consist of linear belts of sand and gravel that lie along streams and the Mississippi River. Population centers are rather dense along parts of the Mississippi and Illinois rivers. These areas are particularly sensitive because of the population distribution and abundance of industry.



Aquifer Vulnerability Map of Illinois

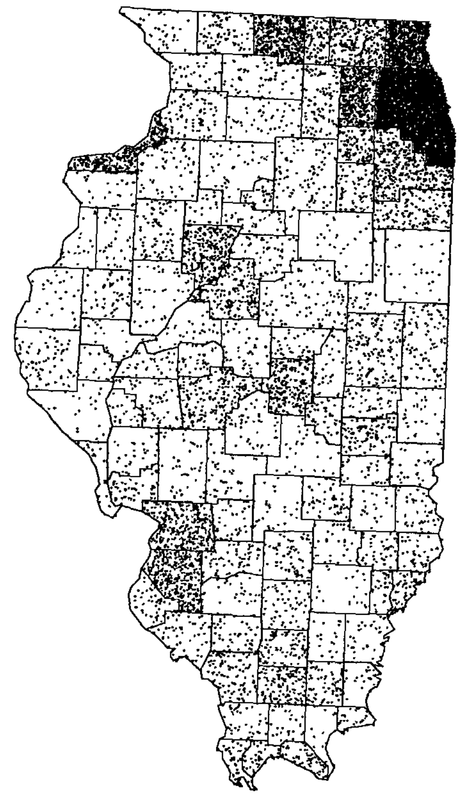


Potential Well Yields in Illinois

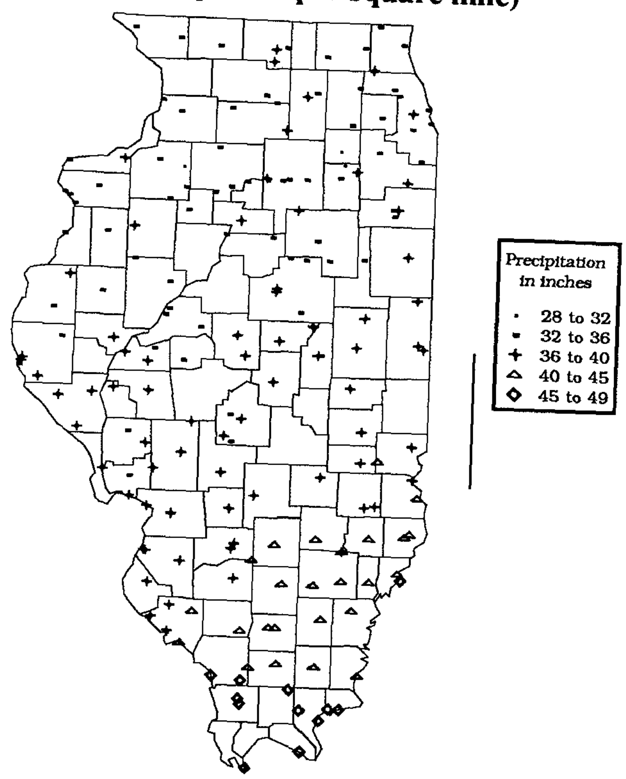


Areas covered by class I aquifers.
Each dot represents a population center.

Aquifer Sensitivity Map of Illinois



Population Density of Illinois
(Dot equals one person per square mile)



Average Annual Precipitation in Illinois

INDIANA

General Setting

Indiana, which contains approximately 36,200 square miles, lies within the unglaciated Interior Low Plateaus in the southern part of the state, and the remainder is in the glaciated Central Lowland. The topography ranges from flat to gently rolling. Indiana is underlain by Paleozoic age sedimentary rocks that dip gently off the northwest-southeast trending Cincinnati-Kankakee Arch.

The state is drained by the Wabash and other southwest-flowing river systems. Average annual precipitation varies from 36 inches in the north to 44 inches in the southern part of the state. Indiana's population, approximately 5.5 million, is concentrated in Indianapolis and several other metropolitan areas. The remainder of the state is moderately populated. About 635 million gallons of fresh ground water are used daily in Indiana.

Unconsolidated Aquifers (Class Ia)

Exposed along river channels, and locally elsewhere, are unconsolidated outwash, glaciofluvial, and alluvial deposits, which consist of sand and gravel with lesser amounts of silt and clay. Well yields commonly range from 100 to 500 gpm, and may exceed 1,500 gpm. Approximately 27 percent of Indiana is covered by Class Ia aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Soluble aquifers are exposed in south-central and southeastern Indiana. These Ordovician and Mississippian age rocks consist of limestone with lesser amounts of shale and sandstone. Well yields commonly range from 10 to 100 gpm, and may exceed 600 gpm. Where present, karst features contribute to the vertical and lateral permeability of the rock. Class Ib aquifers occupy about 6 percent of Indiana.

Variably Covered Soluble and Fractured Bedrock Aquifers (Class Ib-v)

Carbonate aquifers overlain by a variable thickness of glacial till occur in southwest and, locally, in south-central Indiana. These Ordovician to Mississippian age strata, which contain solutional features, consist of limestone with lesser amounts of shale and sandstone. Well yields commonly range from 10 to 100 gpm, and may exceed 600 gpm. Approximately 3 percent of the state is covered by Class Ib-v aquifers.

Covered Aquifers (Class Id)

Soluble aquifers that are overlain by less than 50 feet of glacial till occur in the central part of Indiana. The bedrock consists of Ordovician to Mississippian age limestone with lesser amounts of shale and sandstone. The vulnerability of these covered systems is a function of the overlying low permeability sediments. Well yields commonly range from 10 to 100 gpm, and may exceed 600 gpm. About 3 percent of Indiana is overlain by Class Id aquifers.

Lower Yield Bedrock Aquifers (Class IIb)

Occurring in south-central Indiana are lower yield bedrock aquifers. These Mississippian to Pennsylvanian age aquifers consist of sandstone, shale, and limestone with some coal. Well yields are generally less than 25 gpm. About 8 percent of Indiana is occupied by Class IIb aquifers.

Covered Low Yield Bedrock Aquifers (Class IIc)

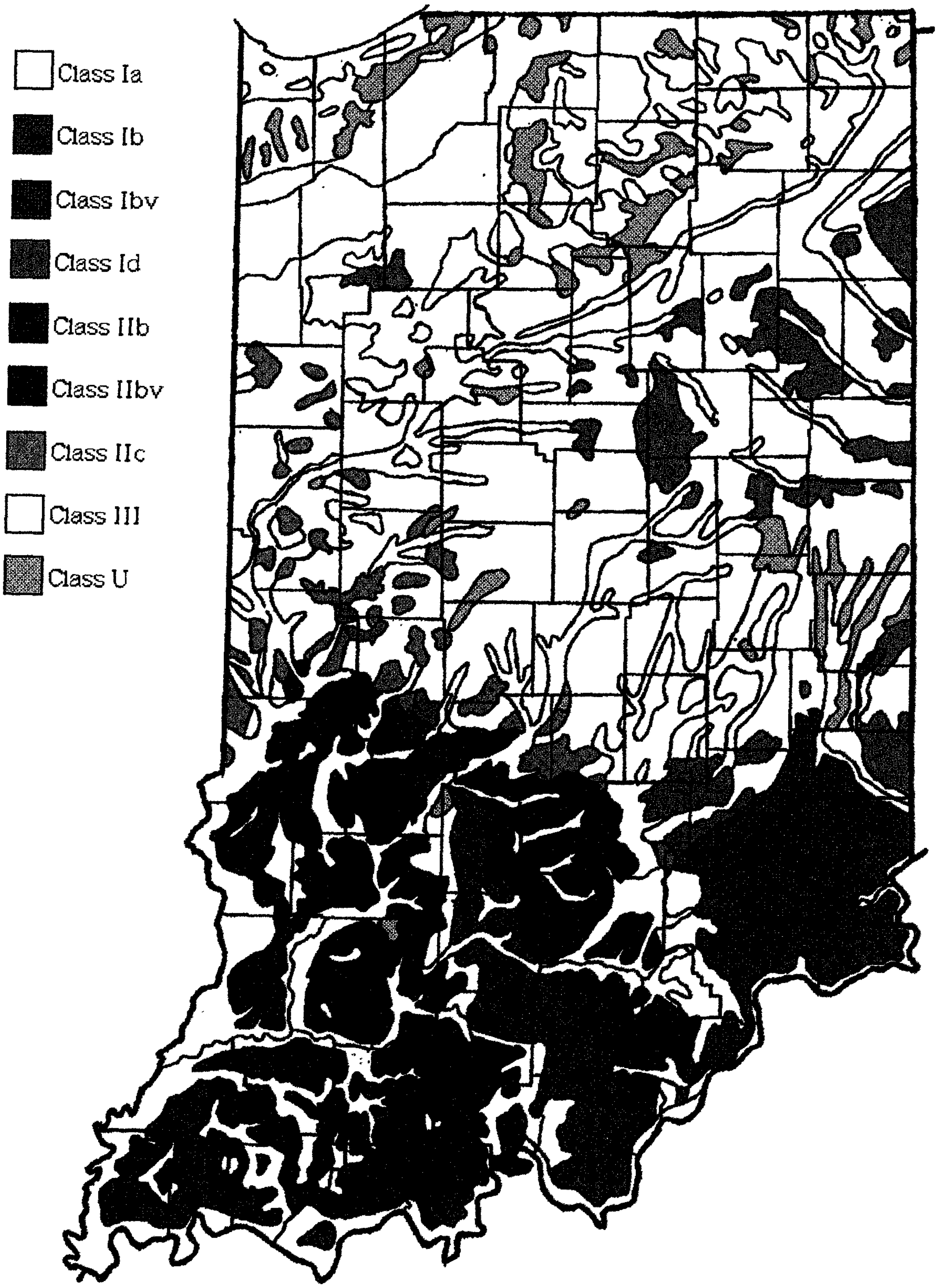
Occurring locally in west-central Indiana are lower yield sedimentary aquifers that are overlain by less than 50 feet of low permeability glacial till. These Mississippian to Pennsylvanian age rocks consist of siltstone, sandstone, and shale with some limestone and coal. Specific well yields are not well defined, but yields of a few tens of gallons per minute are to be expected. About 3 percent of Indiana is covered by Class IIc aquifers.

Undifferentiated Aquifers (Class U)

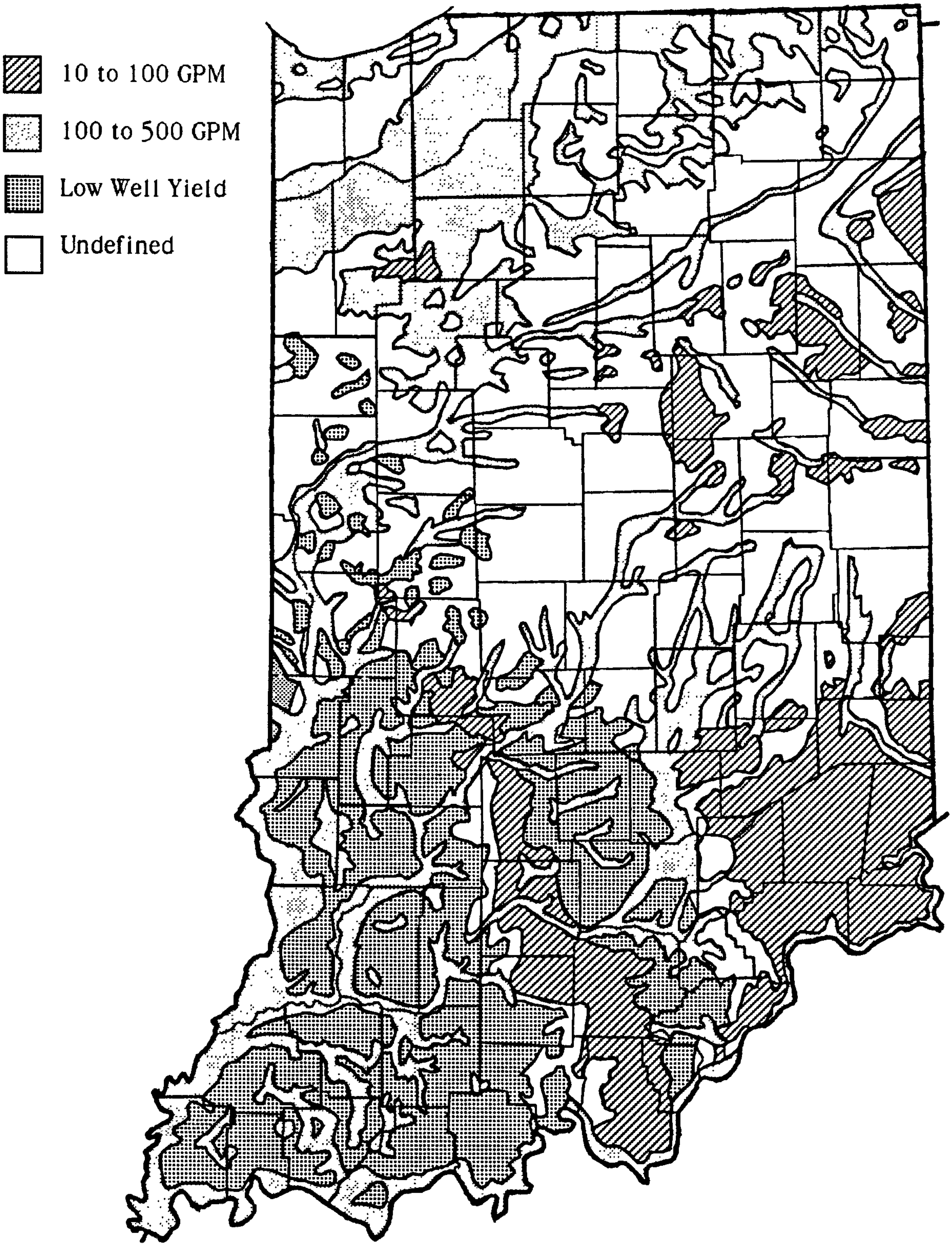
Undifferentiated glacial deposits locally occur throughout the state. These aquifers consist of a heterogeneous mix of stratified drift and till deposits. Well yields are not defined. Approximately 4 percent of Indiana is covered by undifferentiated glacial aquifers.

Sensitivity

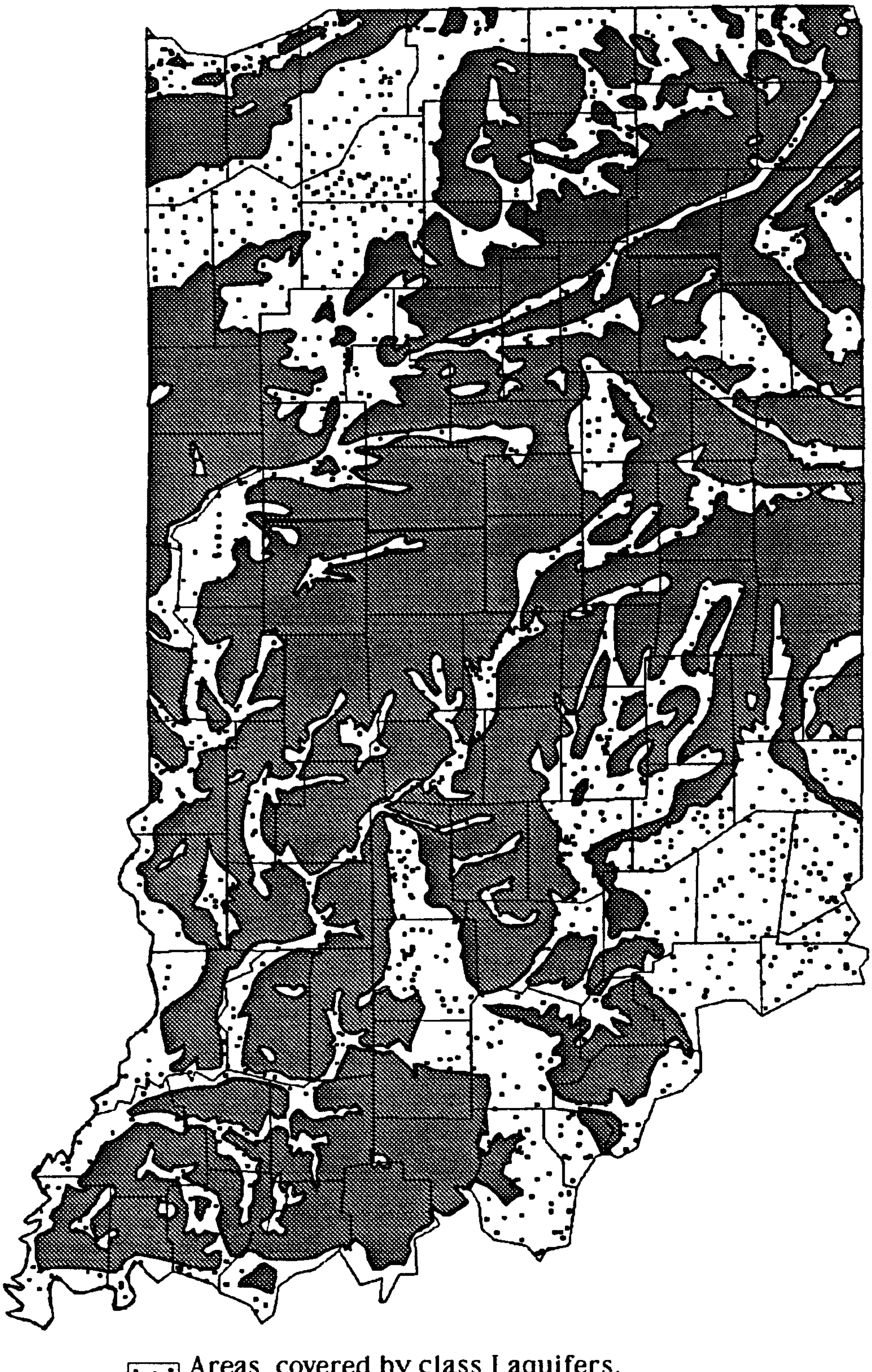
Class I aquifers occupy nearly 37 percent of Indiana. The potential for ground-water contamination from shallow injection wells is moderately low. Although several areas are quite vulnerable, the density of population centers is not great. The most sensitive regions occur in the southeastern and southern parts of the state and along several rivers, such as the Ohio, Wabash, and Kankakee rivers.



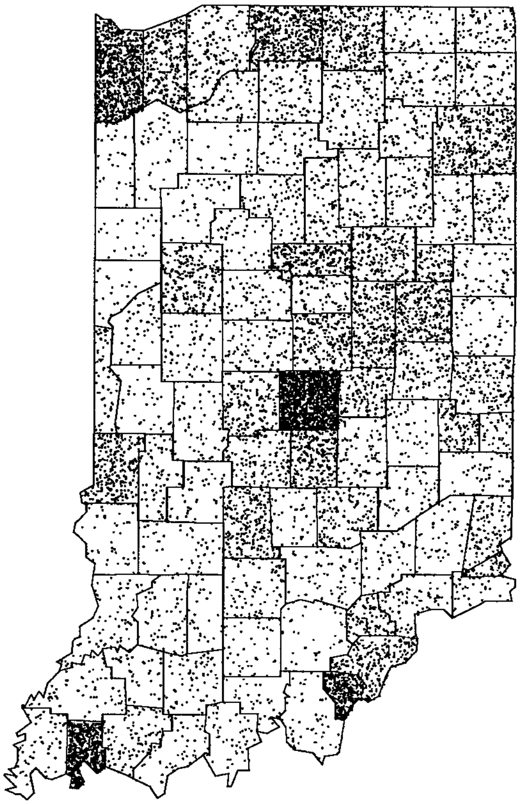
Aquifer Vulnerability Map of Indiana



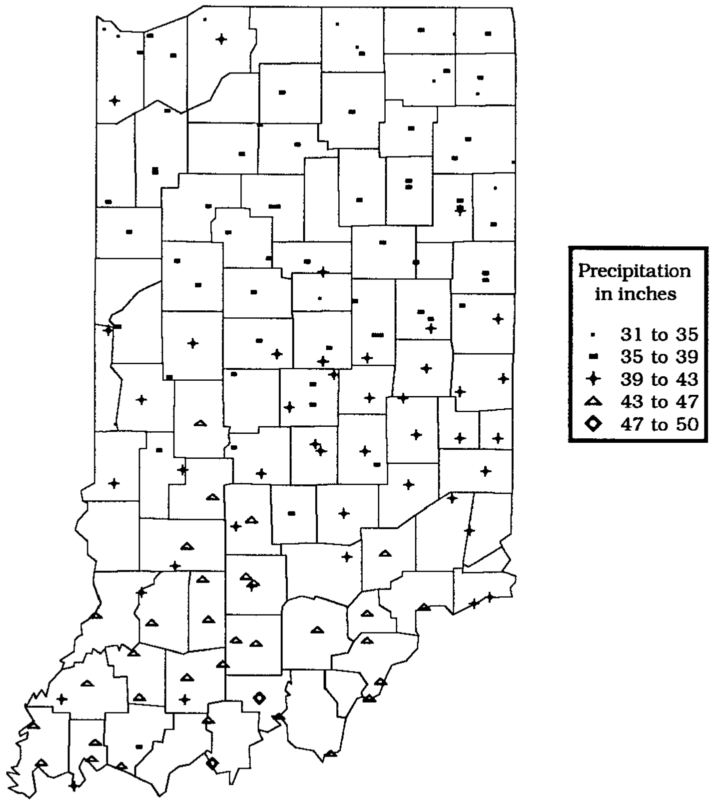
Potential Well Yields in Indiana



Aquifer Sensitivity Map of Indiana



Population Density of Indiana
(Dot equals one person per square mile)



Average Annual Precipitation in Indiana

MICHIGAN

General Setting

Michigan contains approximately 58,200 square miles. The rugged western part of the Upper Peninsula, which lies within the Superior Upland physiographic province, is underlain by Precambrian to Paleozoic age crystalline and sedimentary rock. The gently rolling eastern part of the Upper Peninsula and the gently rolling to rugged hills of the Lower Peninsula lie within the Central Lowlands. This province is underlain by Paleozoic to Mesozoic age sedimentary rock, which has been structurally formed into the Michigan Basin. Overlying the bedrock throughout most of the state are permeable glaciofluvial and relatively low permeable glacial till deposits. These glacial deposits range in thickness from a few feet in the western part of the Upper Peninsula to over 800 feet in the Lower Peninsula.

The Upper Peninsula is drained by several streams that empty into Lake Superior and Lake Michigan. The western half of the Lower Peninsula is drained by rivers that terminate in Lake Michigan. Eastern Michigan is drained by several northerly- and easterly-flowing rivers that discharge into Lake Huron. Average annual precipitation in the Upper Peninsula is about 34 inches, while in the Lower Peninsula it ranges from 28 inches in the east to about 40 inches in the southwest. Michigan's population, about 9.2 million, is concentrated in Detroit and other large cities in the southern part of the state. About 596 million gallons of fresh and 4.5 million gallons of saline water are used daily in Michigan.

Unconsolidated Aquifers (Class Ia)

Exposed intermittently in the Upper Peninsula and fairly extensively in the Lower Peninsula are unconsolidated glacial outwash, glaciofluvial, and lacustrian deposits. They consist of sand, gravel, and variable amounts of locally interbedded silt and clay. Well yields commonly range from 1 to 1,000 gpm, and may exceed 2,000 gpm. Approximately 14 percent of Michigan is covered by permeable unconsolidated aquifers.

Variably Covered Soluble and Fractured Bedrock Aquifers (Class Ib-v)

Underlying the southwestern part of the Upper Peninsula, as well as the southwest and northern parts of the Lower Peninsula, are carbonate bedrock aquifers that are overlain by a variable thickness of glacial till. The bedrock consists of Silurian to Devonian age limestone and dolomite with some sandstone and shale units. The vulnerability of these aquifers is a function of the thickness of the overlying glacial till. Well yields commonly range from 10 to 300 gpm, and may exceed 500 gpm. Nearly 12 percent of Michigan is underlain by Class Ib-v aquifers.

Variably Covered High Yield Bedrock Aquifers (Class IIa-v)

Occurring intermittently throughout the Lower Peninsula are variably covered high yield sedimentary bedrock aquifers. This Mississippian to Pennsylvanian age sequence consists of sandstone and siltstone with some shale, limestone, and coal. The vulnerability of these aquifers is a function of the thickness of the overlying low permeability sediments. Well yields commonly range form 100 to 500 gpm, and may exceed 1,500 gpm. About 16 percent of the state is covered by Class IIa-v aquifers.

Variably Covered Lower Yield Bedrock Aquifers (Class IIb-v)

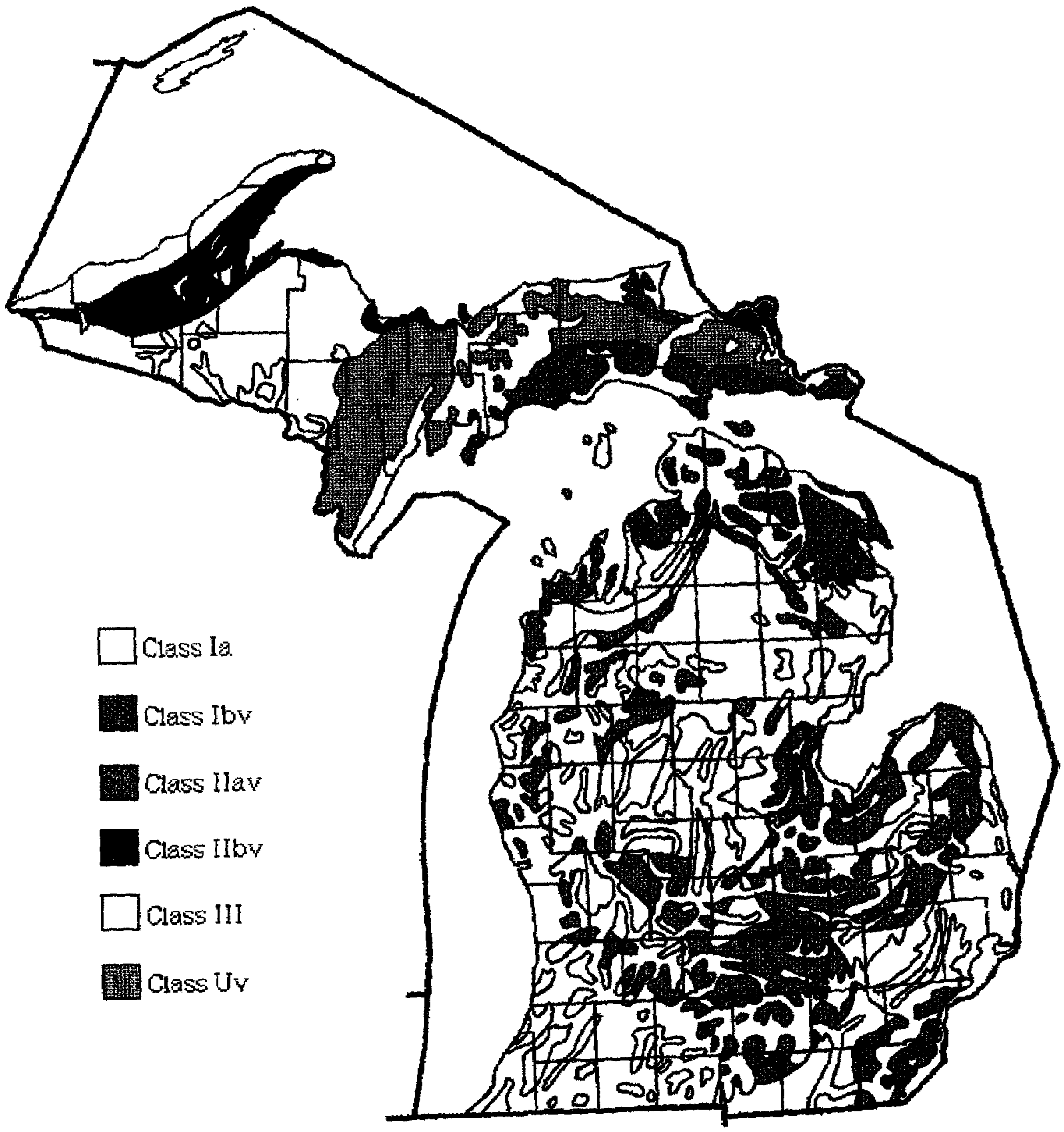
Underlying parts of the Upper Peninsula are variably covered lower yield sedimentary bedrock aquifers. These Precambrian age rocks consist of well-cemented sandstone that is interbedded with shale. The vulnerability of the system is dependent on the thickness of the overlying till. Well yields commonly range from 5 to 50 gpm, and may exceed 100 gpm. About 5 percent of Michigan is underlain by Class IIb-v aquifers.

Variably Covered Undifferentiated Aquifers (Class U-v)

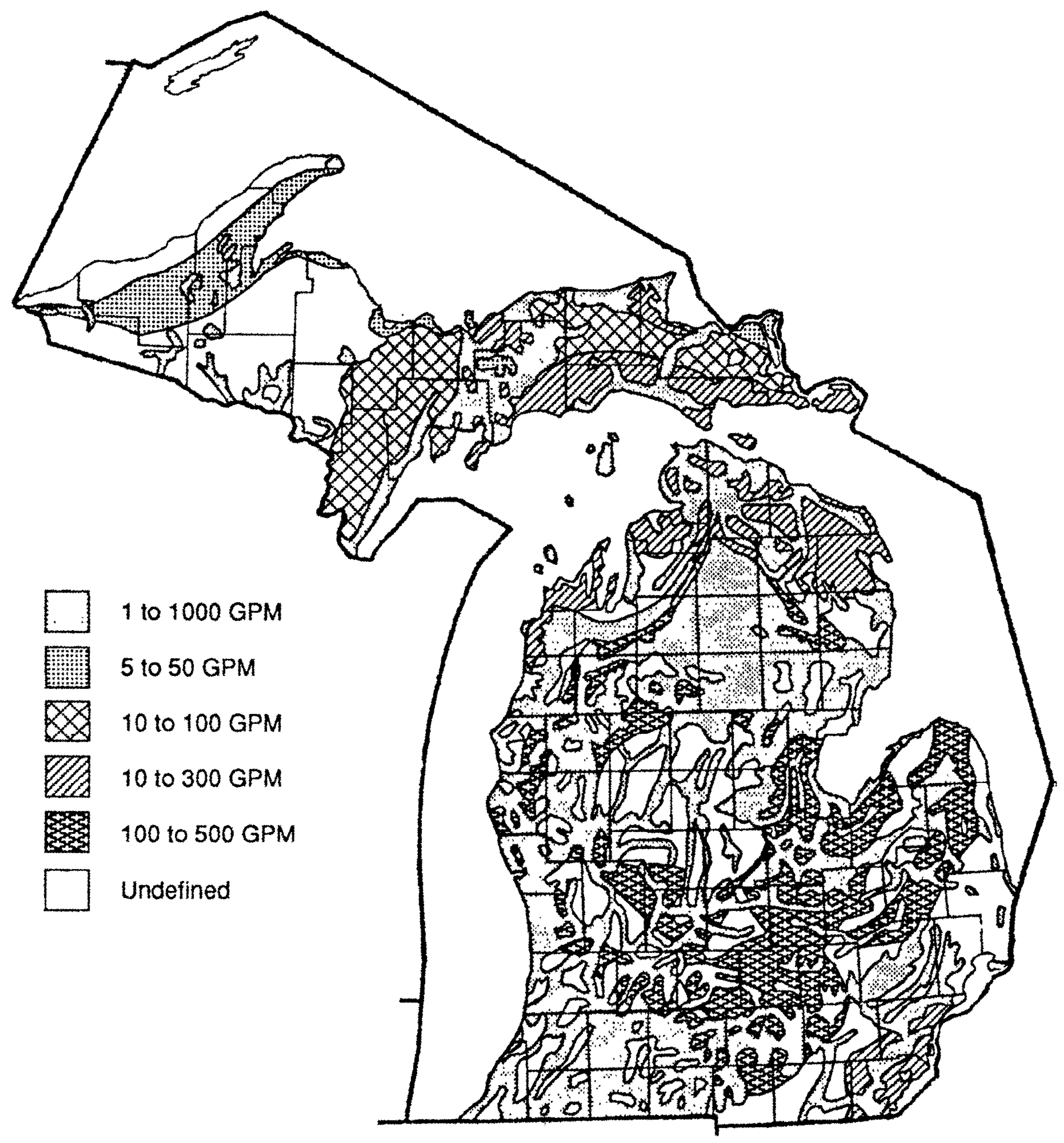
In parts of the eastern side of the Upper Peninsula are variably covered undifferentiated sedimentary bedrock aquifers. These Cambrian to Ordovician age units consist of sandstone, limestone, and dolomite. Vulnerability is a function of the thickness of the overlying glacial till. Well yields commonly range from 10 to 100 gpm, and may exceed 500 gpm. About 6 percent of the state is underlain by Class U-v aquifers.

Sensitivity

About 25 percent of Michigan is covered by vulnerable Class I deposits. Many of these consist of permeable sand and gravel that lie along water courses. The Upper Peninsula is lightly populated and most of the population centers are generally quite small and adjacent to the Lake Michigan shore. The Lower Peninsula is more densely populated, particularly in the southern half where there is more industry and the towns are larger. The potential for ground-water contamination from shallow injection wells is very small in the Upper Peninsula, small in the northern part of the Lower Peninsula, and moderate to high elsewhere.

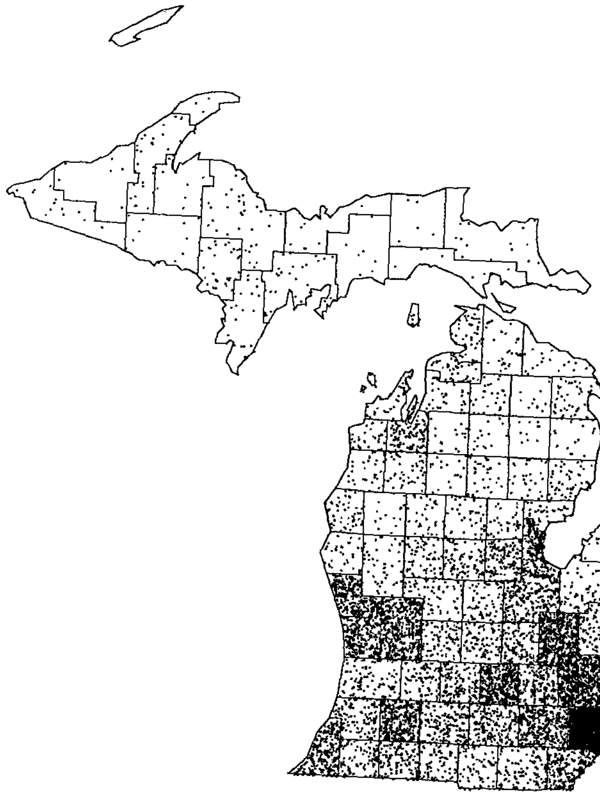


Aquifer Vulnerability Map of Michigan

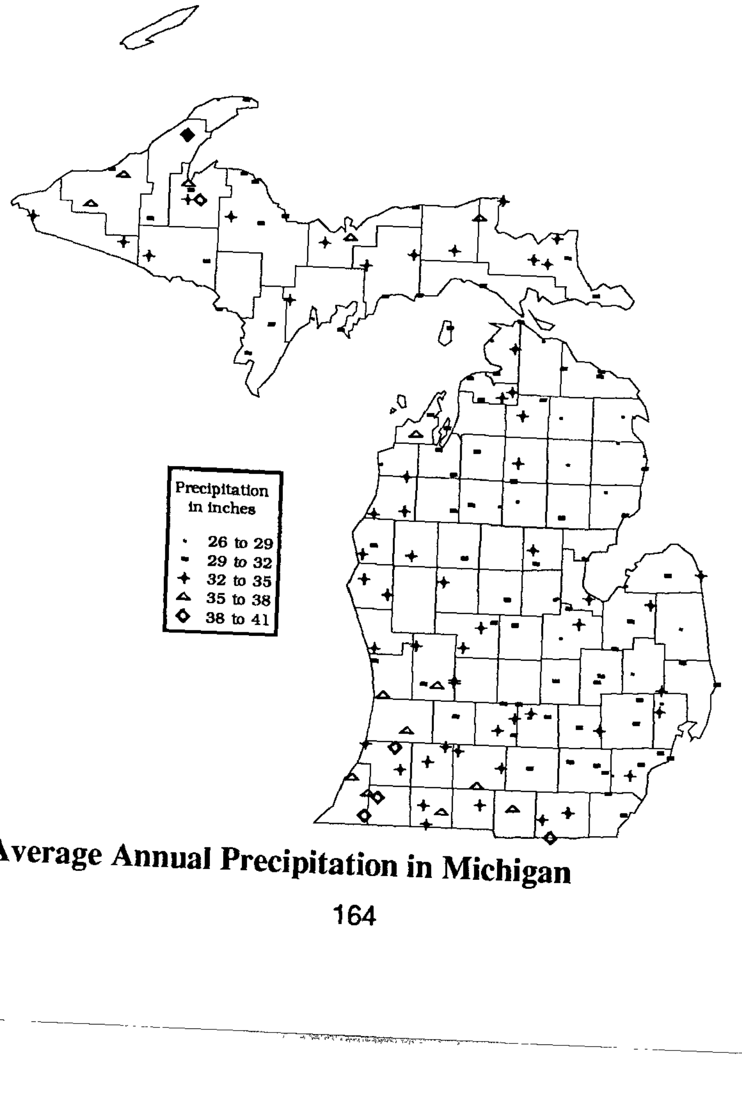


Potential Well Yields In Michigan

Aquifer Sensitivity Map of Michigan



Population Density of Michigan (Dot equals one person per square mile)



Average Annual Precipitation in Michigan

MINNESOTA

General Setting

Minnesota contains approximately 84,000 square miles, and lies primarily in the Central Lowland physiographic province. The northeastern part of the state is in the Superior Upland province. The majority of the state is underlain by Precambrian age igneous and metamorphic rock, with minor amounts of sedimentary rock in east-central Minnesota. In the southeastern part of Minnesota are southwestward dipping clastic and carbonate rocks of Paleozoic age. Minnesota is mantled by unconsolidated outwash, glacial lake deposits, and glacial till.

The Mississippi River system drains the majority of central and southern Minnesota, while the northwestern and western sections are principally drained by the Red River of the North. Annual average precipitation ranges from about 20 inches in the northwest to about 32 inches in the southeast. The population of Minnesota, approximately 4.3 million, is concentrated in the Minneapolis - St. Paul metropolitan area. About 685 million gallons of fresh ground water are used daily in Minnesota.

Unconsolidated Aquifers (Class Ia)

Exposed intermittently throughout the southern three quarters of Minnesota are unconsolidated alluvial, glacial, terrace, and outwash deposits. These deposits generally consist of stratified sand and gravel with some intercalated beds of silt and clay. Well yields commonly range from 100 to 800 gpm, and may exceed 2,000 gpm. Approximately 22 percent of the state is covered by Class Ia deposits.

Covered Aquifers (Class Id)

Carbonate bedrock aquifers with solutional features, which are overlain by less than 50 feet of glacial till, occur in the southeast corner of Minnesota. The bedrock aquifer consists of Cambrian to Devonian age limestone and dolomite with minor amounts of sandstone. The reduced vulnerability of these systems is a function of the thickness of the overlying till. Well yields commonly range from 200 to 1,000 gpm, and may exceed 2,700 gpm. About 3 percent of Minnesota is underlain by Class Id aquifers.

Covered Bedrock Aquifers (Class IIc)

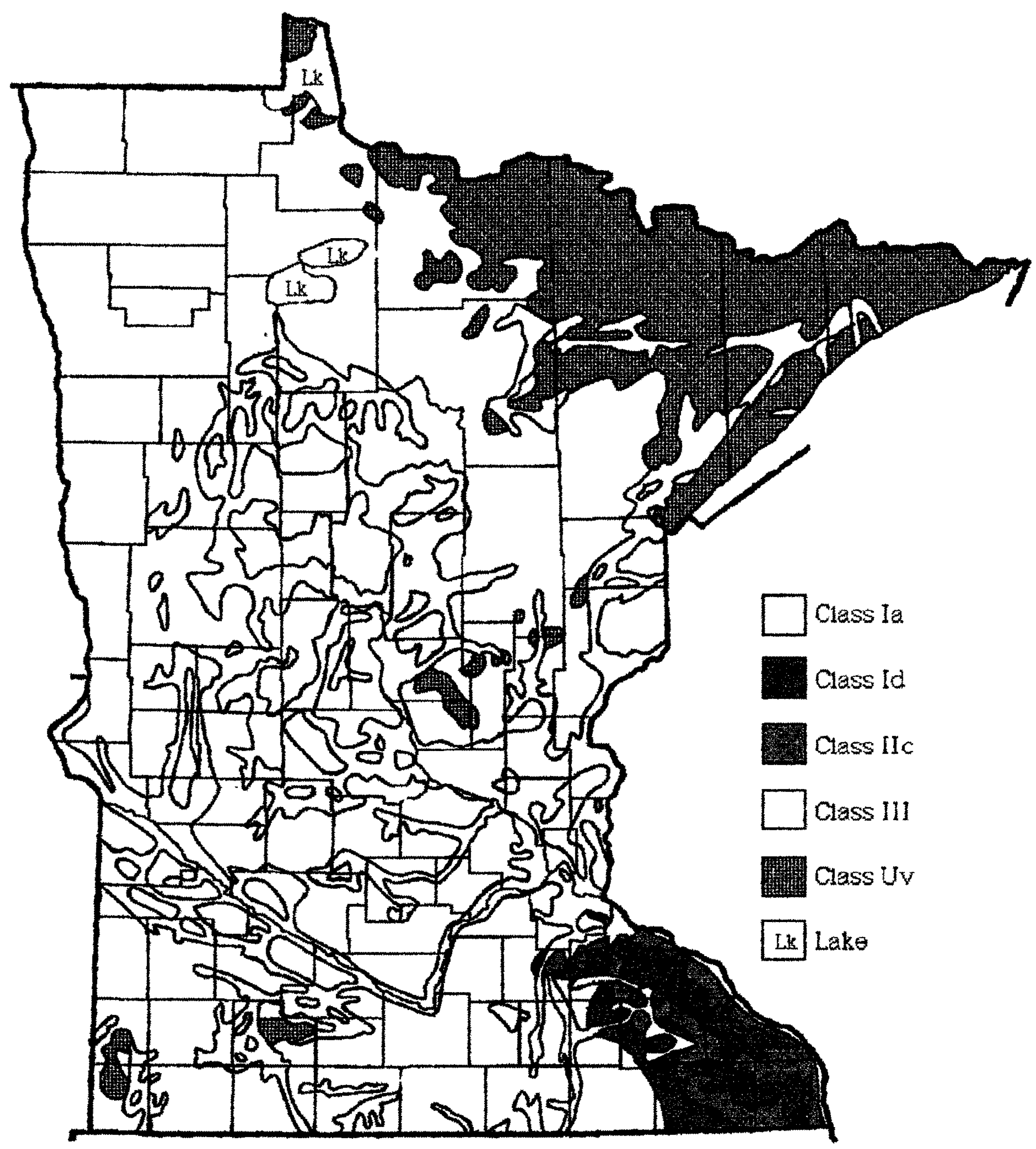
Higher yield bedrock aquifers, which are overlain by less than 50 feet of glacial till, occur in the southeastern corner of the state. The aquifers consist of Cambrian to Ordovician age sandstone with some thin beds of shale and siltstone. The vulnerability of these reservoirs is a function of the thickness of the overlying till. Well yields commonly range from 100 to 250 gpm, and may exceed 1,000 gpm. Nearly 3 percent of the state is underlain by Class IIc aquifers.

Variably Covered Undifferentiated Bedrock Aquifers (Class U-v)

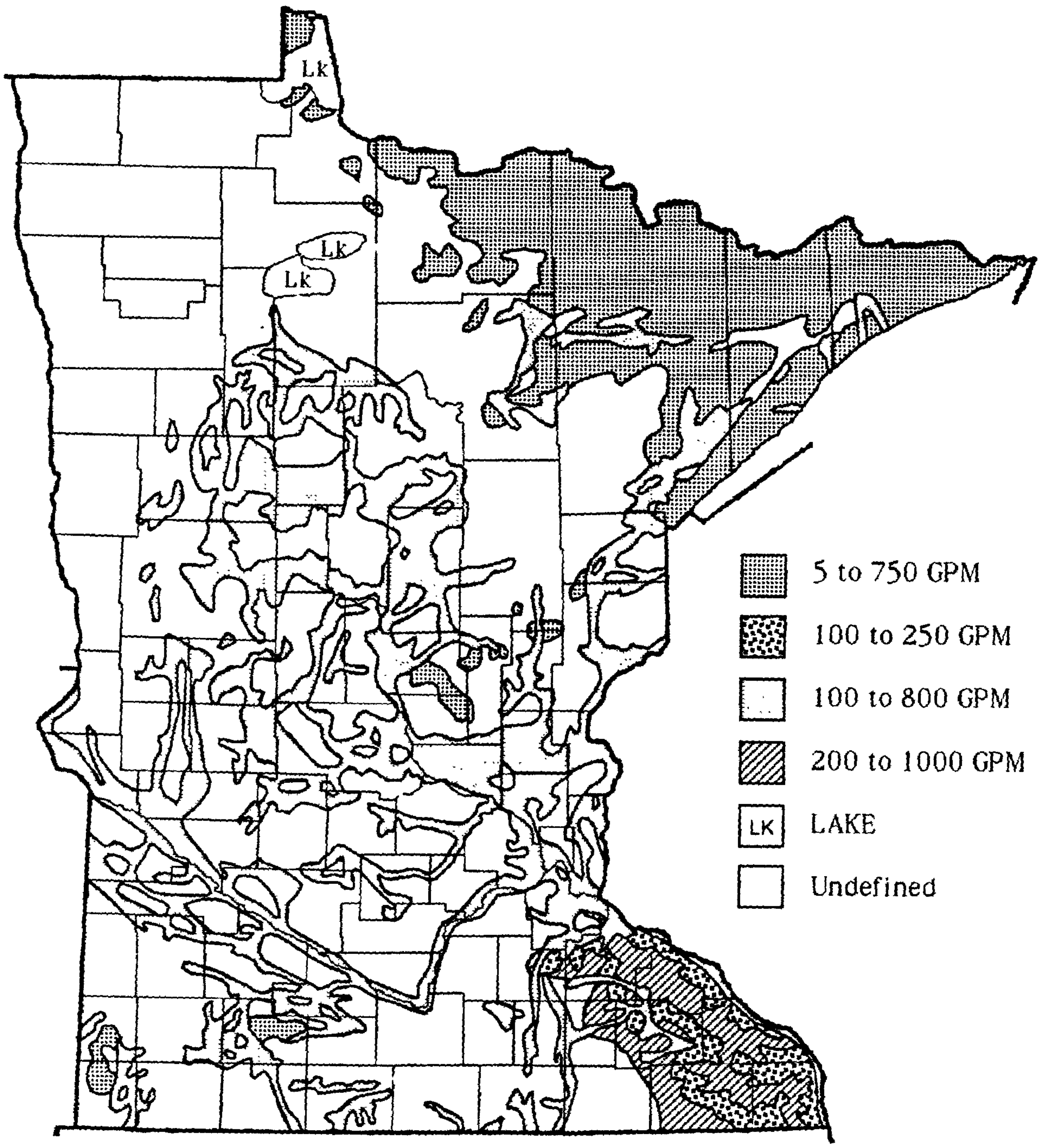
Variably covered undifferentiated bedrock aquifers occur extensively throughout the northeastern part of the state. Small local exposures also are present in central and southwestern Minnesota. These bedrock aquifers consist of Precambrian age crystalline rock and sandstone. Locally in the northeast, bedrock is exposed. The vulnerability of these systems is related to the thickness of the overlying low permeability material. Well yields commonly range from 5 to 750 gpm, and may exceed 1,000 gpm. Variably covered undifferentiated bedrock aquifers occupy nearly 13 percent of Minnesota.

Sensitivity

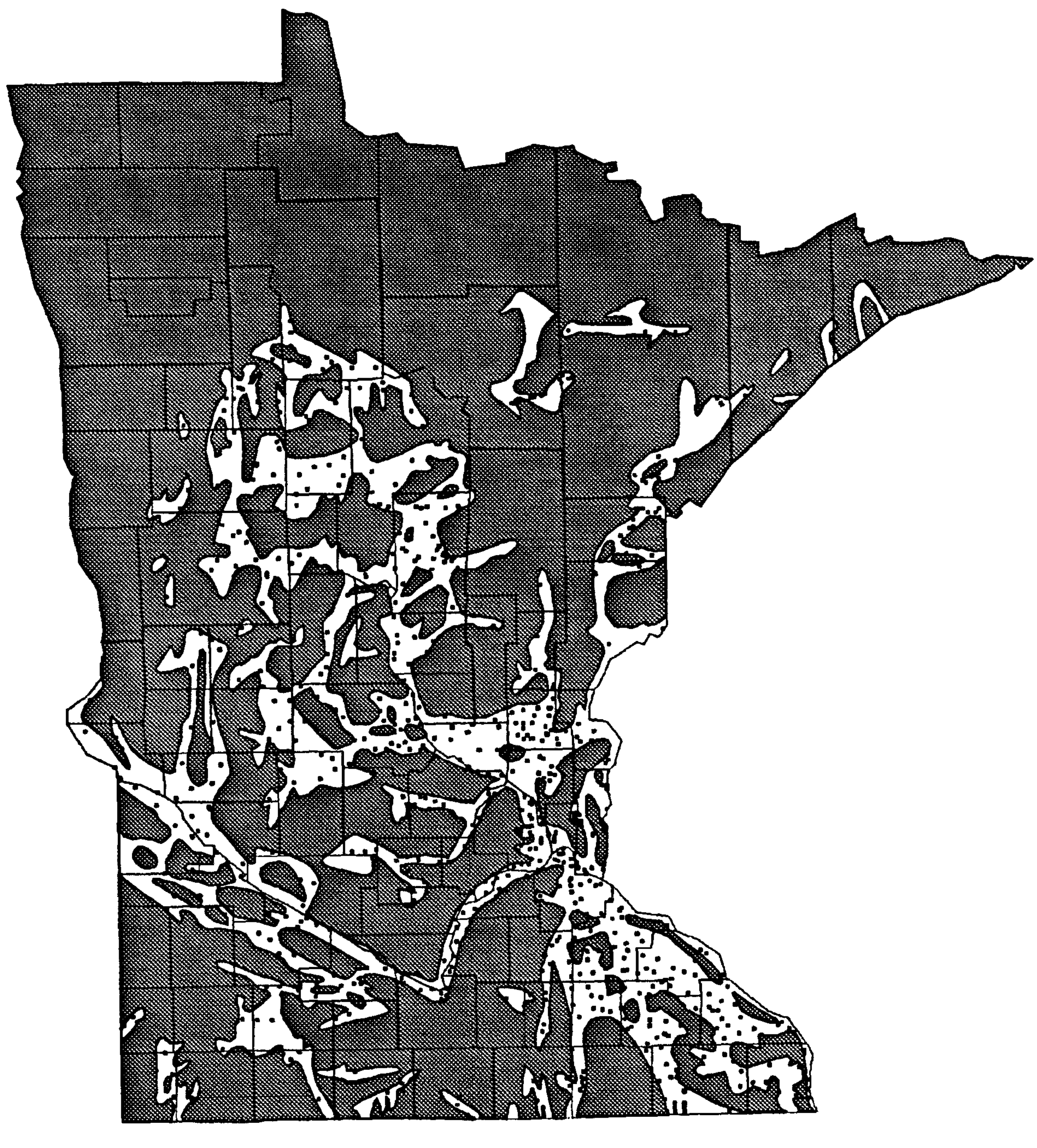
About 22 percent of Minnesota is covered by Class I aquifers. Most of the vulnerable aquifers lie along rivers. The potential for ground-water contamination from shallow injection wells is small in the northern part of the state. Along the Mississippi and Minnesota rivers and in the southeastern part of the state sensitivity increases because of the number of population centers.



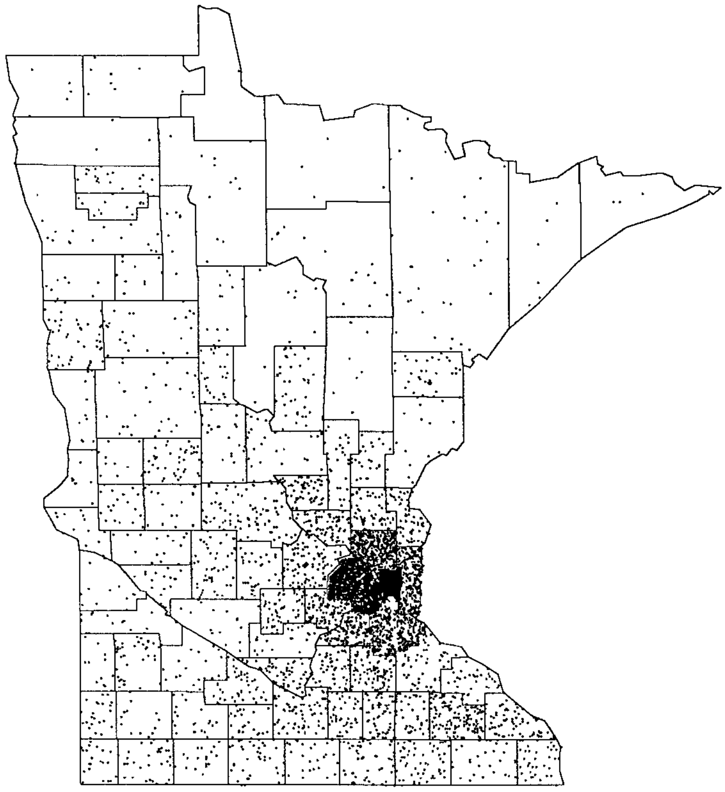
Aquifer Vulnerability Map of Minnesota



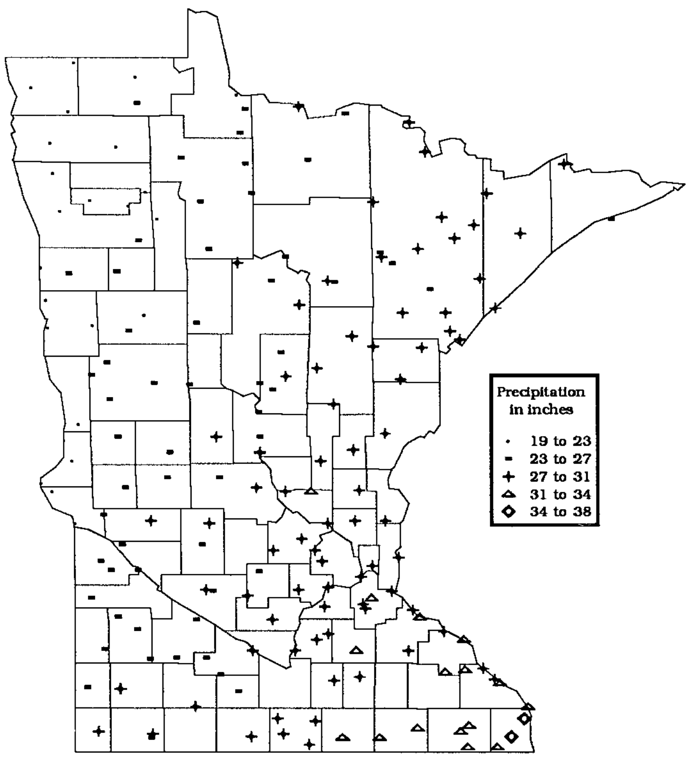
Potential Well Yields in Minnesota



Aquifer Sensitivity Map of Minnesota



Population Density of Minnesota (Dot equals one person per square mile)



Average Annual Precipitation in Minnesota

OHIO

General Setting

Ohio, which contains about 41,300 square miles, lies in the rolling till plains, end moraines, and beach ridges of the Central Lowland, Interior Lowland, and Appalachian Plateaus physiographic provinces. The state is underlain by gently dipping Paleozoic rocks. Along the Cincinnati Arch in southwestern Ohio, Ordovician shale and limestone crop out, while Silurian and Devonian carbonates underlie the west-central and northwestern parts of the state. An eastward-thickening sequence of shale, sandstone, and coal-bearing units of Mississippian to Permian age underlies the eastern third of the state. All but the southeastern third of Ohio is covered by glacial till, outwash, and glacial lake deposits of Quaternary age. These deposits range in thickness from less than 10 to more than 500 feet (Goldthwait, White, and Forsyth, 1961).

Much of Ohio is drained by the Muskingum, Scioto, and Great Miami rivers, all of which discharge into the Ohio River. The Maumee and Cuyahoga rivers, among others, drain the northern third of the state and empty into Lake Erie. Annual precipitation ranges from less than 34 inches in the north to 42 in the south. In northeastern Ohio moisture derived from Lake Erie leads to a yearly precipitation of as much as 44 inches. The majority of Ohio's population, nearly 11 million, is located along major rivers in the southwestern and central parts of the state, and along the shores of Lake Erie. The remainder of the state is moderately populated. Use of fresh and saline ground water in Ohio amounts to about 730 and .1 mgd, respectively.

Unconsolidated Aquifers (Class Ia)

Glacial outwash and alluvial deposits form the most productive aquifers in the Ohio. These generally unconfined systems, which lie along modern streams and throughout the glaciated parts of the state, consist of unconsolidated deposits of sand and gravel, with lesser amounts of clay and silt. Well yields commonly range from 100 to 500 gpm, and may exceed 2,000 gpm. Less productive aquifers, composed of unconsolidated, fine-grained, sand, clay, silt, and gravel, occur as localized lenses within glaciated areas, and as valley fill in abandoned stream valleys. These aquifers locally may be confined by clay or till. Well yields commonly range from 25 to 50 gpm, and may exceed 200 gpm. About 11.4 percent of the state is covered by Class Ia aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Minor outcrops of fractured limestone and dolomite occur in southern Ohio. The presence of fractures and weathered strata contribute to the permeability and vulnerability of these aquifers. Shale and gypsiferous interbeds occur locally. Well yields commonly range from 5 to 300 gpm, and may exceed 500 gpm. Surface exposures of fractured bedrock aquifers occupy about a half of a percent of the state.

Covered Aquifers (Class Id)

Buried outwash and fractured bedrock aquifers that are overlain by less than 50 feet of glacial till and lacustrine deposits, occur throughout the glaciated part of the state. Well yields commonly range from 5 to 500 gpm, and they may exceed 2,000 gpm. The reduced vulnerability of these covered systems is a function of the thickness of the overlying low permeability material. About 36 percent of Ohio is underlain by Class Id aquifers.

Lower Yield Bedrock Aquifers (Class IIb)

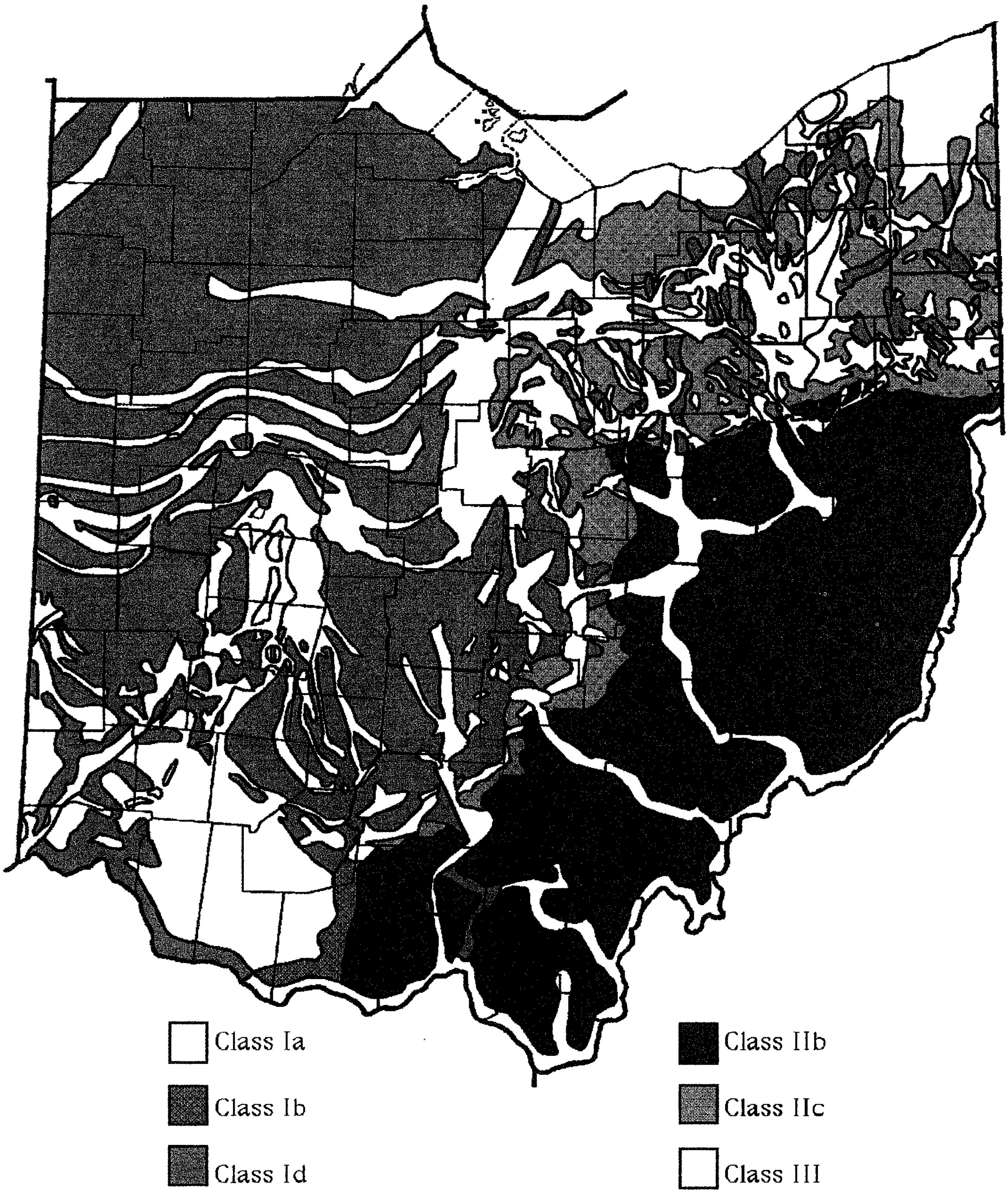
Lower yield bedrock aquifers, consisting primarily of fine-to medium-grained sandstone, occur in eastern and southeastern Ohio. Sandstone aquifers, which contain interbedded limestone, shale, coal, and siltstone, are unconfined in the outcrop area. Well yields range from about 1 to about 25 gpm, and may exceed 250 gpm. Surface exposures of lower yield bedrock aquifers occupy about 22 percent of the state.

Covered Bedrock Aquifers (Class IIc)

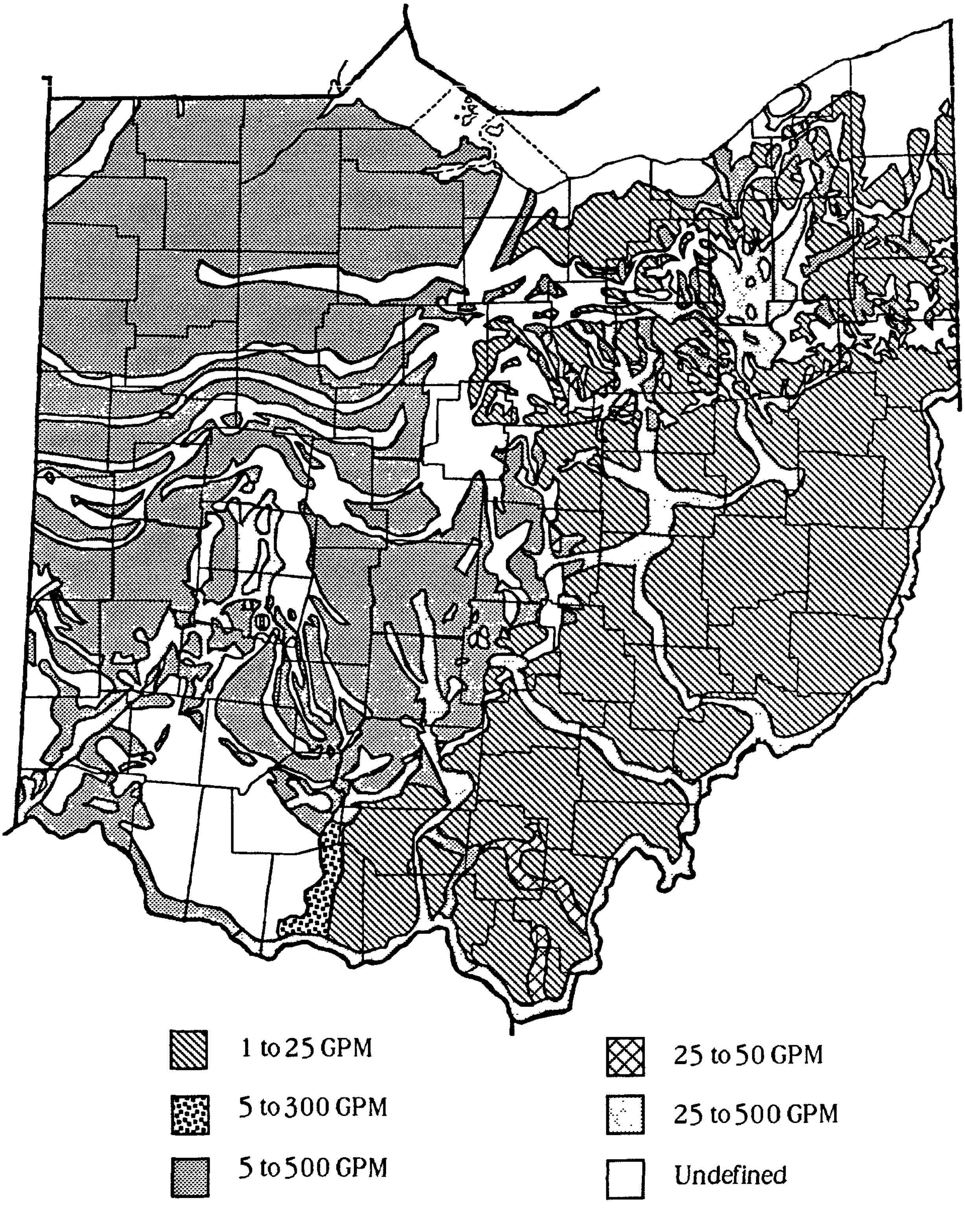
Lower yield bedrock aquifers that are overlain by less than 50 feet of glacial till and lacustrine deposits, occur along the eastern and northeastern glaciated parts of the state. The reduced vulnerability of these systems is a function of the thickness of the overlying low permeability material. About 9.6 percent of the state is underlain by Class IIc aquifers.

Sensitivity

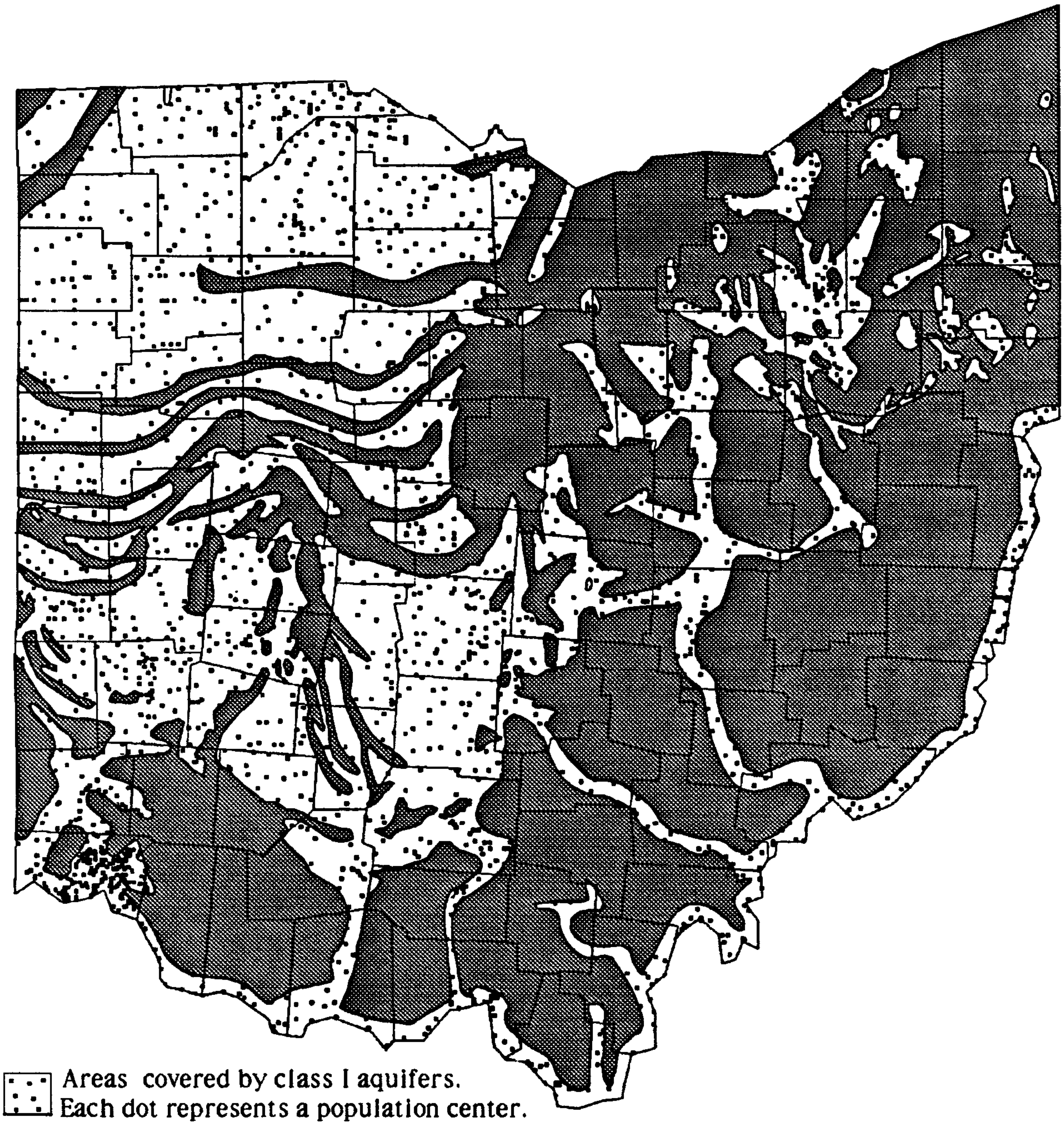
Nearly 48 percent of Ohio is covered by Class I aquifers. The potential for ground-water contamination from shallow injection wells is moderately high owing to the high population density on and near many of these aquifers, particularly the stream valleys. Additionally, the permeable nature of many of the carbonate rocks, which are mantled by glacial till, has led to the fairly widespread practice of using sinkholes and wells for waste disposal in north-central Ohio.



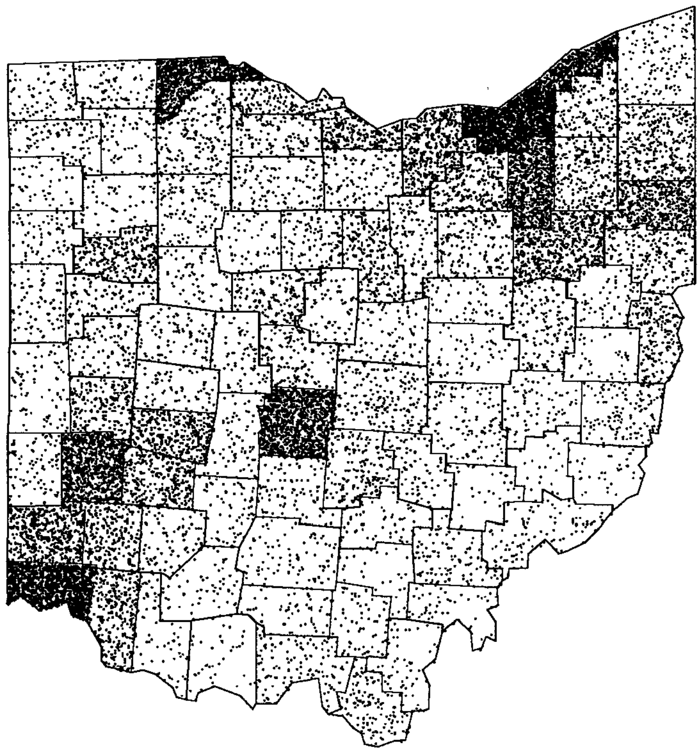
Aquifer Vulnerability Map of Ohio



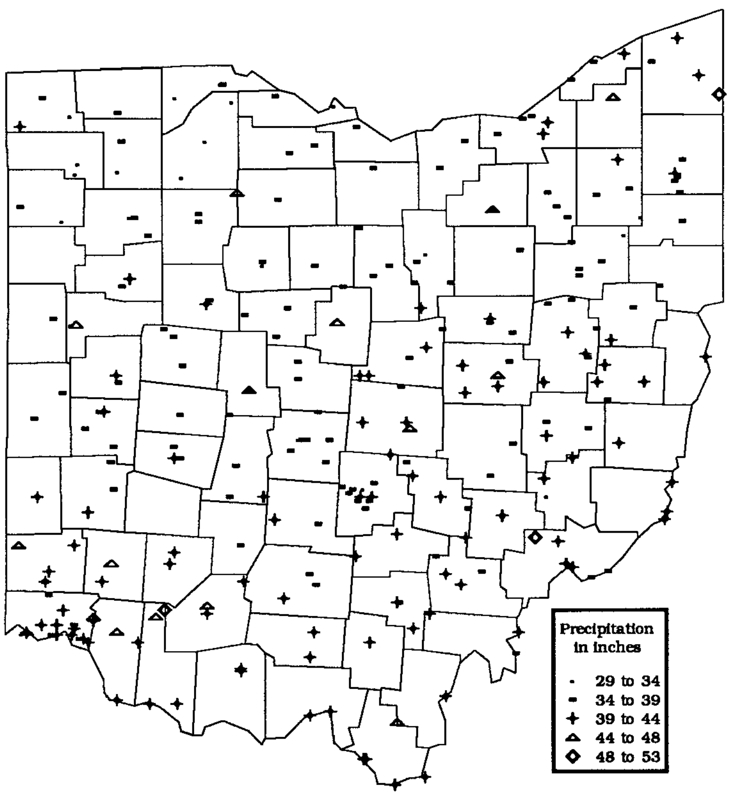
Potential Well Yields in Ohio



Aquifer Sensitivity Map of Ohio



Population Density of Ohio (Dot equals one person per square mile)



Average Annual Precipitation in Ohio

WISCONSIN

General Setting

Wisconsin, which contains approximately 56,150 square miles, lies within the Superior Upland province in the north, and the Central Lowland province in the southern part of the state. Underlying northwestern, north-central, and northeastern Wisconsin is Precambrian material, which consists of sedimentary rock in the extreme northwest and igneous rock elsewhere. Western, southern, and eastern Wisconsin is underlain by a series of Cambrian to Devonian age clastic and carbonate rocks that dip to the southeast, south, and west. With the exception of so called "driftless area" in southwestern Wisconsin, the state is covered by a variable thickness of unconsolidated glacial deposits, which can be several hundreds of feet thick.

Northeastern Wisconsin is drained by several streams that empty into Green Bay. The remainder of the state is drained by southwesterly-flowing water courses that discharge into the Mississippi River on the state's western boundary. Average annual precipitation averages about 32 inches, with the least amount occurring during the winter months. Wisconsin's population, nearly 4.9 million, is concentrated in the Milwaukee, Madison, and Green Bay metropolitan areas. Use of fresh ground water amounts to about 570 million gallons per day.

Unconsolidated Aquifers (Class Ia)

Exposed intermittently from the northwest to the south are unconsolidated alluvial and glacial outwash deposits, which consist predominantly of stratified sand and gravel with variable amounts of silt and clay. Well yields commonly range from 10 to 100 gpm, and may exceed 2,000 gpm. Approximately 16 percent of the state is overlain by unconsolidated aquifers.

Variable Covered Soluble and Fractured Bedrock Aquifers (Class Ib-v)

Carbonate aquifers with solutional features that are overlain by a variable thickness of glacial till occur in eastern Wisconsin. The bedrock aquifers consist of Ordovician to Devonian age dolomite and lesser amounts of limestone and shale. Well yields commonly range from 5 to 50 gpm, and may exceed 200 gpm. Nearly 10 percent of the state is occupied by Class Ib-v aquifers.

Undifferentiated Aquifers (Class U)

(Class Uw-v)

Undifferentiated crystalline bedrock aquifers that are overlain by a variable thickness of glacial till occur in northwest and central Wisconsin. The underlying Precambrian age igneous and metamorphic rocks yield small quantities of water from fractures and crevices. Well yields commonly range from .5 to 10 gpm, and may exceed 50 gpm. The reduced vulnerability of these systems is a function of the thickness of the overlying low permeability material. Variably covered undifferentiated crystalline bedrock aquifers occupy about 8 percent of Wisconsin.

(Class U-x)

Exposed in northern and south-central Wisconsin is an undifferentiated mass of outwash, till, and glaciolacustrian deposits. These deposits consist of variable amounts of sand, gravel, silt, and clay, which vary in thickness from a few feet to hundreds of feet. A wide range of well yields could be expected from these aquifers, the highest being in the areas of outwash. About 25 percent of Wisconsin is covered by undifferentiated class U-x aquifers

(Class U-y)

Exposed in the "driftless area" in southwestern Wisconsin are undifferentiated deposits of Cambrian to Ordovician age sandstone, dolomite with solutional features, dolomitic sandstone, and shale beds. Well yields commonly range from 10 to 500 gpm, and may exceed 1,000 gpm. Approximately 13 percent of Wisconsin is occupied by Class U-y aquifers.

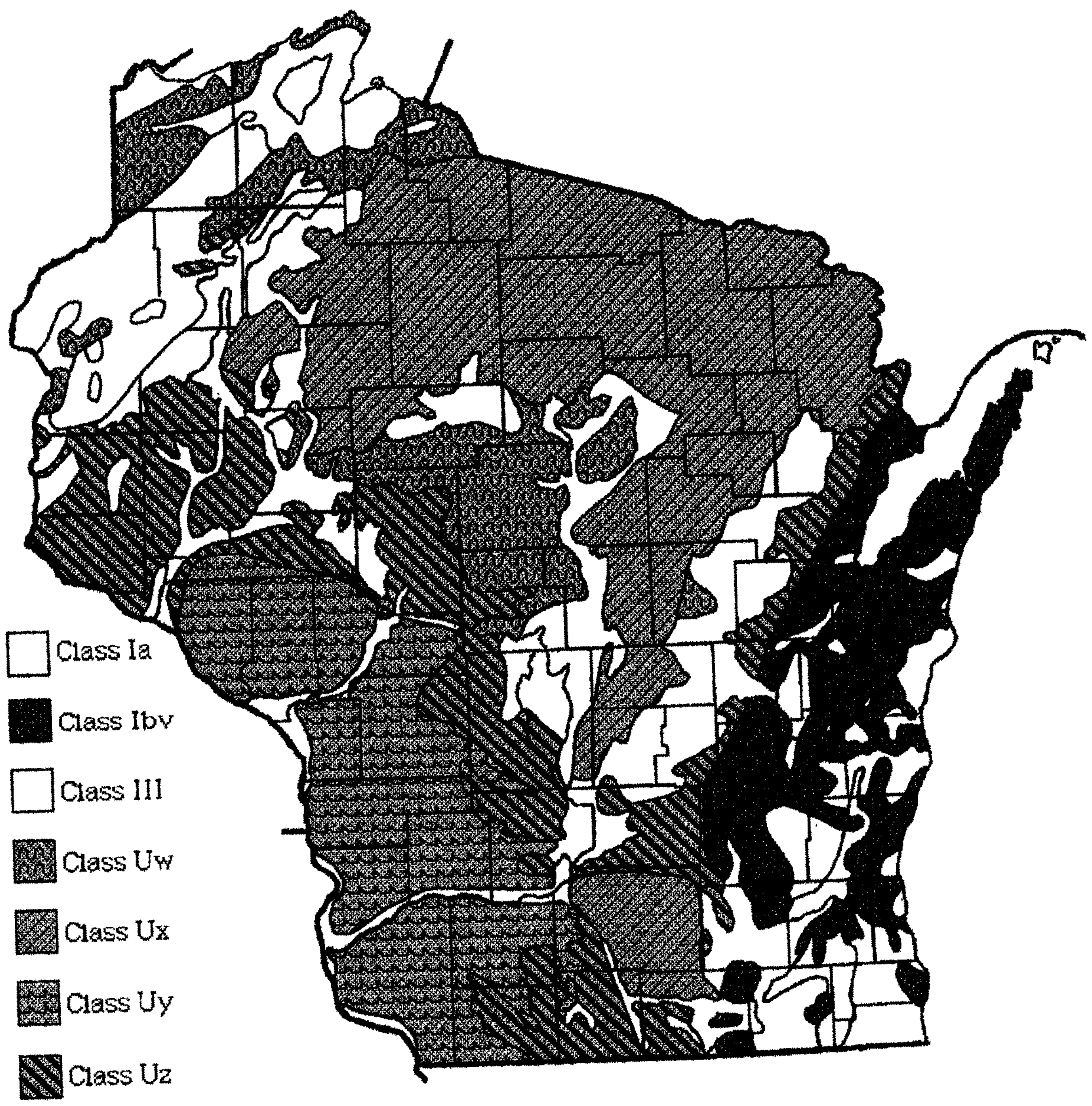
(Class Uz-v)

Undifferentiated clastic and carbonate bedrock aquifers, which are covered by a variable thickness of glacial till, occur intermittently in western and eastern

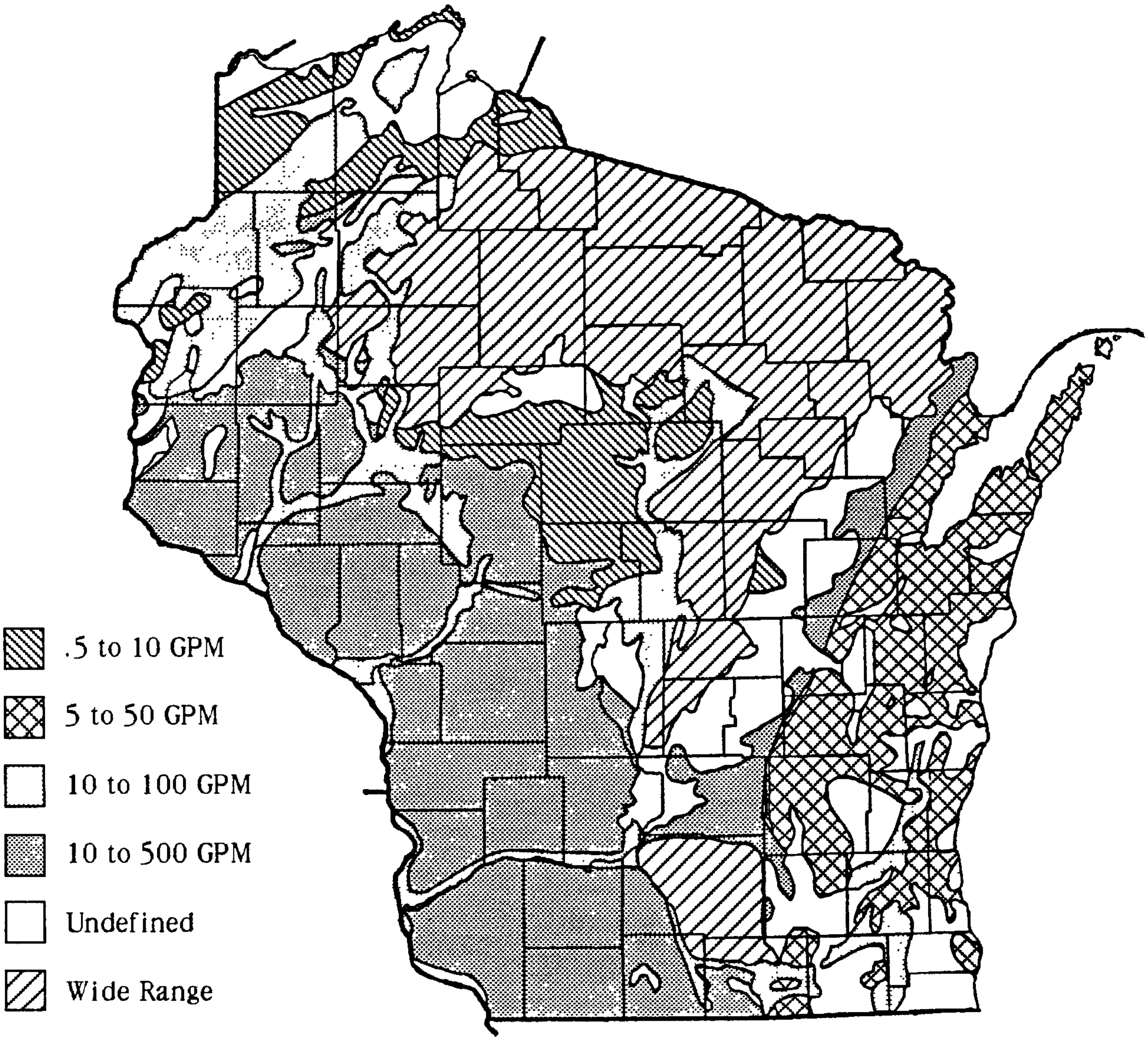
Wisconsin. The underlying Cambrian to Ordovician age sediments consist of sandstone, dolomite, dolomitic sandstone, and shale units. The reduced vulnerability of these systems is a function of the thickness of the overlying low permeable material. Well yields commonly range from 10 to 500 gpm, and may exceed 1,000 gpm. Approximately 19 percent of Wisconsin is underlain by Class Uz-v aquifers.

Sensitivity

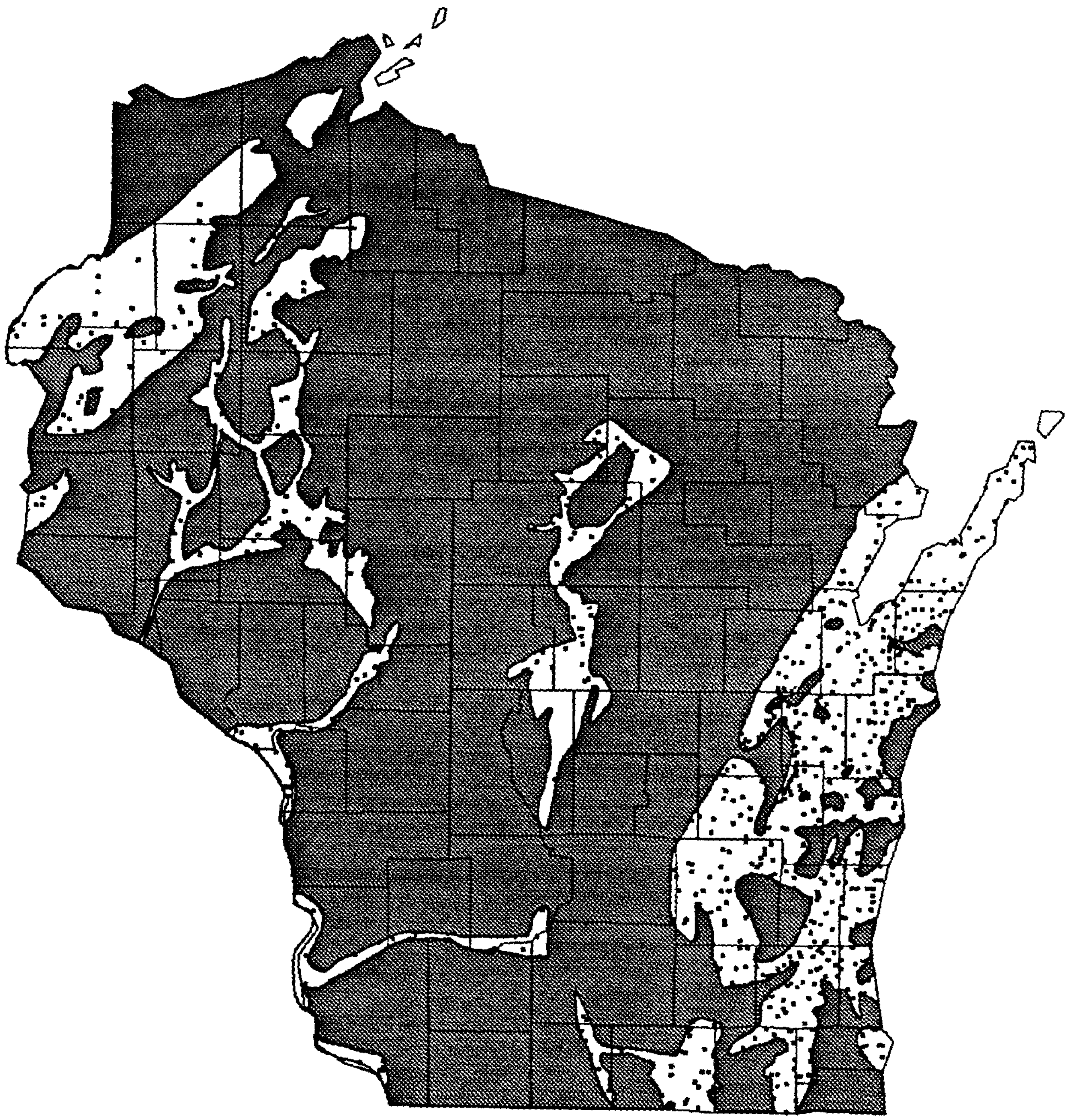
Nearly 26 percent of Wisconsin is covered by Class I aquifers. The most sensitive area extends southwestward from Green Bay. Elsewhere in vulnerable areas population centers are widely distributed. On a county scale, several other areas that are shown as Class U-x would be considered moderately sensitive owing to the presence of masses of outwash.



Aquifer Vulnerability Map of Wisconsin

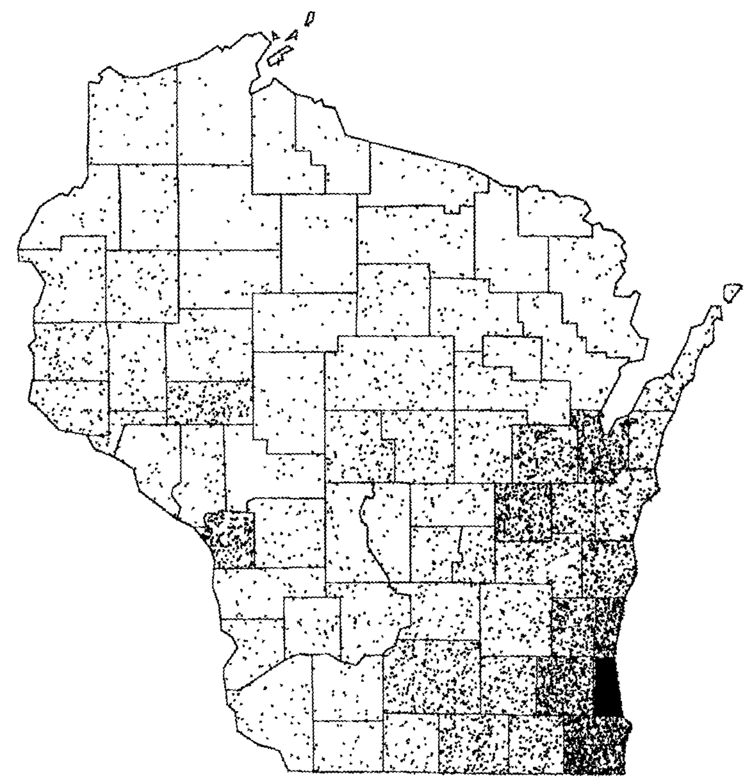


Potential Well Yields in Wisconsin

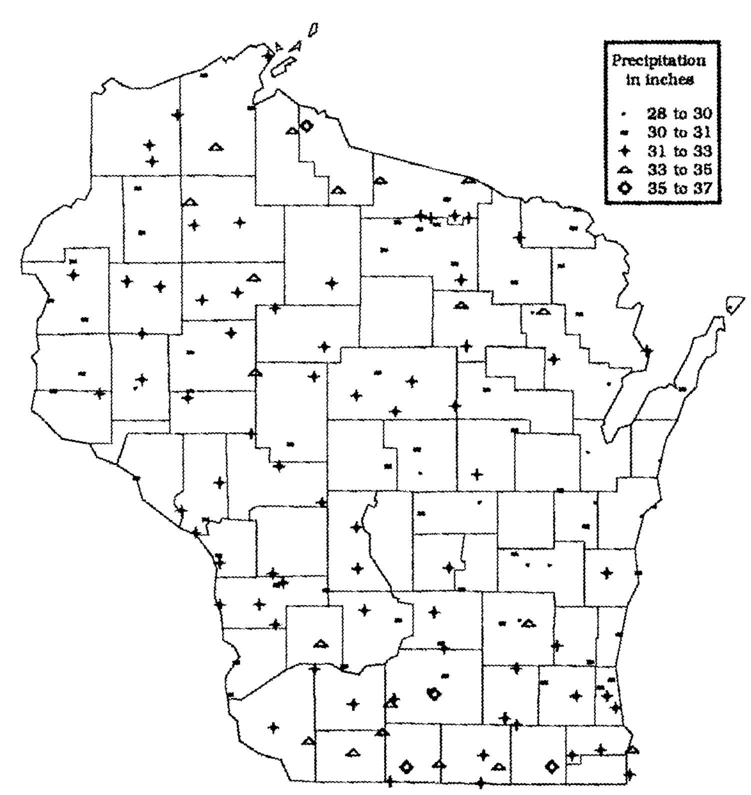


Areas covered by class I aquifers.
Each dot represents a population center.

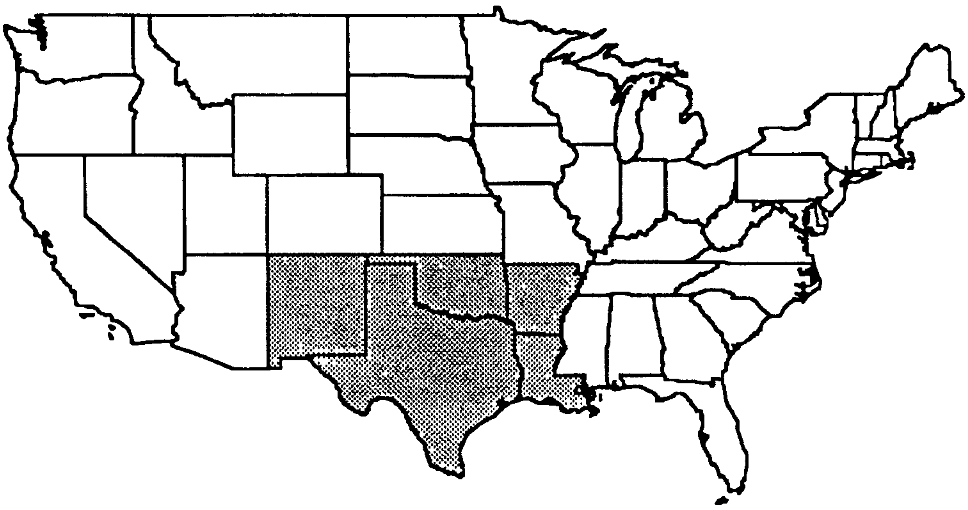
Aquifer Sensitivity Map of Wisconsin



Population Density of Wisconsin,(Dot equals one person per square mile)



Average Annual Precipitation in Wisconsin



REGION 6

Arkansas
Louisiana
New Mexico
Oklahoma
Texas

ARKANSAS

General Setting

Arkansas contains approximately 53,000 square miles, and is somewhat equally divided by the northeast-southwest trending Fall Line. Northwest of this line lies the gently rolling to rugged terrain of the Ozark Plateaus and Ouachita province. This area is underlain by Ordovician to Pennsylvanian age faulted and folded sedimentary rock. Southeast of the Fall Line is the generally flat-lying Gulf Coastal Plain province, which is underlain by southeastward-dipping unconsolidated strata of Cretaceous to Quaternary age. These deposits range in thickness from the out crop along the Fall Line to over 4500 feet at the southeastern corner of the state.

Arkansas is principally drained by the southeast-flowing White, Arkansas, and Ouachita river systems. Average annual precipitation varies 40 inches to 56 inches with the greatest amount occurring in the southern half of the state. The population of Arkansas, about 2.4 million, is distributed fairly evenly throughout the state, with Little Rock being the largest city. About 381 billion gallons of fresh ground water are used daily in Arkansas.

Unconsolidated Aquifers (Class Ia)

Streamside alluvial and marine terrace deposits occur along the Arkansas River and extensively in the southeastern half of the state. These unconsolidated Quaternary age deposits consist of sand, gravel, silt and clay. Well yields commonly range from 50 to 2,000 gpm, and may exceed 5,000 gpm. About 51 percent of Arkansas is covered by unconsolidated aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Karst features are present in carbonate units in northern Arkansas. These Ordovician to Pennsylvanian age rocks consist of limestone, dolomite, shale, and lesser amounts of sandstone. Where present, karst and other solutional features contribute to the vertical and lateral permeability of the rocks. Well yields commonly range from 150 to 300 gpm, and may exceed 500 gpm. Soluble aquifers occupy about 17 percent of the state.

Semiconsolidated Aquifers (Class Ic)

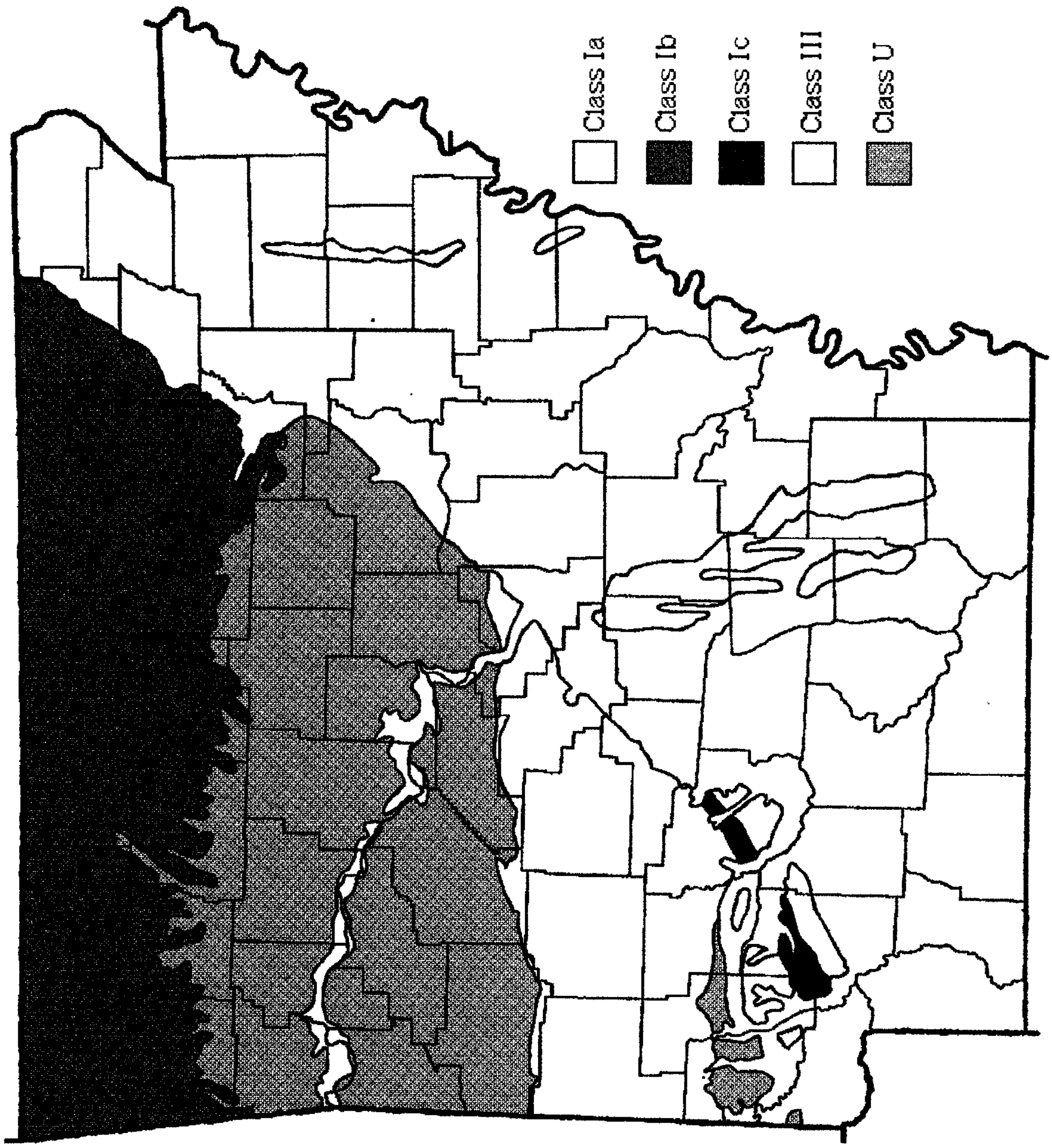
Small exposures of semiconsolidated strata occur in southwestern Arkansas. These Cretaceous to Tertiary age deposits consist of fine-grained quartz sand, silt, clay, and lignite. Well yields commonly range from 150 to 300 gpm, and may exceed 500 gpm. About .6 percent of Arkansas is covered by Class Ic aquifers.

Undifferentiated Aquifers (Class U)

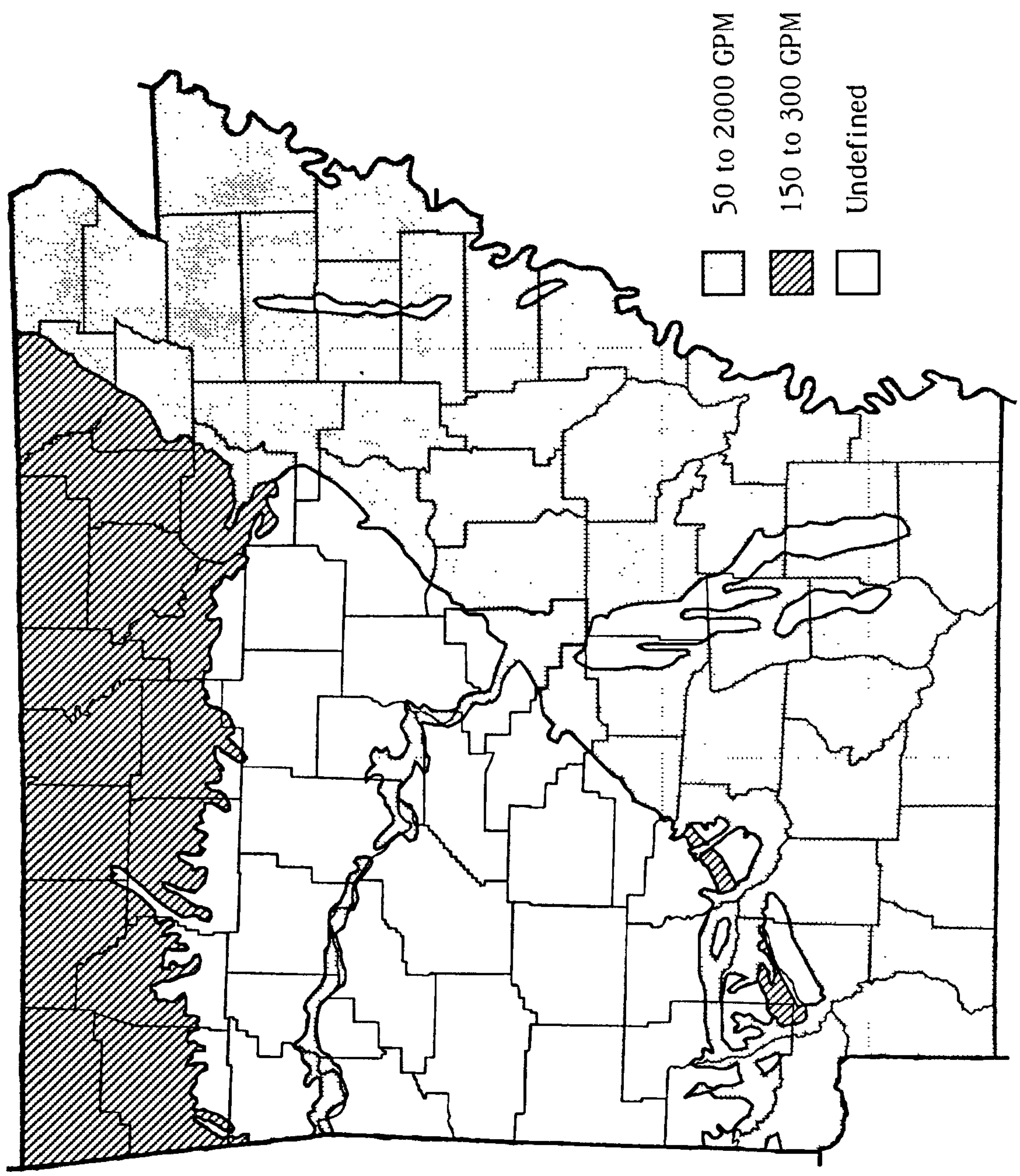
Pennsylvanian age sedimentary rocks, which occur in northern Arkansas, are undifferentiated and consist of shale and lesser amounts of sandstone. Small quantities of water are derived from bedding planes and local fracturing. Well yields commonly range from 1 to 3 gpm, and may exceed 25 gpm (Lamonds, 1972). Undifferentiated aquifers occur in about 21 percent of Arkansas.

Sensitivity

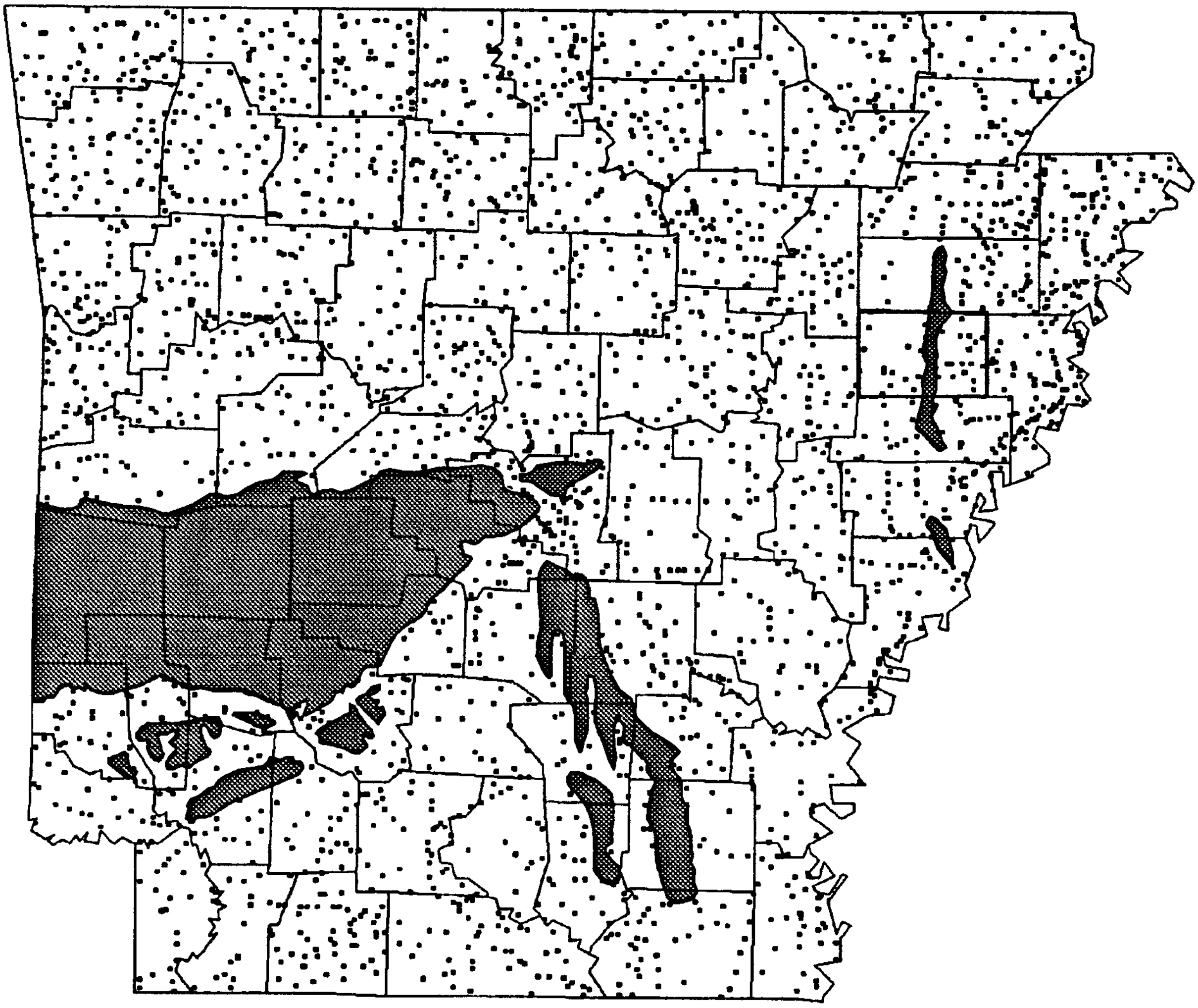
About 68 percent of Arkansas is covered by Class I aquifers. A large wedge of less vulnerable deposits occurs in the west-central part of the state and in a few relatively narrow belts, largely in the southern half. Although the population of Arkansas is not large, population centers are rather evenly distributed throughout the state.



Aquifer Vulnerability Map of Arkansas

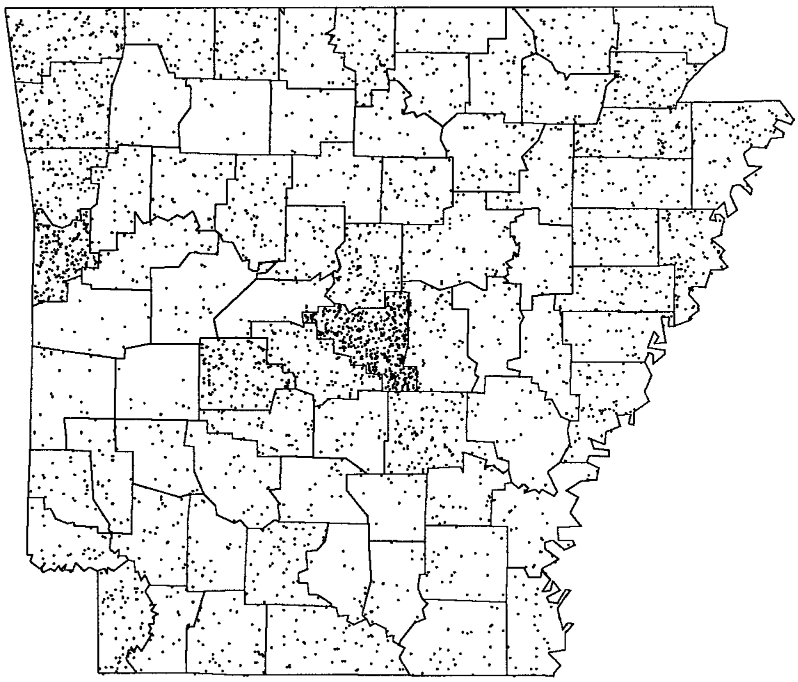


Potential Well Yields in Arkansas

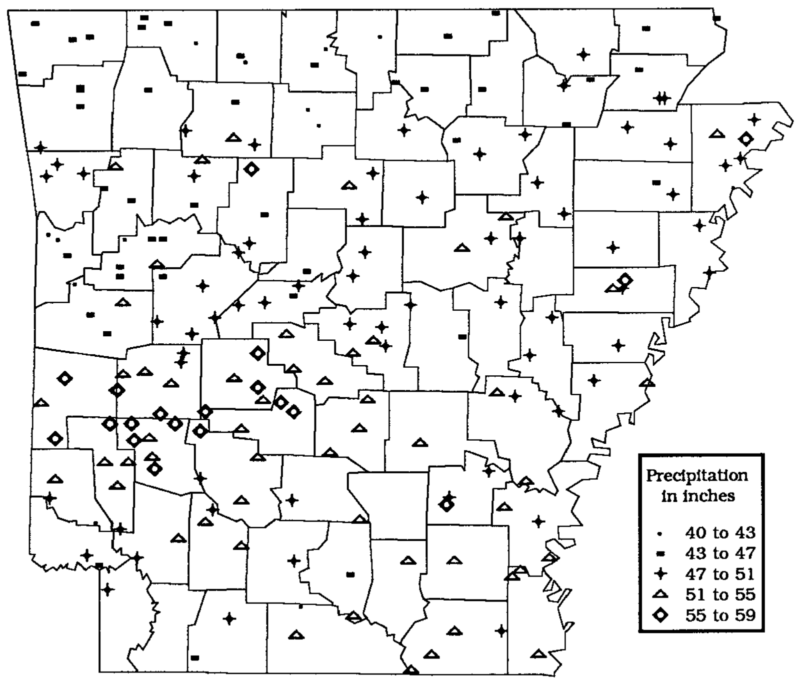


Areas covered by class I aquifers.
Each dot represents a population center.

Aquifer Sensitivity Map of Arkansas



Population Density in Arkansas (Dot equals one person per square mile)



Average Annual Precipitation in Arkansas

LOUISIANA

General Setting

Louisiana contains approximately 48,000 square miles, and lies entirely in the relatively flat lying Coastal Plain physiographic province. The state is underlain by a southward dipping wedge of semiconsolidated to unconsolidated, interbedded silt, clay, sand, gravel, shale, limestone, and tuffaceous and lignitic beds that range in age from Cretaceous to Holocene.

Louisiana is drained by the south to southeast flowing Sabine, Red, and Mississippi rivers, and their numerous tributaries. Annual precipitation ranges from less than 48 inches in the northwest to more than 66 inches in the southeast. Evapotranspiration rates, which average about 20 to 22 in/yr are high due to the flat topography, low surface runoff, warm climate, and dense vegetation (McGuinness, 1963). The majority of Louisiana's population, about 4.4 million, occurs in several large cities located along major rivers. The remainder of the state is sparsely populated. Use of fresh ground water within the state averages 1430 million gallons per day.

Unconsolidated Aquifers (Class Ia)

Streamside alluvial and terrace deposits occur throughout the state and form vulnerable and productive aquifers. These confined to unconfined systems consist of fining upward sequences of interbedded and unconsolidated deposits of silt, clay, sand, and gravel. Glacial outwash deposits in northeastern Louisiana consist of unconsolidated, fine to coarse sand, and lesser amounts of clay, silt, and gravel that are locally overlain by loess. Well yields range from 500 to 2,500 gpm, and may exceed 7,000 gpm. Nearly 40 percent of the state is covered by Class Ia aquifers.

Semiconsolidated Aquifers (Class Ic)

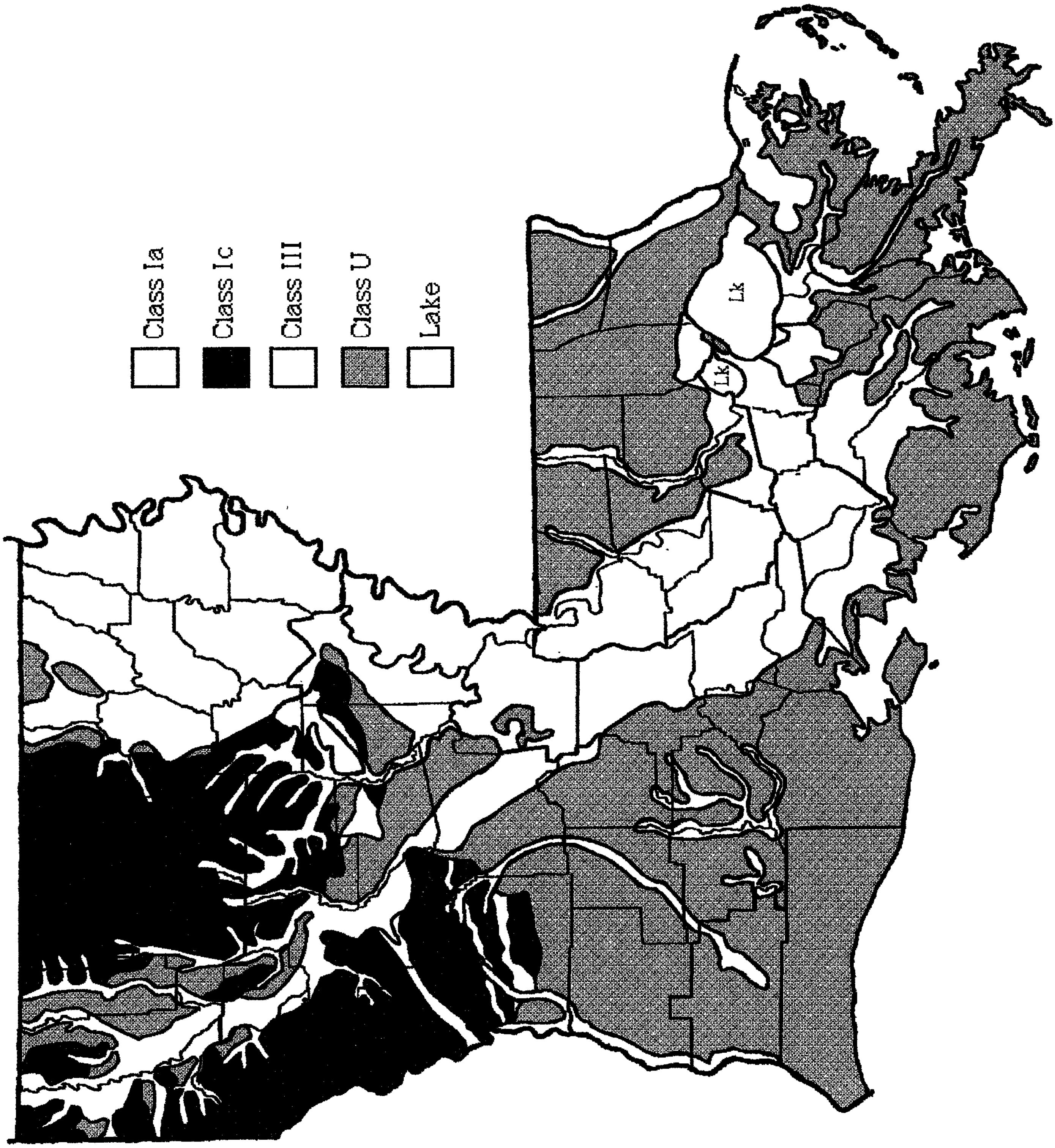
Exposures of semiconsolidated sediments occur throughout northern Louisiana. Early Tertiary age sediments that consist of partially indurated, fine to medium sand that is interbedded with silt and clay occur in northwestern Louisiana. Lignite, limestone, and glauconite also are present within the section. Well yields range from 40 to 150 gpm, and may exceed 350 gpm. Exposures of Eocene to Pliocene age sediments extend across north-central and western Louisiana, and consist of interbedded, sand, clay, silt, gravel, sandstone, siltstone, marl, and shale. These strata contain tuffaceous beds, ironstone concretions, glauconite, and other diagenetic constituents. Well yields commonly range from 50 to 1,800 gpm, and may exceed 3,000 gpm. Surface exposures of semiconsolidated aquifers occupy 17 percent of the state.

Undifferentiated Aquifers (Class U)

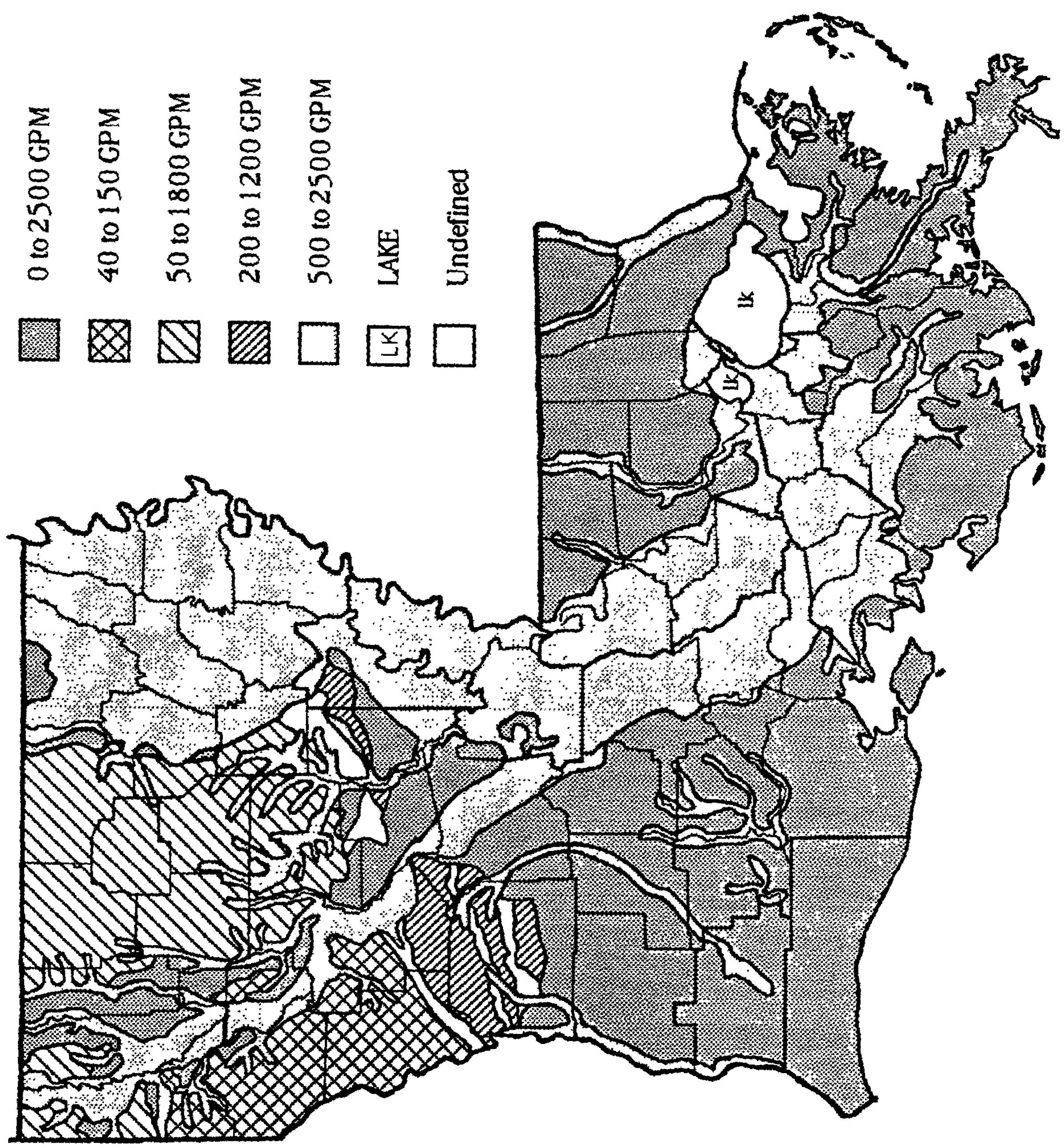
Lithologically varied sediments of Quaternary age occur throughout Louisiana, and consist of interbedded and unconsolidated deposits of clay, silt, sand, and gravel, locally overlain by loess. Due to their textural heterogeneity, a wide range in aquifer productivity and vulnerability should be expected in these areas. About 40 percent of the state is covered by Class U aquifers.

Sensitivity

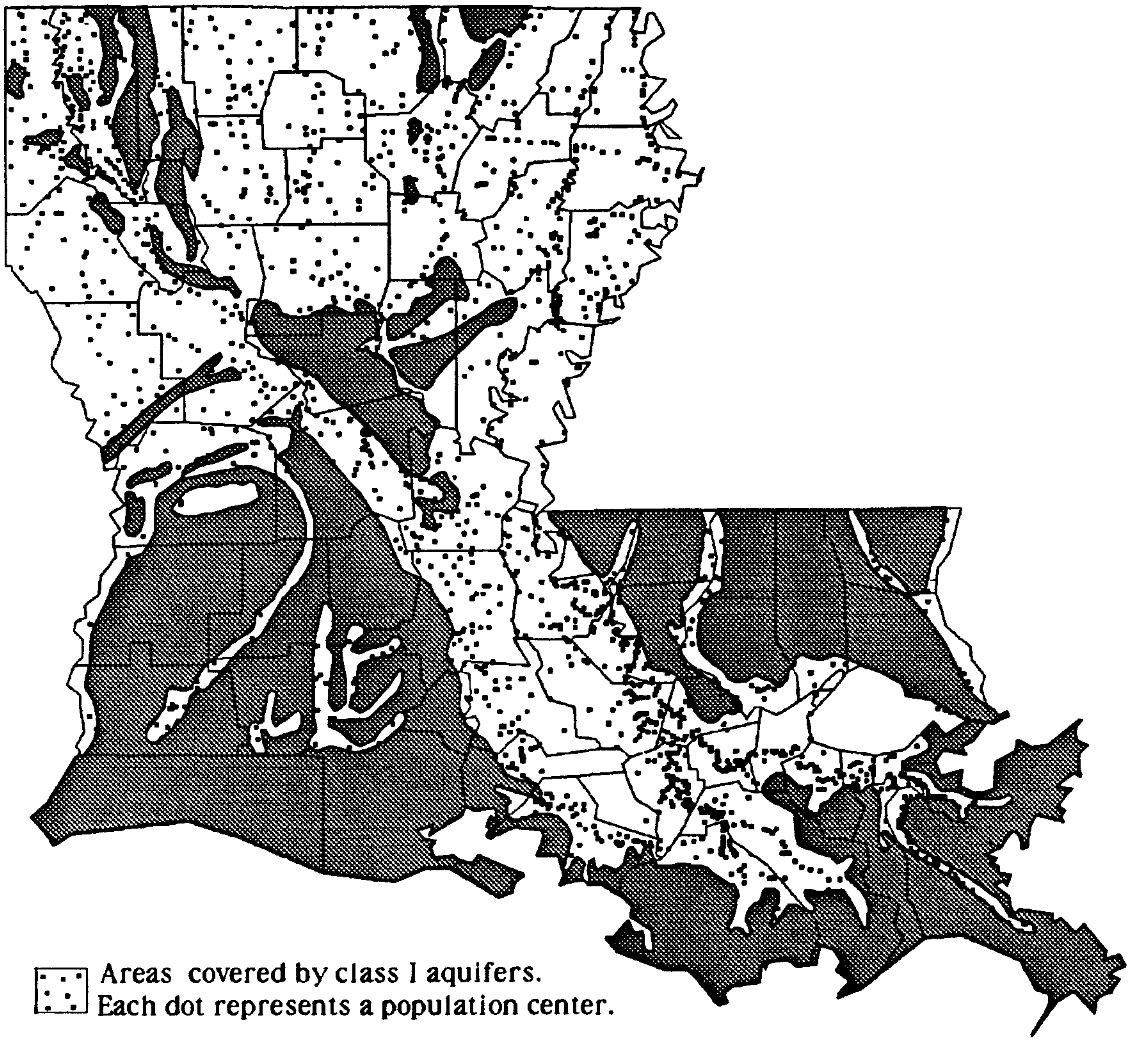
Nearly 57 percent of Louisiana is covered by Class I aquifers. In addition, another 40 percent has been mapped as Class U, and much of this area also is likely to be quite vulnerable. The potential for ground-water contamination from shallow injection wells in Louisiana is high due to the extensive occurrence of vulnerable aquifers and the abundance of population centers, which are rather evenly distributed throughout the state.



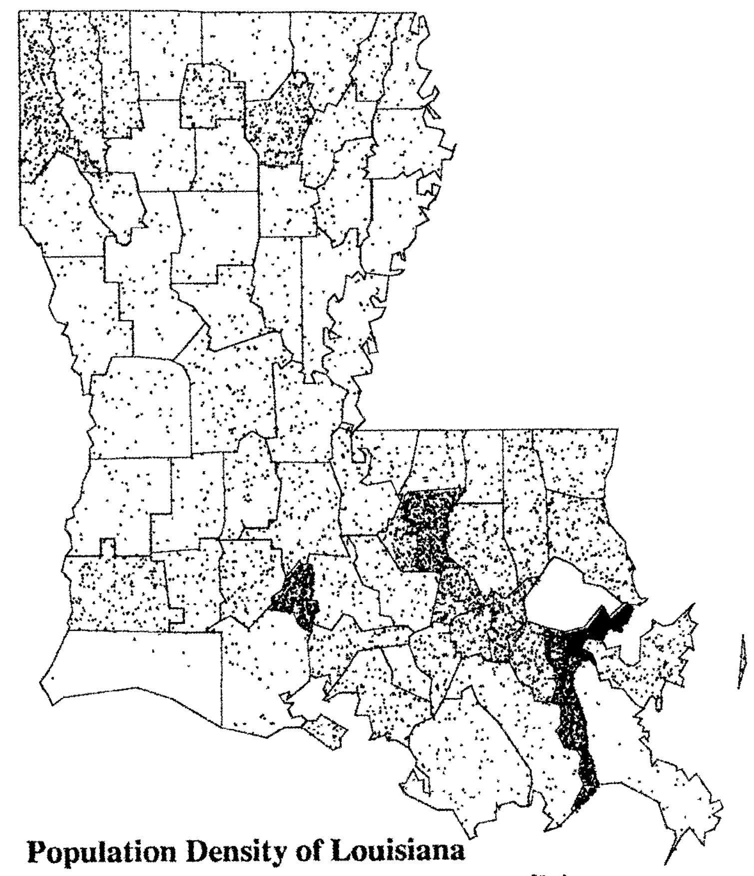
Aquifer Vulnerability Map of Louisiana



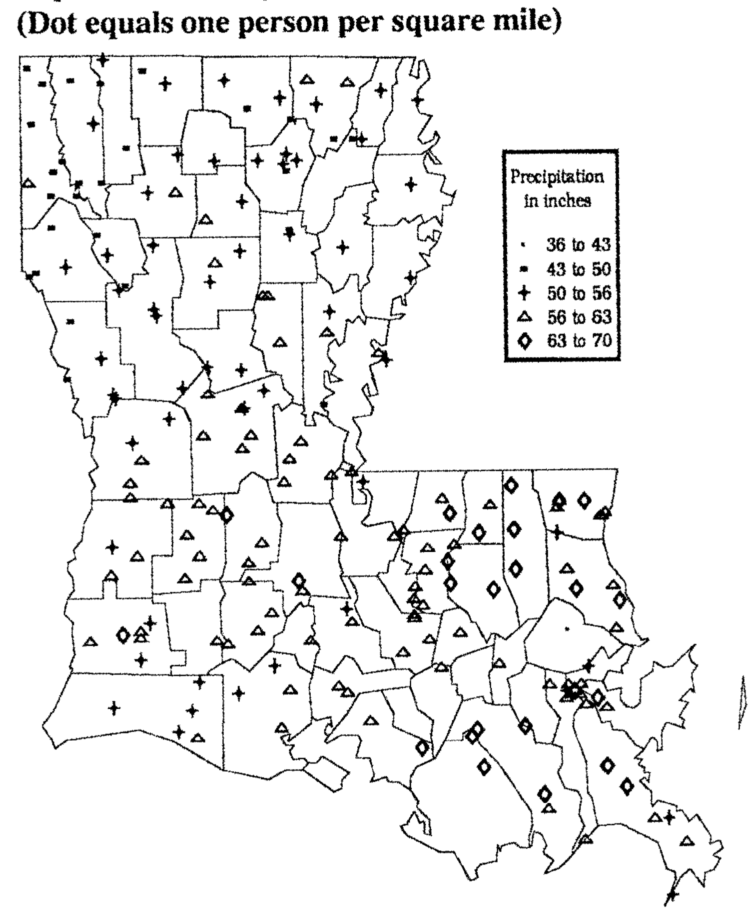
Potential Well Yields in Louisiana



Aquifer Sensitivity Map of Louisiana



Population Density of Louisiana
(Dot equals one person per square mile)



Average Annual Precipitation in Louisiana

NEW MEXICO

General Setting

New Mexico, containing 121,593 square miles, lies in the mountains, intermountain basins, dissected plateaus, and high plains of the Basin and Range, Southern Rocky Mountains, Colorado Plateau, and Great Plains physiographic provinces. The mountains of northern, central, and southwestern New Mexico consist largely of Tertiary and Quaternary age basalt, andesite, and rhyolite flows, pyroclastic deposits, and associated sediments. Scattered throughout the state are isolated exposures of Precambrian age metamorphic rocks, Paleozoic and Mesozoic sedimentary units, and Cretaceous and Tertiary age intrusives. Intermountain basins contain thick accumulations of Cenozoic age alluvial, bolson, eolian, lacustrine, and volcanic deposits. The plateaus and plains of northwestern and eastern New Mexico are underlain by relatively flat-lying Paleozoic, Mesozoic, and Tertiary age sandstone, shale, limestone, and gypsum deposits.

The extreme western part of New Mexico is drained by the west-flowing San Juan River system, and several tributaries of the Colorado River. The remainder of the state is drained by the Rio Grande and Pecos systems, and the east-flowing Canadian River. Annual precipitation ranges from 6 inches in the desert valleys to 35 inches at higher elevations in the mountains. Evapotranspiration, caused by direct evaporation and loss to phreatophytes, ranges from 40 to 80 in/yr. The majority of New Mexico's population, approximately 1.5 million, is located in the vicinity of Albuquerque, Santa Fe, and Las Cruces. The remainder of the state is sparsely populated. Daily use of fresh ground water amounts to about 1510 million gallons.

Unconsolidated Aquifers (Class Ia)

Alluvial, bolson, eolian, and lacustrine deposits occur in basins and valleys throughout the state, forming vulnerable and productive aquifers. These unconfined and confined systems consist of unconsolidated deposits of sand, gravel, silt, clay, and volcanic material of Quaternary age. In most places, these strata range from a few hundred to as much as 2,000 feet in thickness, but they may be as much as 20,000 feet thick in the Rio Grande Valley. Well yields commonly range from 100 to 500 gpm, and may exceed 3,000 gpm. About 30 percent of New Mexico is covered by Class Ia aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Karst features are present in fractured Permian age limestone, which is exposed in southeastern New Mexico. Where present, karst features and fractures contribute to the vertical and lateral permeability of the rock, creating highly productive and vulnerable aquifers. Well yields commonly range from 400 to 800 gpm, and may exceed 3,000. Surface exposures of karst carbonate aquifers occupy slightly more than 1 percent of the state.

Semiconsolidated Aquifers (Class Ic)

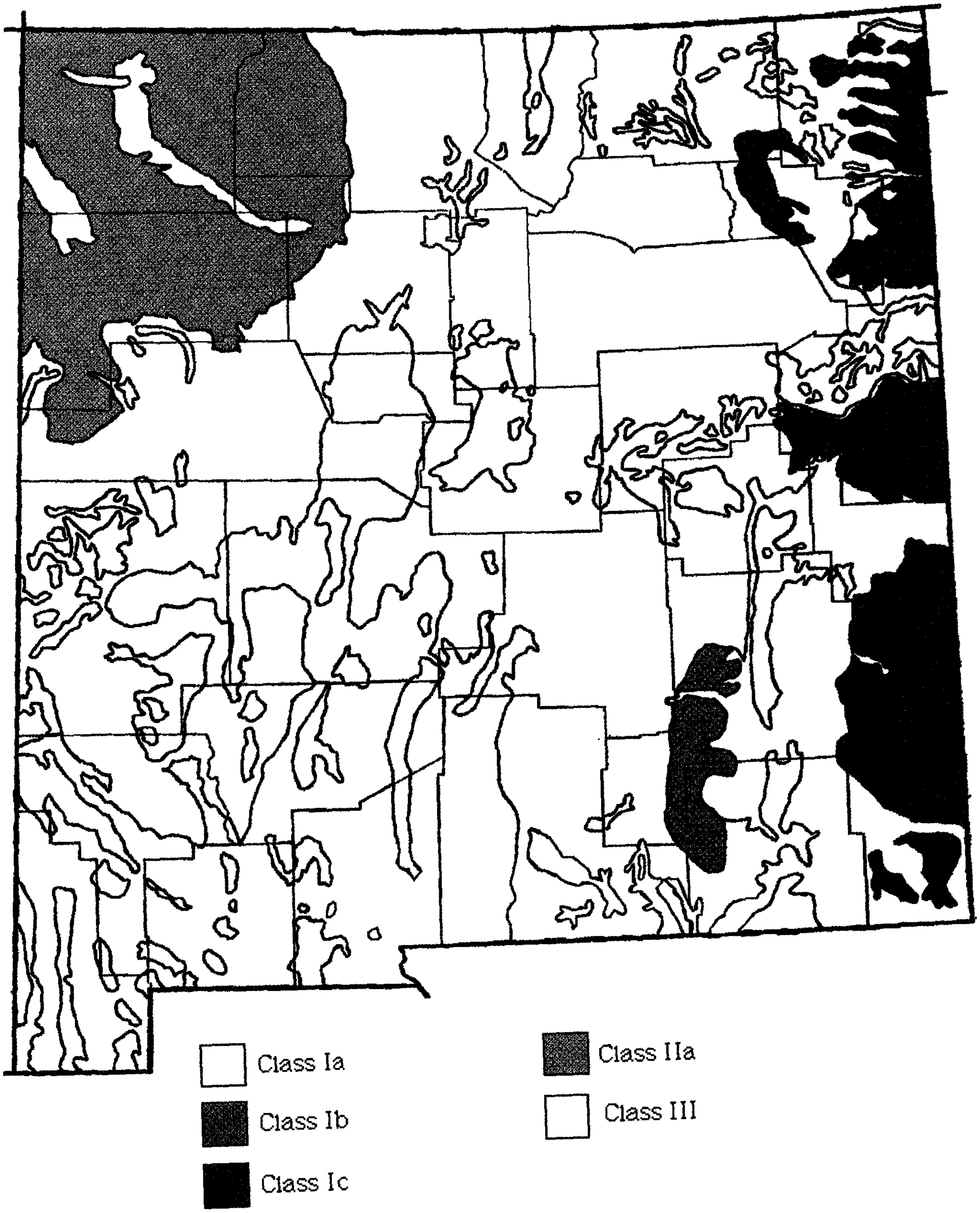
The High Plains Aquifer, exposed along the eastern margin of New Mexico, consists of the Tertiary age Ogallala Formation. The Ogallala contains semiconsolidated, fine- to coarse-grained sand, gravel, clay, silt, and thin beds of caliche. Well yields commonly range from 100 to 500 gpm, and may exceed 3,000 gpm. The presence of intercalated layers of low permeability strata coupled with an unsaturated zone of substantial thickness reduces the physical vulnerability of the aquifer system. Surface exposures of semiconsolidated aquifers occupy about 7.4 percent of the state.

Higher Yield Bedrock Aquifers (Class IIa)

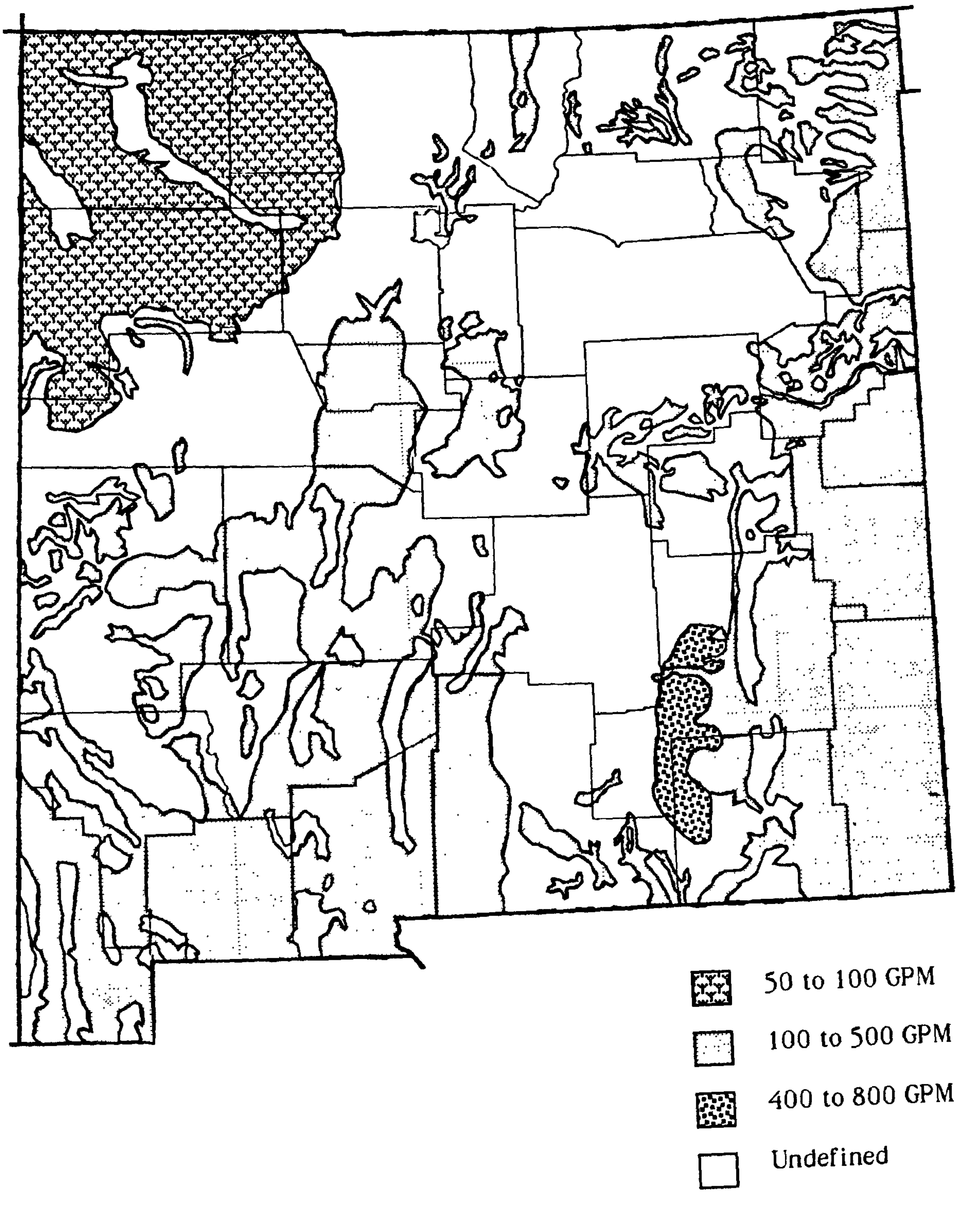
Higher yield bedrock aquifers crop out in northwestern New Mexico, and consist of a series of hydraulically connected Mesozoic and Tertiary age very fine- and medium-grained sandstones of both marine and continental origin. Well yields commonly range from 50 to 100 gpm, and may exceed 1,200 gpm. Surface exposures of higher yield bedrock aquifers occupy about 6.4 percent of the state.

Sensitivity

Nearly 39 percent of New Mexico is covered by Class I aquifers. Owing to the light population density, aquifer sensitivity is low. In a few vulnerable areas there are a considerable number of population centers that lie along the major transportation routes.

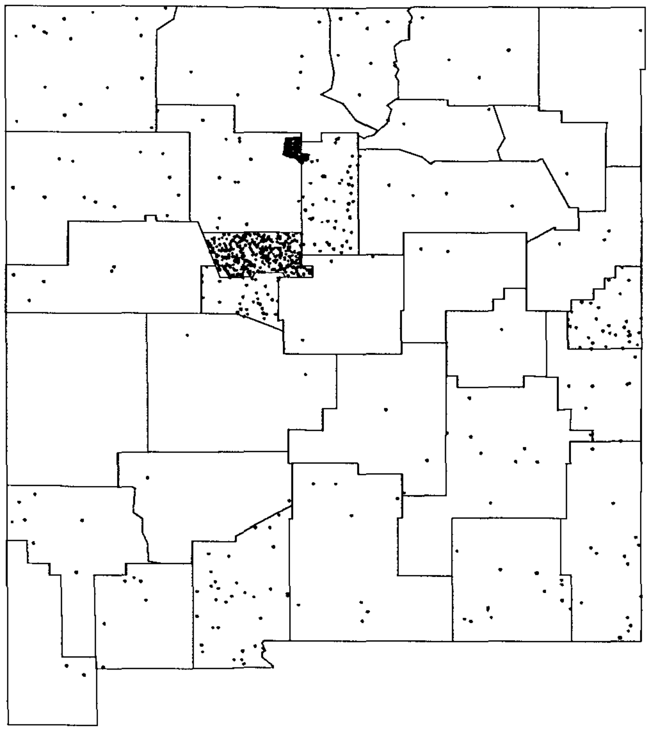


Aquifer Vulnerability Map of New Mexico

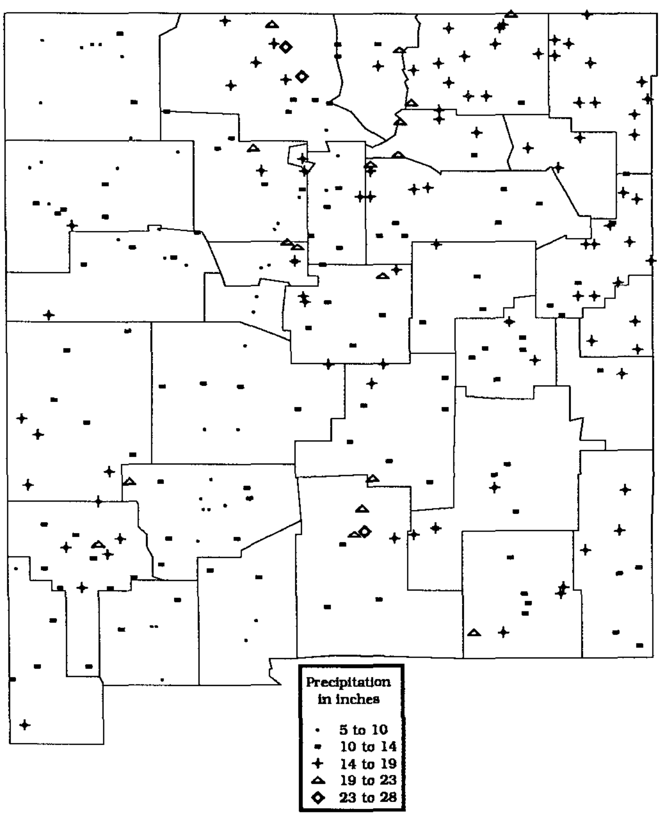


Potential Well Yields In New Mexico

Aquifer Sensitivity Map of New Mexico



Population Density of New Mexico (Dot equals one person per square mile)



Average Annual Precipitation in New Mexico

OKLAHOMA

General Setting

Oklahoma, which contains approximately 70,000 square miles, lies primarily in the rolling plains and low hills of the Central Lowlands, the Great Plains, and the Coastal Plains physiographic provinces. Mountainous regions along Oklahoma's eastern margin lie within the Ozark Plateaus and Ouachita provinces. The less extensive Arbuckle and Wichita Mountains occur in the south-central and southwestern parts of the state, respectively. Most of Oklahoma is underlain by thick sequences of westward dipping Paleozoic age limestone, dolomite, and shale. The Anadarko, Ardmore, and Arkoma basins in west-central, south-central, and east-central Oklahoma, respectively, contain as much as 40,000 feet of marine, and minor terrigenous sediments. Folded and faulted Paleozoic age rocks crop out in the Wichita, Arbuckle, and Ouachita Mountains, and in the Ozark Plateaus, while Precambrian crystalline rocks are exposed in the Wichita and Arbuckle Mountains. Flat lying clastic and carbonate units of Mesozoic age are exposed in the northwestern part of the Panhandle, and southward-dipping clastic and carbonate strata of Cretaceous age crop out in the southeastern part of the state. Exposures of semiconsolidated to consolidated sand and gravel, forming the Ogallala Formation of Tertiary age, dominate northwestern Oklahoma. Unconsolidated Quaternary age alluvial and terrace deposits, which lie along all of Oklahoma's major rivers, may extend as much as 15 miles from the rivers.

The Arkansas River and its eight principal tributaries drain the northern two thirds of Oklahoma. The Red River and its five principal tributaries drains the southern third of the state. Annual precipitation ranges from less than 16 inches in the west to more than 54 inches in the southeast. April and September are the months that generally have the greatest precipitation. Evapotranspiration ranges from about 16 in/yr in the west to 36 in the northeast. The majority of Oklahoma's population, approximately 3.2 million, is located in Oklahoma, Tulsa, and Cleveland counties. The remainder of the state is sparsely populated. About 568 million gallons of fresh ground water are used daily in the state.

Unconsolidated Aquifers (Class Ia)

Streamside alluvial and terrace deposits form some of the most vulnerable aquifers in the state. These unconfined systems generally consist of permeable, unconsolidated, gravel, sand, silt, and clay that commonly are tens of feet thick. Well yields normally range from 20 to 600 gpm, and may exceed 1,200 gpm. Dune sands locally overlie alluvium and terrace deposits. About 18 percent of the state is covered by Class Ia aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Solutional features are present in carbonate and gypsiferous units in southwestern, south-central and northeastern Oklahoma. Where present, karst features contribute to the vertical and lateral permeability of the rock, creating both productive and vulnerable aquifers. Well yields generally range from 90 to 600 gpm, but locally may exceed 2,500 gpm. Several springs discharge from 50 to 18,000 gpm. In northeast Oklahoma, well yields of 10 gpm or less are common, but springs may discharge as much as 3,500 gpm. Soluble aquifers and fractured bedrock aquifers occupy about 4.7 percent of the state.

Semiconsolidated Aquifers (Class Ic)

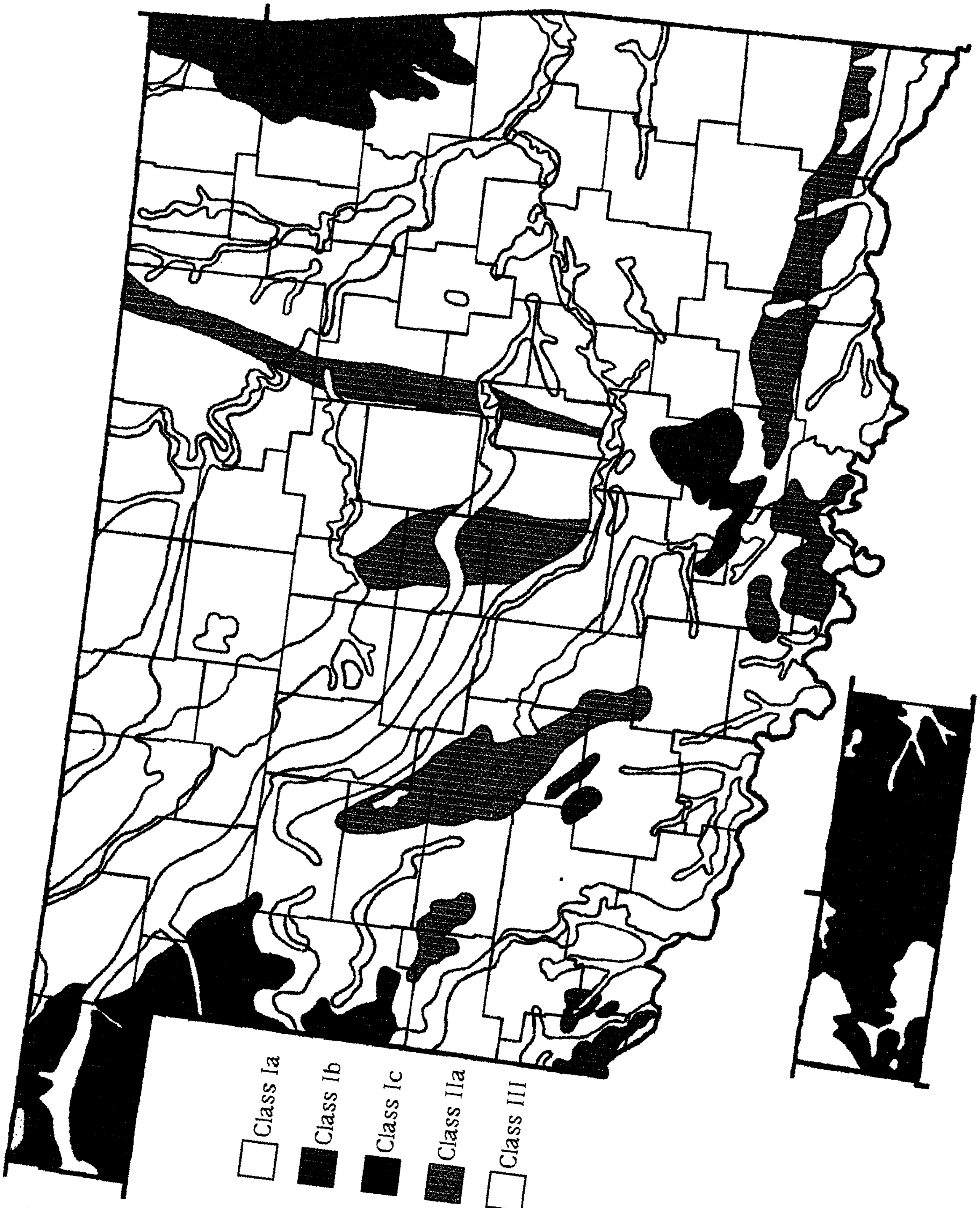
The High Plains Aquifer, located in northwestern Oklahoma, consists of the Ogallala Formation and overlying alluvial and basin-fill deposits of reworked Ogallala. The Ogallala contains semiconsolidated, fine-grained sandstone and siltstone, with lesser amounts of clay and gravel, and thin beds of limestone and caliche. The overlying alluvial deposits consist of unconsolidated sand, silt, clay, and gravel. The High Plains Aquifer is largely unconfined and the saturated thickness ranges from a few feet to as much as 500 feet. Well yields commonly range from 100 to 1,000 gpm, and may locally exceed 2,000 gpm. The presence of numerous intercalated layers of low permeability strata, coupled with an unsaturated zone of substantial thickness, reduces the vulnerability of the aquifer system. Surface exposures of Class Ic aquifers occupy slightly more than 8 percent of the state.

Higher Yield Bedrock Aquifers (Class IIa)

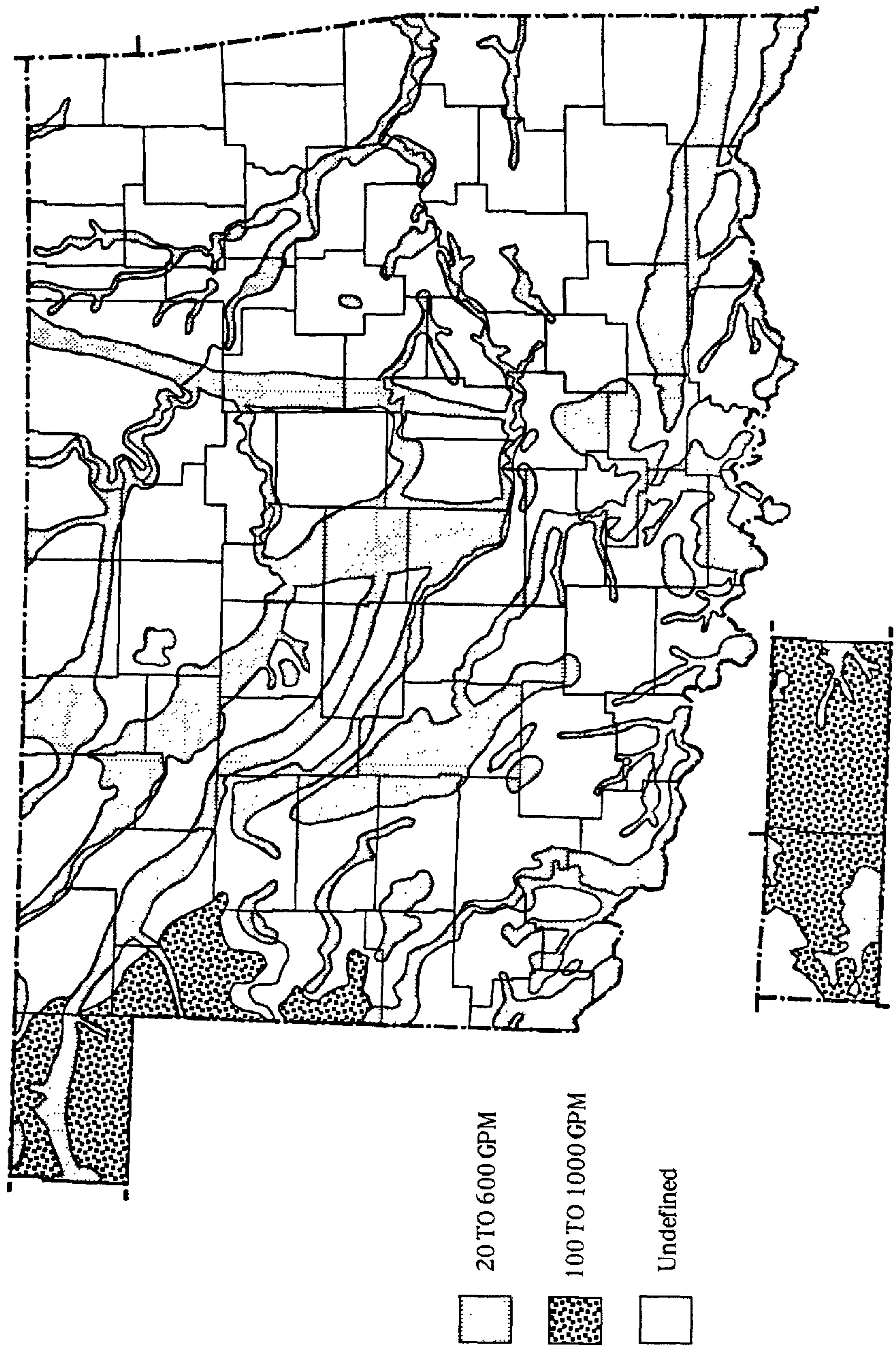
Higher yield bedrock aquifers, consisting primarily of sandstone, occur throughout much of the state. Sandstone aquifers, which contain variable amounts of siltstone, shale, dolomite, and gypsum, are unconfined in the outcrop area. Well yields range from 50 to 600 gpm, and may exceed 1,700 gpm. Surface exposures of Class IIa aquifers occupy about 8 percent of the state.

Sensitivity

Although 31 percent of the state is covered by Class I aquifers, the potential for ground-water contamination from shallow injection wells is small owing to Oklahoma's low population density. The most sensitive areas are the Class Ia aquifers, most of which lie along the major rivers, and these amount to only about 18 percent of the state. The number of population centers within Class Ia also is very small. Class Ic, which reflects the lightly populated High Plains Aquifer, covers about 8.3 percent of the state, but in this area the water table generally lies at a considerable depth, and several zones of caliche tend to reduce ground-water recharge.

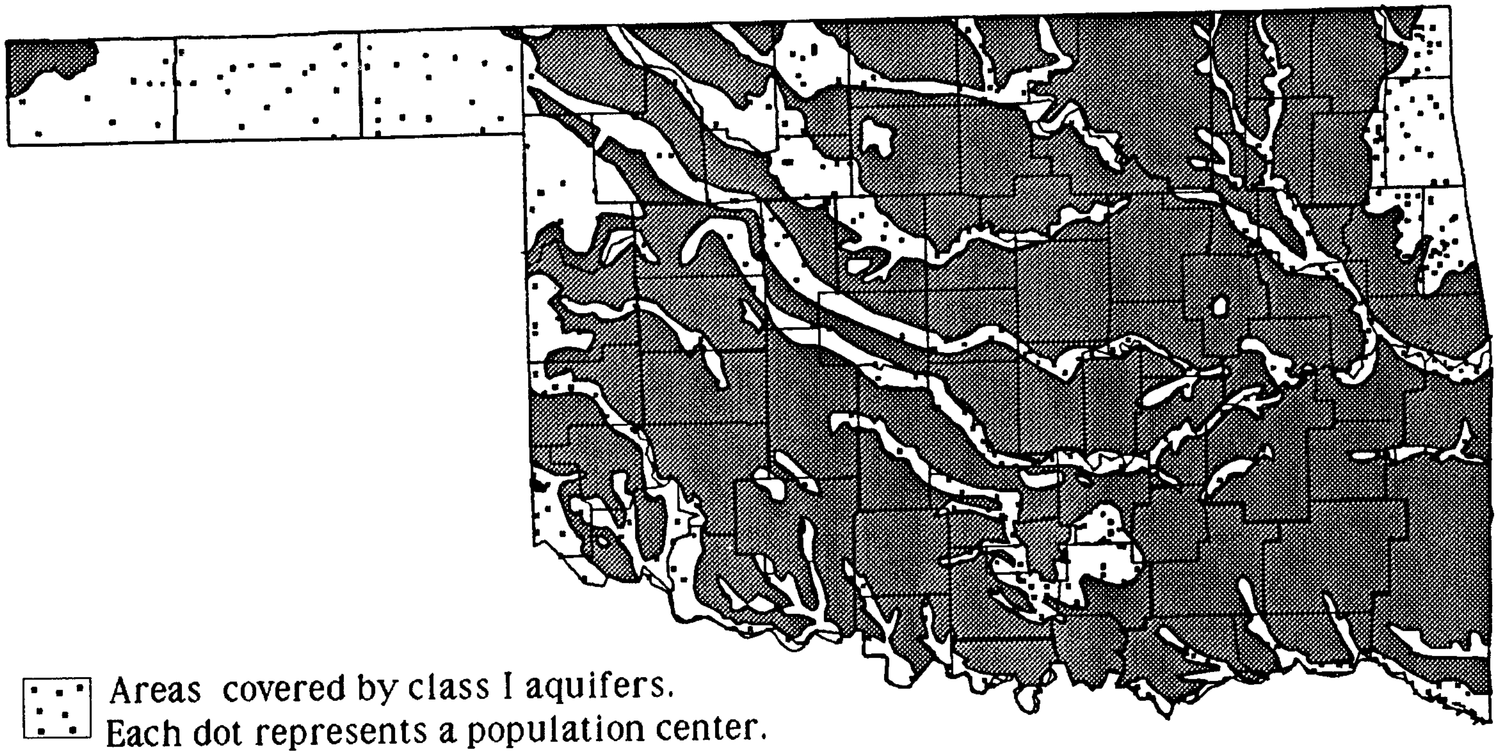


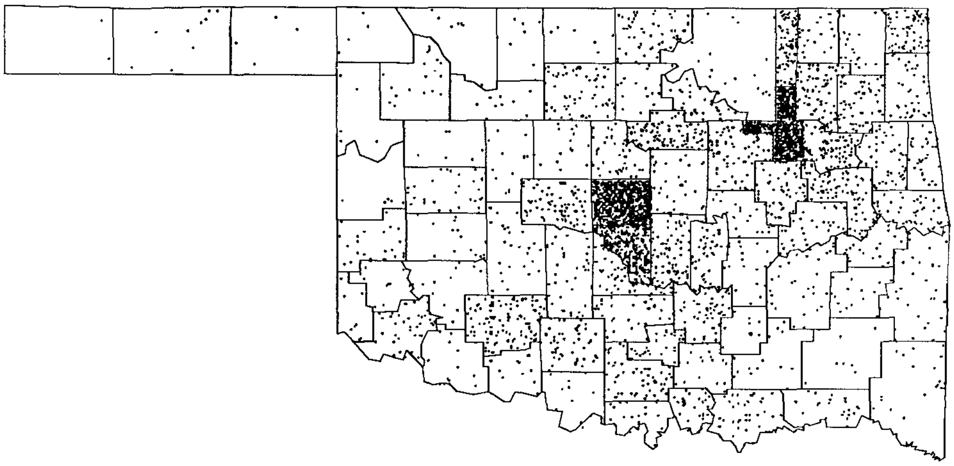
Aquifer Vulnerability Map of Oklahoma



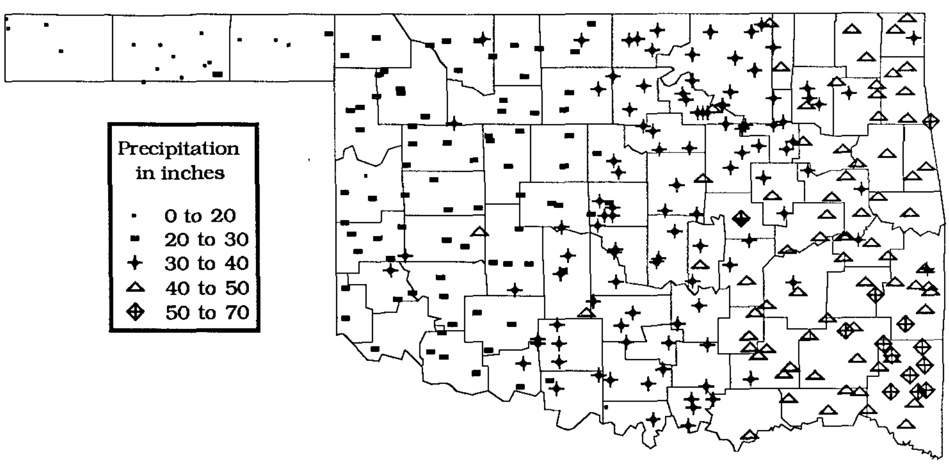
Potential Well Yields In Oklahoma

Aquifer Sensitivity Map of Oklahoma





Population Density of Oklahoma (Dot equals one person per square mile)



Average Annual Precipitation in Oklahoma

TEXAS

General Setting

Texas, which contains approximately 266,800 square miles, lies primarily in the low hills and dissected plains of the Coastal Plain, Central Lowland, and Great Plains physiographic provinces. The mountainous southwest corner of the state lies within the Basin and Range province. Most of Texas is underlain by gently dipping carbonate and clastic sedimentary rocks of Paleozoic age. These units crop out throughout the central and north-central parts of the state. Folded and faulted Paleozoic age rocks, which are intruded and locally overlain by Tertiary age igneous rocks, crop out in the southwest corner of Texas. Exposures of Precambrian age igneous and metamorphic rocks occur within anticlinal Paleozoic strata in the Llano Uplift in central Texas. Mesozoic age carbonate and clastic rocks, which unconformably overlie the Paleozoic section, are exposed across south-central and northeastern Texas. Semiconsolidated, clastic sediments of the Tertiary age Ogallala Formation mantle Paleozoic rocks in northwestern Texas. The Coastal Plain is underlain by an eastward thickening wedge of Cretaceous to Holocene age semiconsolidated to unconsolidated, interbedded, sand, silt, clay, gravel, and marl.

Several north- and east-flowing rivers drain the Texas Panhandle. The remainder of the state is drained by numerous south to southeast-flowing waterways. Annual precipitation ranges from less than 8 inches in the west to more than 56 inches in the east. The majority of Texas' population, nearly 17 million, is located in and around several large cities. Elsewhere the state is sparsely populated. More than 7180 and 229 million gallons of fresh and saline ground water, respectively, are used in Texas each day.

Unconsolidated Aquifers (Class Ia)

Alluvial, marsh, lagoonal, and beach deposits occur throughout the Texas Coastal Plain, and form both vulnerable and productive aquifers. These confined to unconfined, multi-layered systems consist of interbedded and interfingering, unconsolidated deposits of clayey sand, silt, clay, sand, and gravel. Well yields range from 300 to 1,500 gpm, and may exceed 4,500 gpm. Alluvial and bolson deposits provide important sources of ground water in north-central and west Texas. These generally unconfined aquifers consist of unconsolidated sand, gravel, silt, and clay. Locally bolson deposits in western Texas reach several thousand feet in thickness. Well yields range from 500 to 900 gpm, and may exceed 2,500 gpm. Nearly 25 percent of the state is covered by Class Ia aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Karst features are present in the folded, faulted, and fractured limestone, dolomite, and marls that are exposed along the Balcones fault zone in south-central Texas. Where present, karst features contribute to the vertical and lateral permeability of the the rock, creating highly productive and vulnerable aquifers. Well yields range from 400 to 1,200 gpm, and may exceed 16,000 gpm. Karst features also are present in the limestone and dolomitic rocks that are widely exposed throughout west-central Texas. Minor clay, sand, and sandstone interbeds occur within the carbonate section. Well yields range from 50 to 200 gpm, and may exceed 3,000 gpm. Exposures of karstic evaporite deposits, which extend southward from the eastern Texas Panhandle, consist of beds of anhydrite, gypsum, halite, silty shale, and dolomite. Ground water occurs primarily in solution channels and cavities within beds of anhydrite and gypsum. Several formations, consisting of karstic limestone, dolomite, and evaporites, locally crop out in west Texas. Fractured volcanic aquifers occur in west Texas. These systems are unconfined in the outcrop area, and consist of interbedded lava flows, tuffs, and volcanic breccia. Ground-water movement is controlled by the density of jointing and secondary fractures, the degree of welding, and the presence of permeable breccias. Surface exposures of karst and fractured bedrock aquifers occupy about 13 percent of the state.

Semiconsolidated Aquifers (Class Ic)

The High Plains Aquifer in the Panhandle consists of the Ogallala Formation, which is overlain locally by eolian and alluvial deposits. The Ogallala contains as much as 900 feet of unconsolidated, fine- to coarse-grained sand that is interbedded with loam, gravel, clay, silt, and caliche zones. Well yields commonly range from 100 to 1,000 gpm, and may exceed 2,000 gpm. The presence of intercalated layers of low permeability strata coupled with an unsaturated zone of substantial thickness reduces the physical vulnerability of the aquifer system. Semiconsolidated continental and marine sediments crop out along a northeast trend across eastern Texas. These Cretaceous to Tertiary age sediments consist of ferruginous, glauconitic, and calcareous sand and interbedded clay, sandstone, shale, silt, marl, and chalk. Well yields commonly range from 100 to 1,000 gpm, and may exceed 3,000 gpm. Surface exposures of Class Ic aquifers occupy nearly 25 percent of the state.

Higher Yield Bedrock Aquifers (Class IIa)

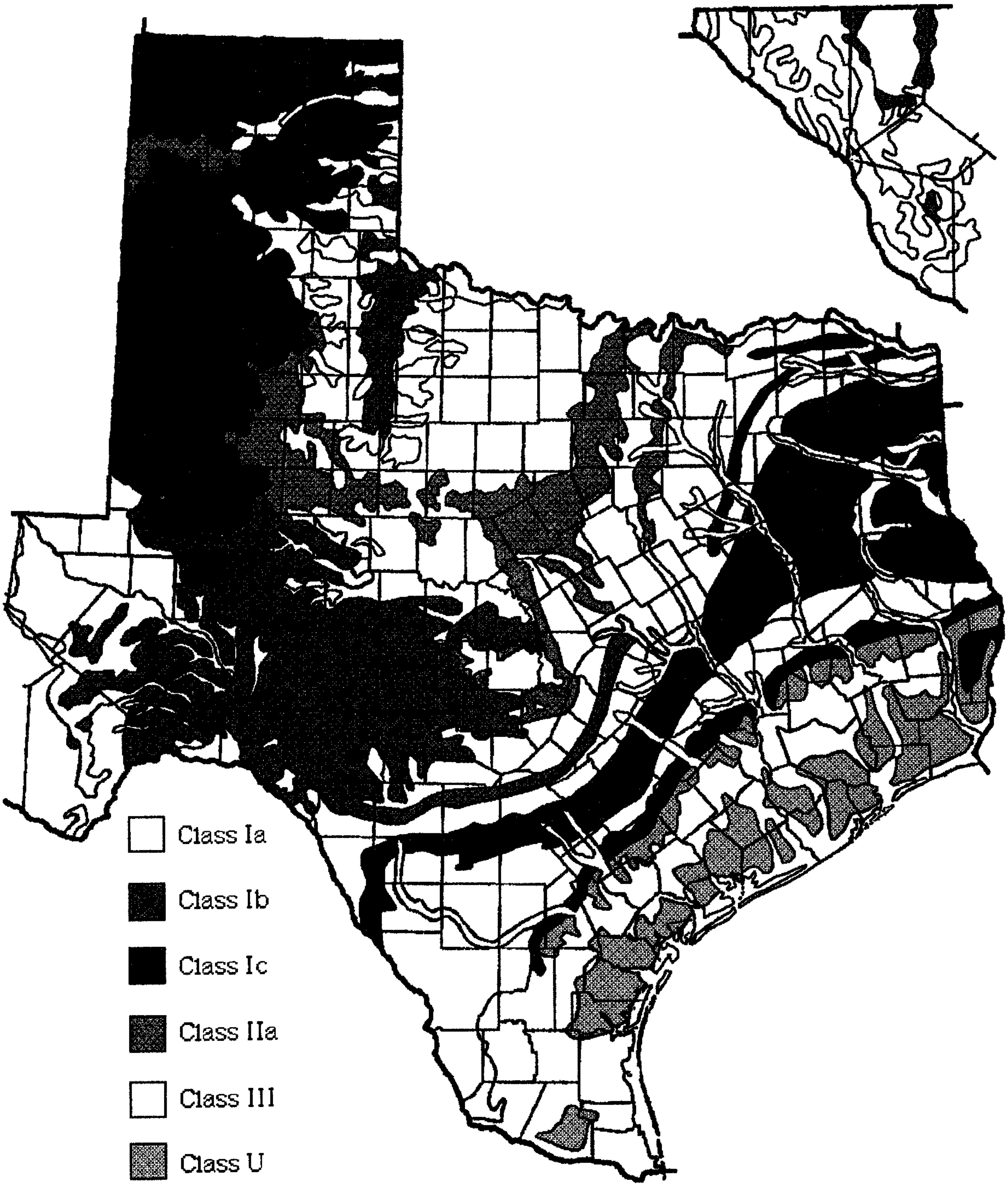
Higher yield bedrock aquifers, consisting of sandstone and sand, interbedded with clay, shale, conglomerate, caliche, limestone, and evaporite deposits, crop out in north-central and northwest Texas. Well yields range from 100 to 300 gpm, and may exceed 1,000 gpm. Surface exposures of Class IIa aquifers occupy nearly 7 percent of the state.

Undifferentiated Aquifers (Class U)

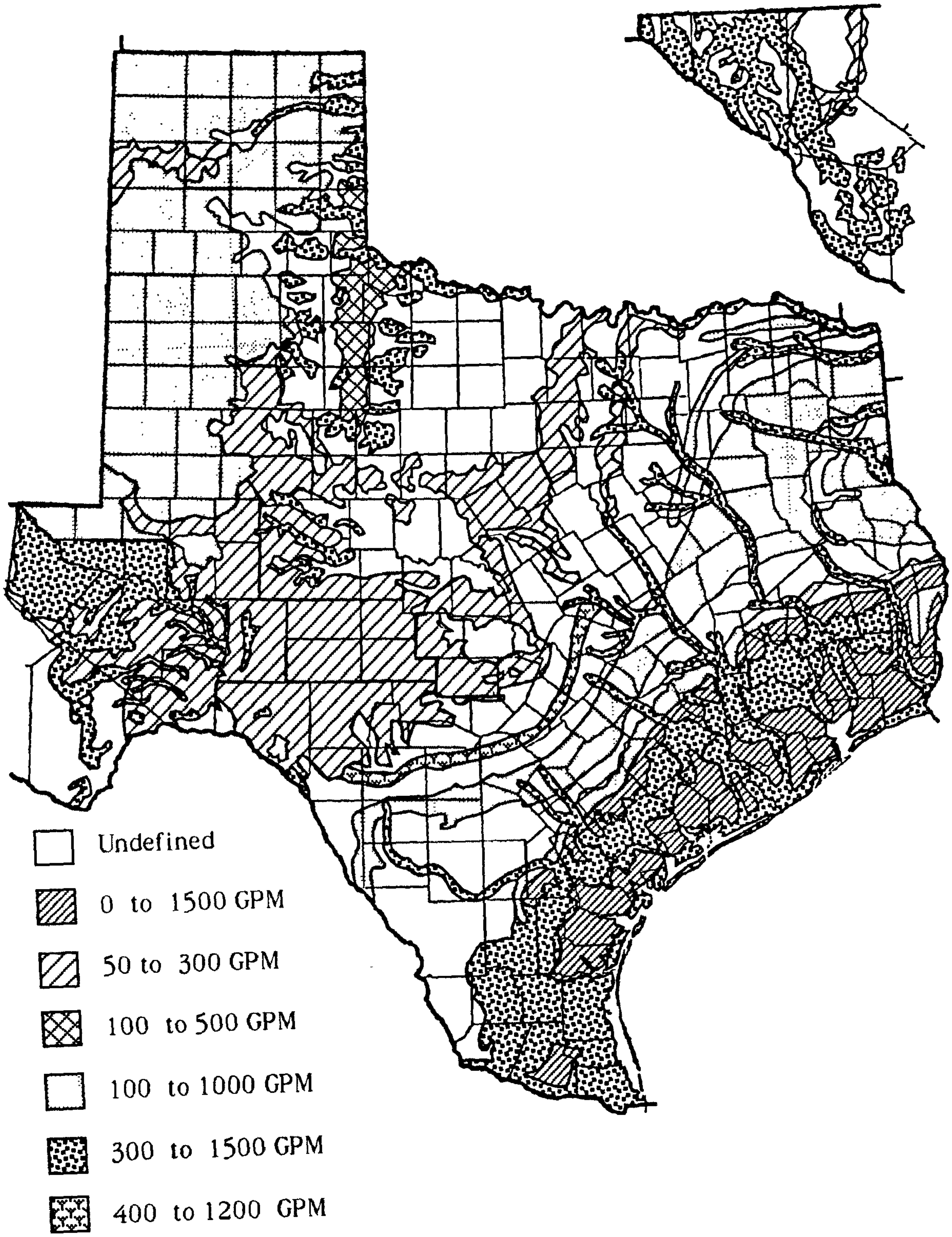
Lithologically varied Quaternary age sediments, which occur throughout the Texas Coastal Plain, consist of interbedded and interfingering, unconsolidated, clay, mud, sand, silt, and gravel. Due to their textural heterogeneity, a wide range in aquifer productivity and vulnerability should be expected in these areas. Nearly 6 percent of the state is covered by undifferentiated aquifers.

Sensitivity

About 62 percent of Texas is covered by Class I aquifers. The potential for ground-water contamination from shallow injection wells is moderately high in those critical areas that have a high population density, such as the coastal plain sediments in the southeastern part of the state. Although vulnerable strata exist in the Panhandle and in other western parts of Texas, aquifer sensitivity is less because the water table generally lies at a greater depth and, commonly, units of low permeability lie above major reservoirs.

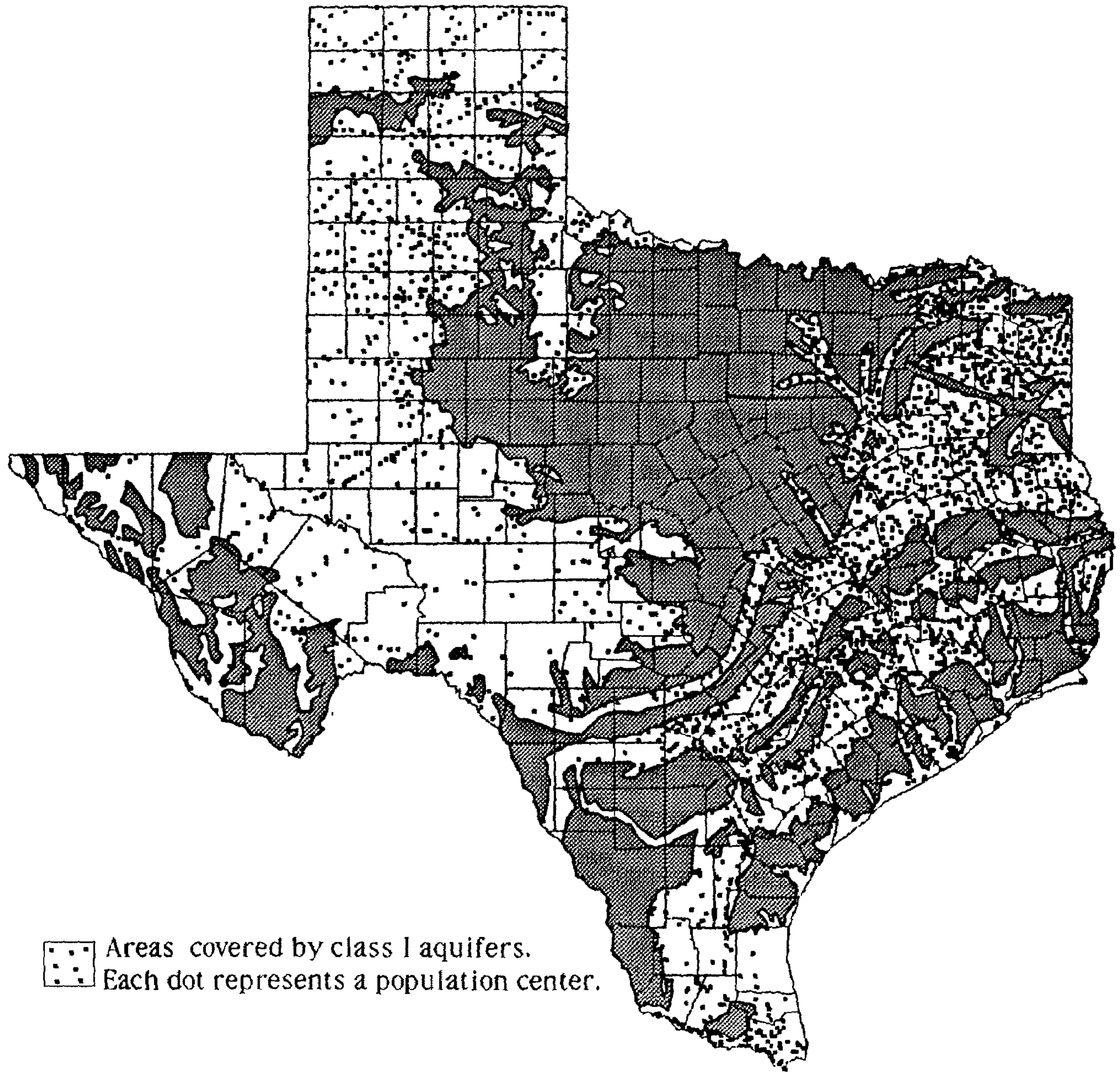


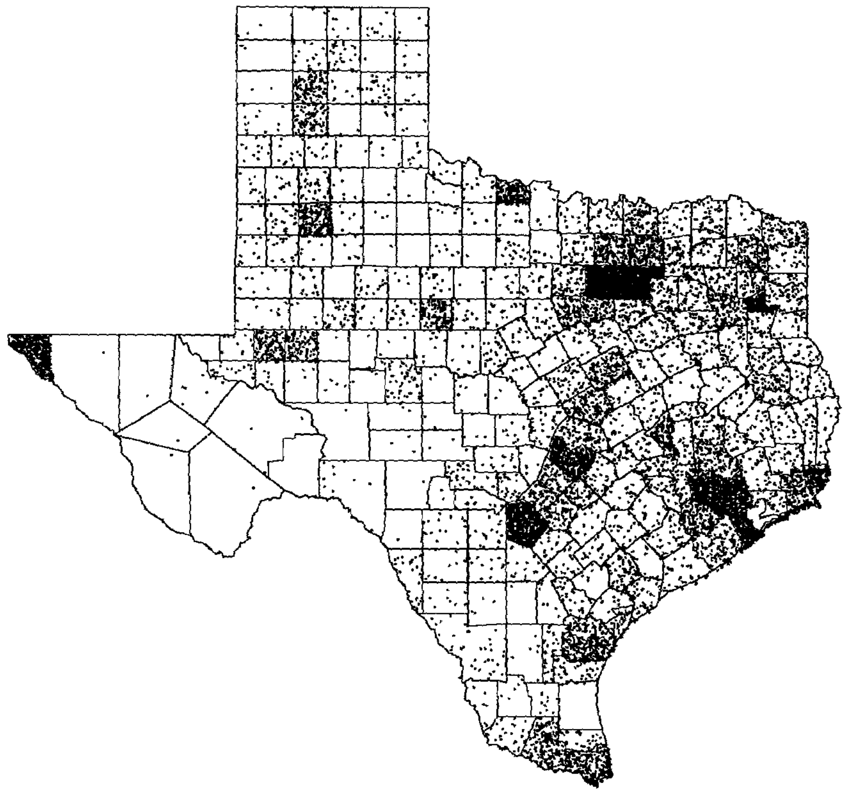
Aquifer Vulnerability Map of Texas



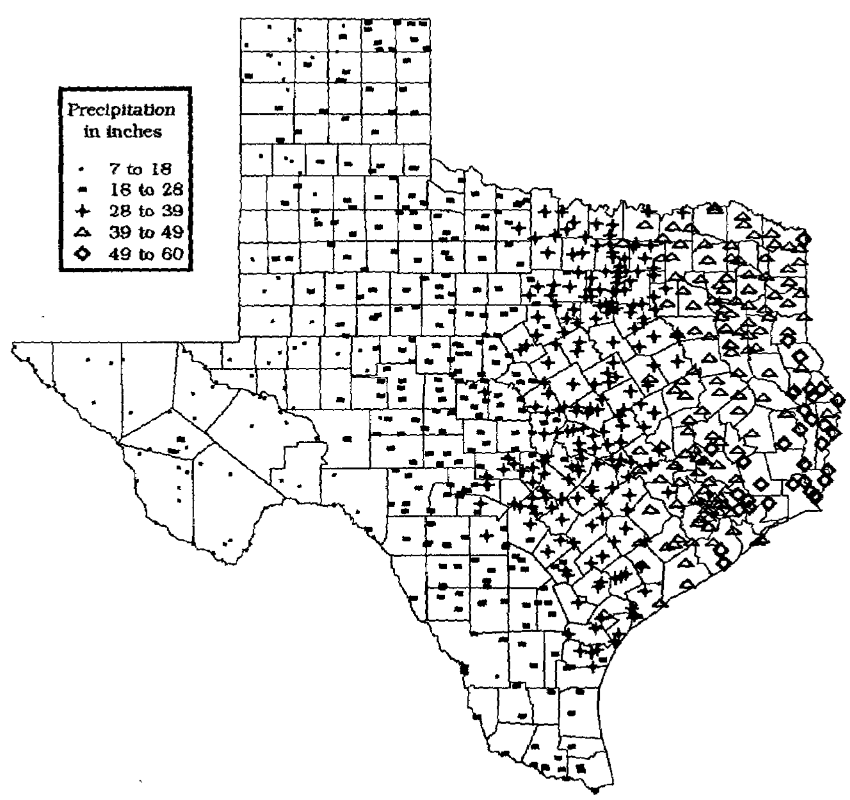
Potential Well Yields in Texas

Aquifer Sensitivity Map of Texas

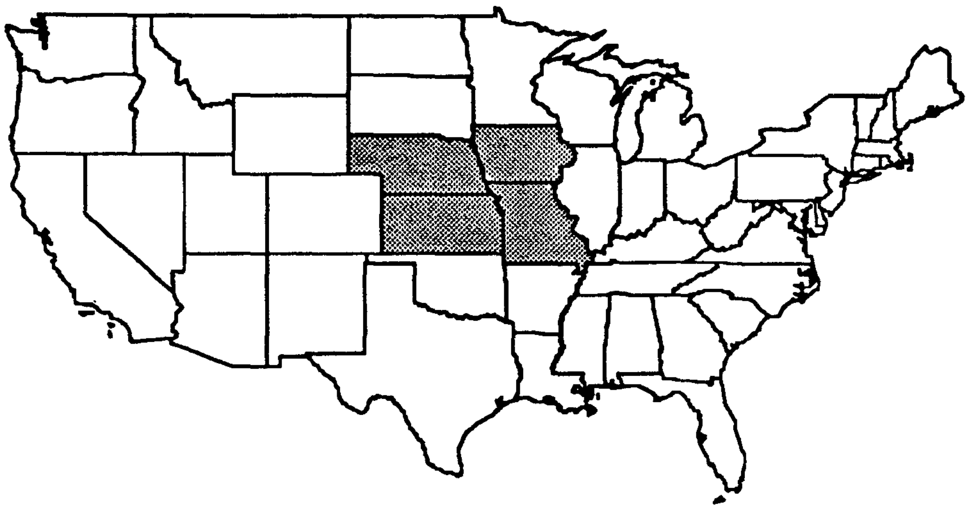




Population Density of Texas (Dot equals one person per square mile)



Average Annual Precipitation in Texas



REGION 7

Iowa
Kansas
Missouri
Nebraska

IOWA

General Setting

Iowa, which contains approximately 56,275 square miles, lies within the Central Lowland physiographic province. The topography varies from steep hills and high bluffs in the northeast to gently rolling hills in the southwest. Sculptured by five successive major glacial advances, Iowa's bedrock is mantled by a variable thickness of unconsolidated glacial drift and wind blown loess that averages roughly 200 feet in thickness. These deposits cover most of the state. The underlying bedrock is predominantly sandstone, limestone, and dolomite that ranges in age from Cambrian to Cretaceous. These strata have been gently folded and downwarped, dipping from structurally higher areas in the north and northeast into a broad basin in the south and southwest.

Western Iowa is drained by several southwest-flowing rivers that empty into the Missouri River. Central and eastern Iowa, situated in the Mississippi Valley, are drained by many southeasterly-flowing streams. Annual average precipitation varies from 28 inches in the northwest to 34 inches in the southeast. Iowa's population, about 2.8 million, is distributed among several moderately sized cities that lie along major rivers and throughout a lightly populated rural area. About 671 million gallons of fresh ground water are used daily in the state.

Unconsolidated Aquifers (Class Ia)

Unconsolidated Quaternary age alluvium occurs along the flood plains and terrains of Iowa's principle streams and rivers. These deposits consist of fine- to coarse-grained sand and gravel with varying amounts of silt and clay. Well yields commonly range from 200 to 1,000 gpm, and may exceed 2,000 gpm. About 14.3 percent of Iowa is covered by Class Ia aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Exposed in the northeast and locally along major rivers in eastern Iowa are carbonate aquifers. These Ordovician to Mississippian age rocks consist of limestone and dolomite with shale and some sandstone. Where present, solutional features contribute to the vertical and lateral permeability of the rock, creating productive and vulnerable aquifers. Well yields commonly range from 50 to 1,000 gpm, and may exceed 4,000 gpm. Class Ib aquifers are exposed in nearly 12 percent of the state.

Variably Covered Soluble and Fractured Bedrock Aquifers (Class Ib-v)

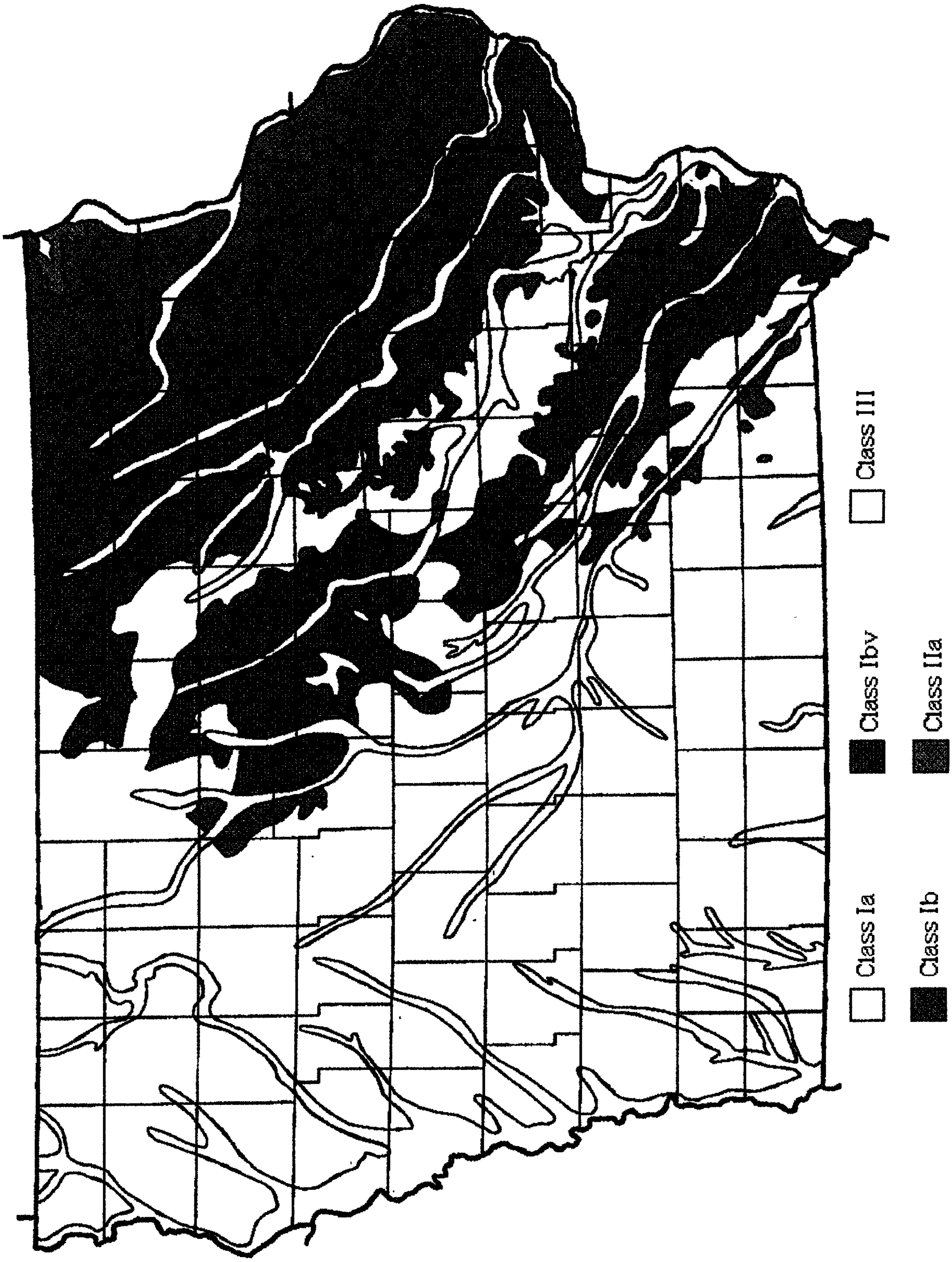
Occurring in central and eastern Iowa are Ordovician to Mississippian age carbonate rocks with solutional features that are overlain by a variable thickness of glacial till and loess. Aquifer vulnerability is a function of the thickness of the overlying sediments. Well yields commonly range from 50 to 1,000, and may exceed 4,000 gpm. About 22.5 percent of Iowa is underlain by Class Ib-v aquifers.

Higher Yield Bedrock Aquifers (Class IIa)

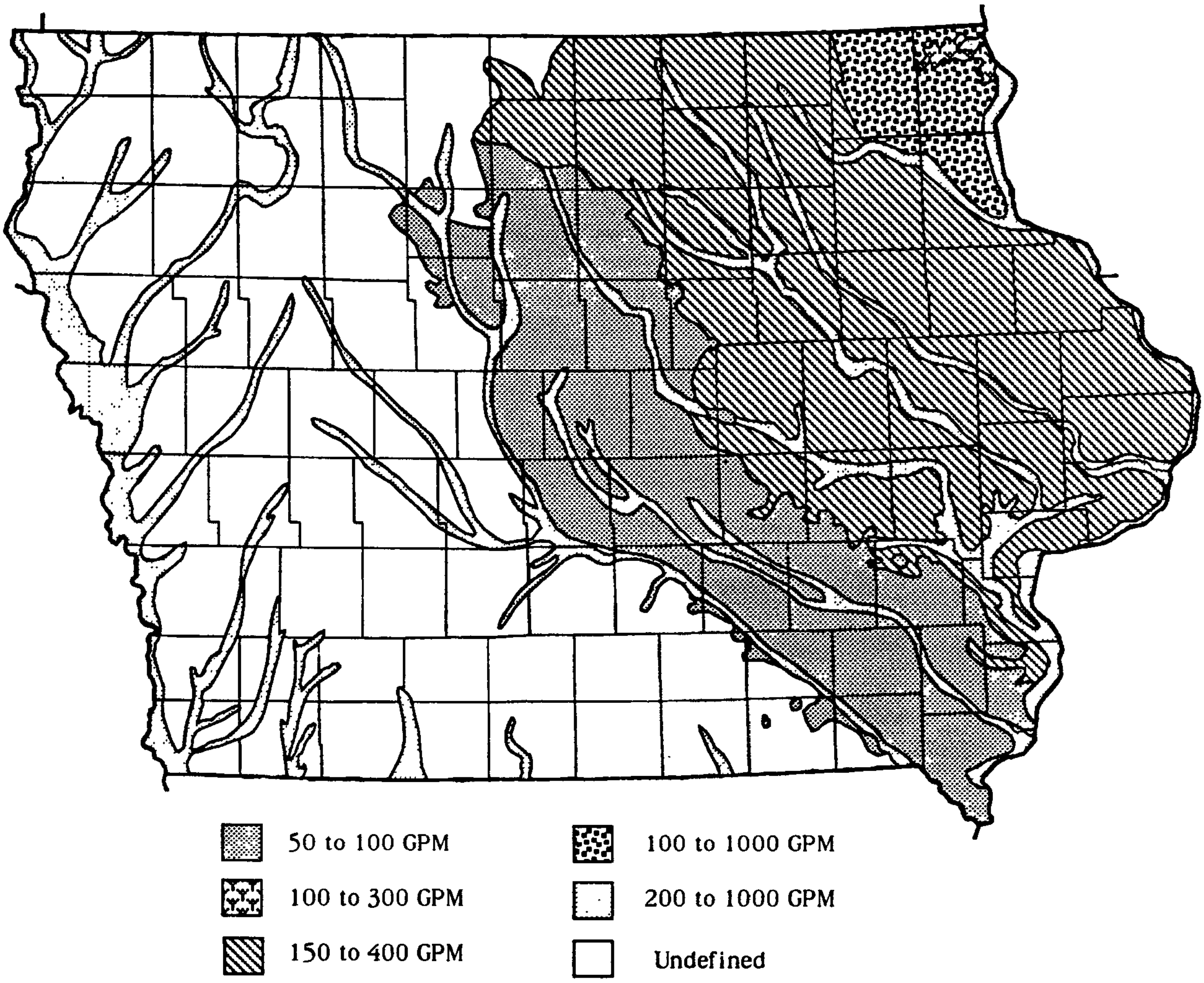
Exposed in far northeastern Iowa is a small area of Cambrian age sandstone. Well yields commonly range from 100 to 1,000 gpm. About .2 percent of Iowa is covered by higher yield bedrock aquifers.

Sensitivity

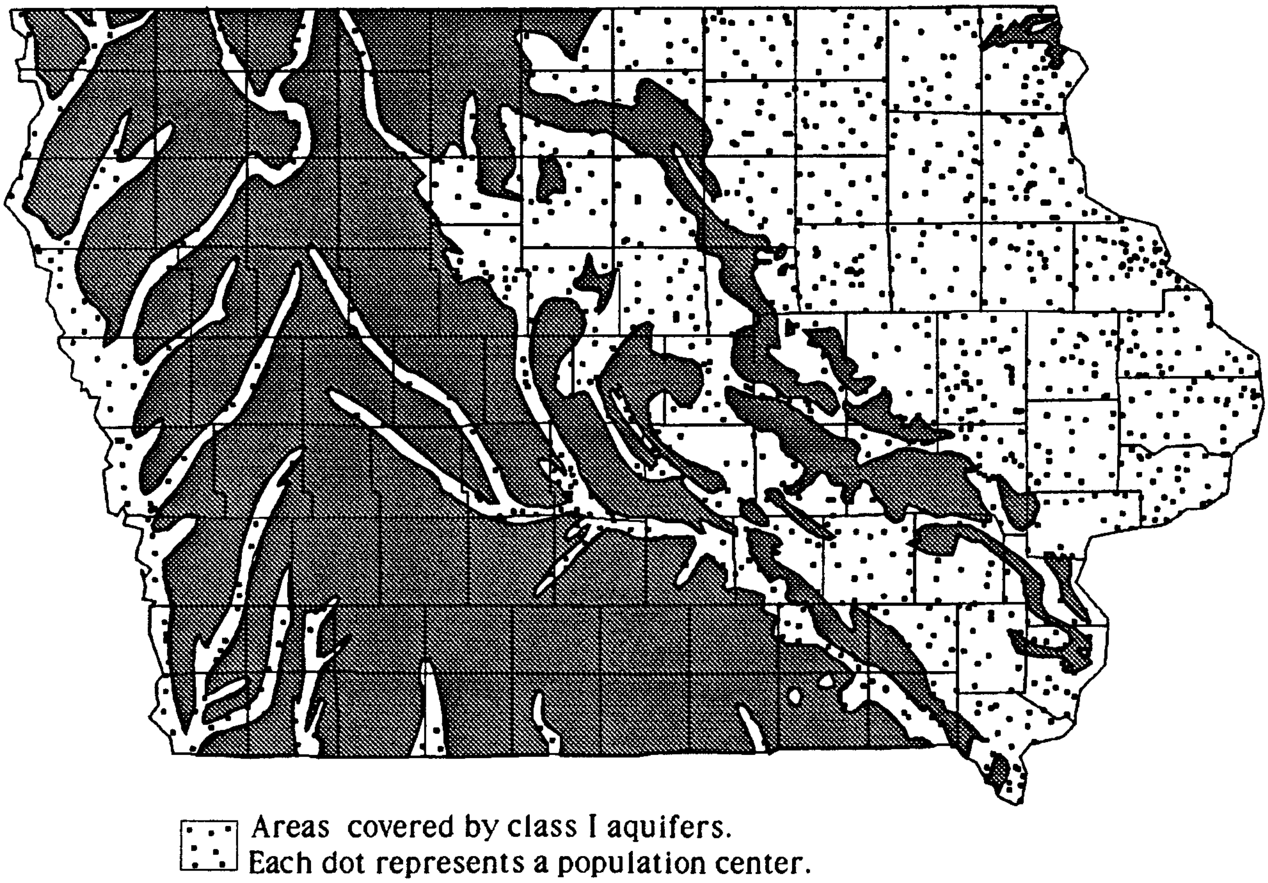
About 49 percent of Iowa contains Class I aquifers. The largest area lies in the northeastern half of the state, while a rather extensive band of alluvium occurs along the western margin. Population centers are rather evenly distributed throughout the vulnerable areas, but most of the towns are small. The potential for ground-water contamination from shallow injection wells in Iowa is moderately low.



Aquifer Vulnerability Map of Iowa

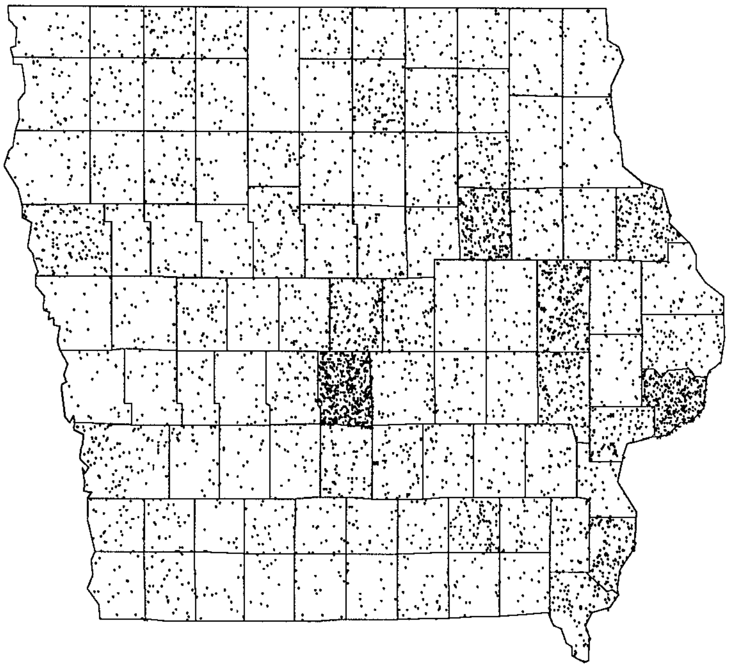


Potential Well Yields in Iowa

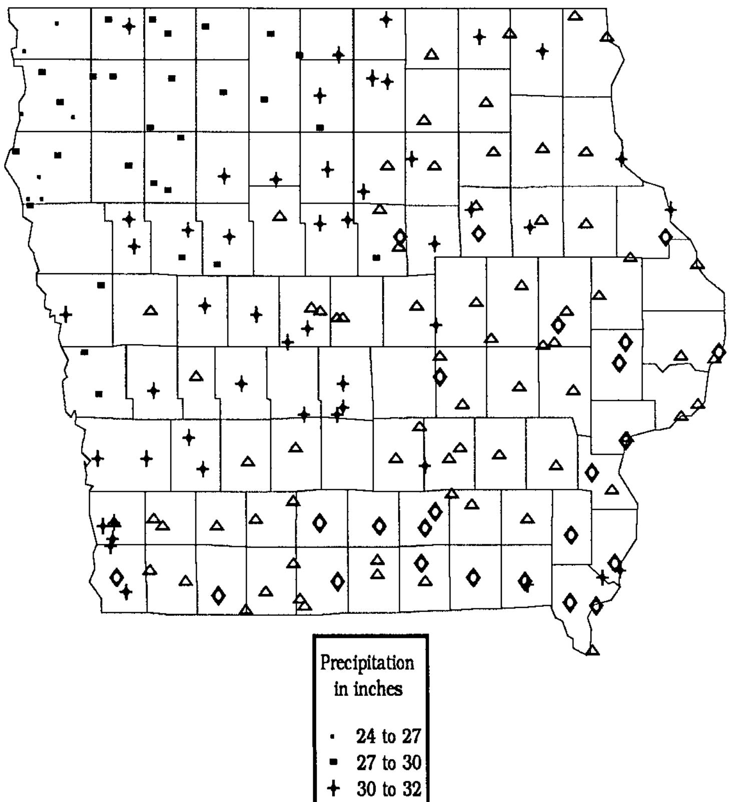


Areas covered by class I aquifers.
Each dot represents a population center.

Aquifer Sensitivity Map of Iowa



Population Density of Iowa
(Dot equals one person per square mile)



Average Annual Precipitation in Iowa

KANSAS

General Setting

Kansas contains approximately 82,000 square miles, and lies primarily in the high plains and mesas, rolling plains, and low hills of the Great Plains and Central Lowlands physiographic provinces. The Ozark Plateau province occupies the southeastern corner of the state. Kansas is underlain by Paleozoic age rocks that dip gently westward from the structurally higher Ozark Plateaus in Missouri, into the north-trending shallow structural basin beneath the Great Plains. Pennsylvanian and Permian age shale, limestone, and sandstone crop out in the southeastern part of the state and dip to the northwest. Pleistocene age glacial deposits mantle large areas of Pennsylvanian and Permian rocks in the northeast. Paleozoic rocks lie beneath Cretaceous age shale, sandstone, limestone, and chalk in central Kansas. Cretaceous strata are mantled, especially to the west, by the Tertiary age Ogallala Formation, as well as by younger fluvial and eolian sediments. Quaternary age alluvial deposits are present along major river valleys throughout the state. Several east-flowing tributaries of the Missouri River drain the northern half of Kansas. A network of east- to southeast-flowing rivers drains the southern half of the state.

Annual precipitation ranges from 15 inches in the west to 45 inches in the east. The spring and early summer months generally have the greatest precipitation. Evapotranspiration from lake surfaces ranges from 44 in/yr in the northeast to 68 in/yr in the southwest (Farnsworth and others, 1982). The majority of Kansas' population, approximately 2.5 million, is located in Johnson, Wabaunsee, and Sedgwick counties. The remainder of the state is sparsely populated. About 4800 million gallons of fresh ground water are used each day in Kansas.

Unconsolidated Aquifers (Class Ia)

Streamside alluvial deposits form some of the most productive and vulnerable aquifers in the state. These unconfined systems generally consist of unconsolidated clay, silt, sand, and gravel. Well yields commonly range from 10 to 500 gpm, and may exceed 1,000 gpm. Glacial outwash aquifers, consisting of unconsolidated clay, silt, sand, and gravel, occur within the northeast corner of the state, and may reach 500 feet in thickness. Well yields commonly range from 10 to 100 gpm, and may exceed 500 gpm. About 29 percent of the state is covered by Class Ia aquifers.

Semiconsolidated Aquifers (Class Ic)

The High Plains Aquifer, exposed throughout the western half of the state, consists of the Ogallala Formation, which is locally overlain by eolian and alluvial deposits. The Ogallala contains lenses of semiconsolidated, poorly- to moderately-sorted sand, gravel, and silt. Limestone, marl, and clay interbeds occur throughout the section, and, along with carbonate- and silica-cemented sandstone beds, produce locally confined conditions. The overlying eolian deposits consist of unconsolidated fine-grained sand and silt. The saturated thickness of the High Plains Aquifer commonly ranges from a few feet to 400 feet, and may exceed 600 feet in southwestern Kansas (Weeks and Gutentag, 1981). Well yields commonly range from 500 to 1,000 gpm, and may locally exceed 1,500 gpm. Surface exposures of semiconsolidated aquifers occupy about 24 percent of the state.

Higher Yield Bedrock Aquifers (Class IIa)

Higher yield bedrock aquifers, consisting primarily of sandstone of Cretaceous age, crop out in northern and north-central Kansas. Sandstone aquifers, which contain minor shale beds, are unconfined in the outcrop area. Well yields range from 10 to 100 gpm, and may exceed 1,000 gpm. Surface exposures of higher yield bedrock aquifers occupy about 4.4 percent of the state.

Lower Yield Bedrock Aquifers (Class IIb)

Class IIb aquifers, composed of limestone, sandstone, and minor shale beds of Pennsylvanian age, crop out in the eastern third of the state. Well yields commonly range from 10 to 40 gpm, and may exceed

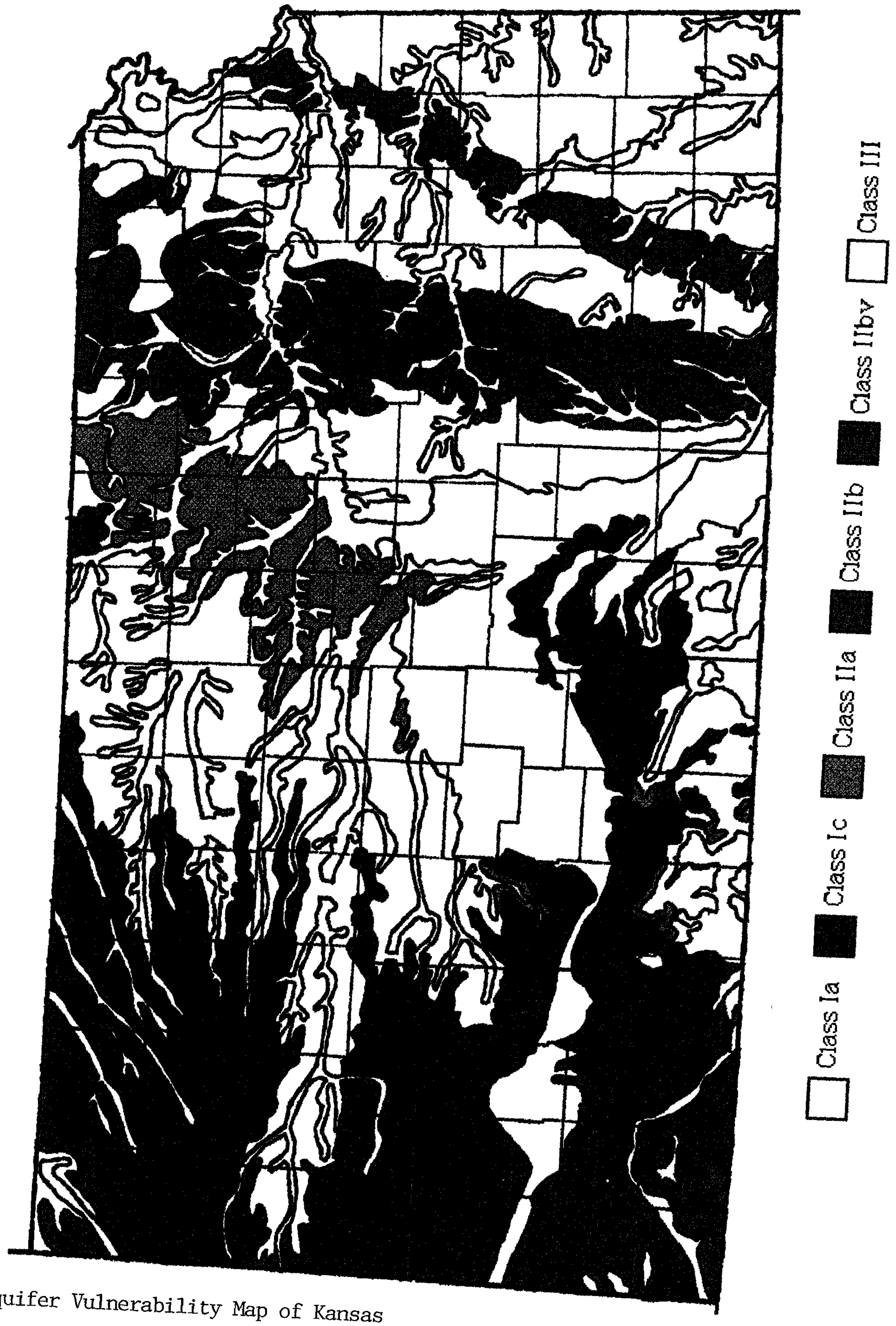
200 gpm. Surface exposures of lower yield bedrock aquifers occupy about 11 percent of the state.

Covered Bedrock Aquifers (Class IIb-v)

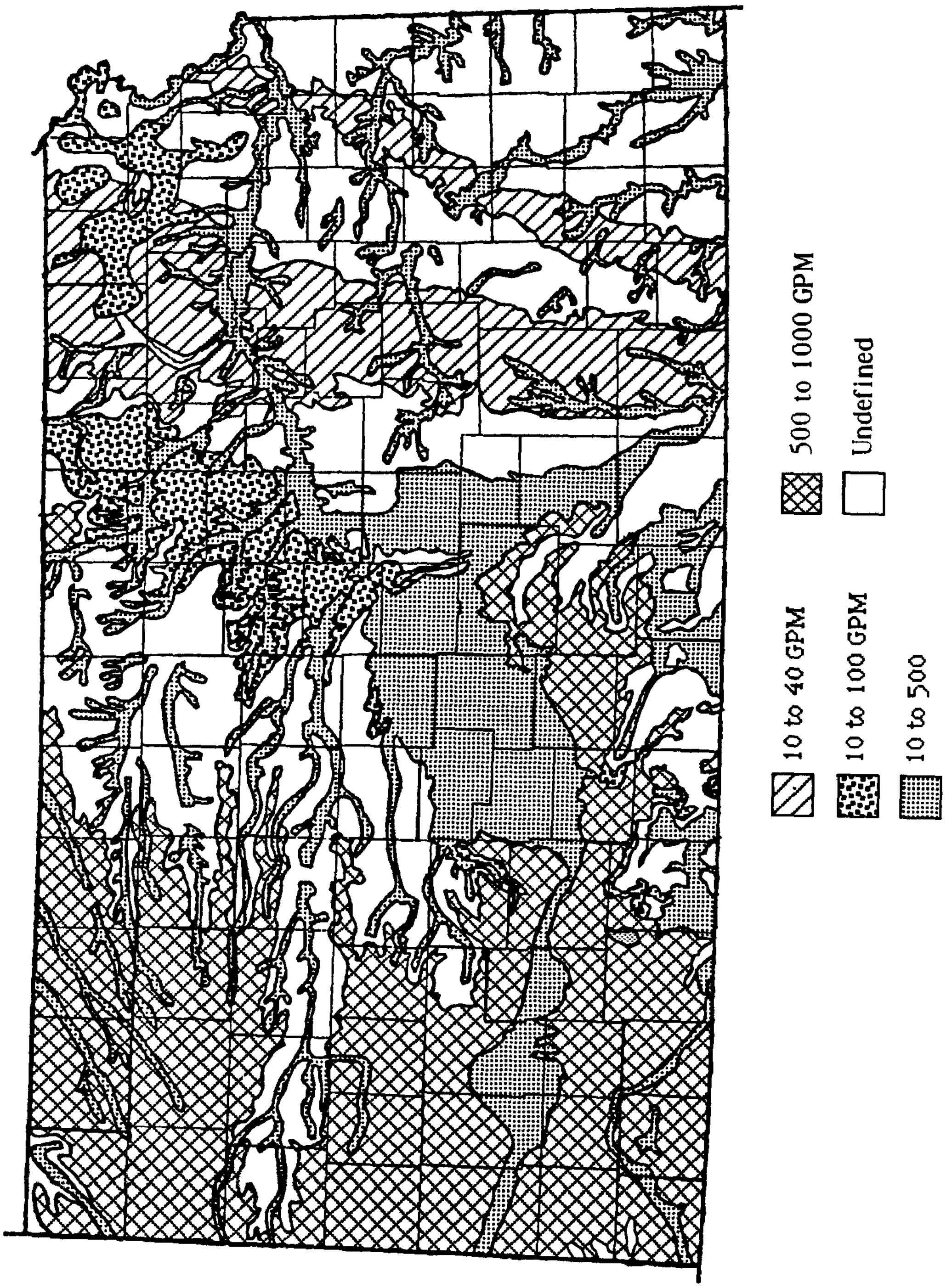
Lower yield limestone aquifers, overlain by an undetermined thickness of glacial till, occur in northeastern Kansas. The vulnerability of these systems is a function of the thickness of the overlying low permeability sediments. Only about 1 percent of the state is covered by Class IIb-v aquifers.

Sensitivity

About 53 percent of Kansas is covered by Class I aquifers, largely in the western half of the state. The potential for ground-water contamination from shallow injection wells is relatively small due to the state's low population density. Many of the population centers are located along major highways.

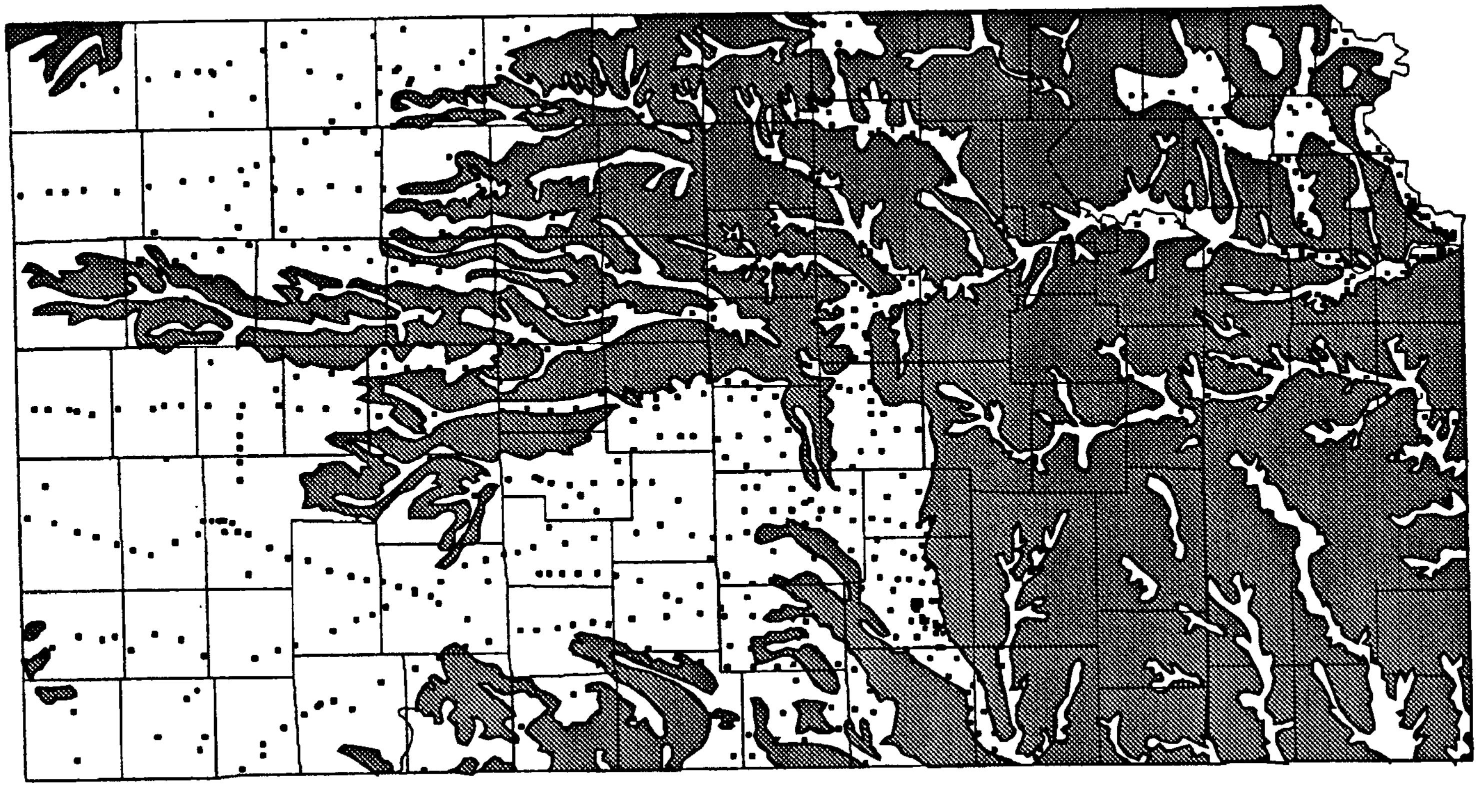


Aquifer Vulnerability Map of Kansas

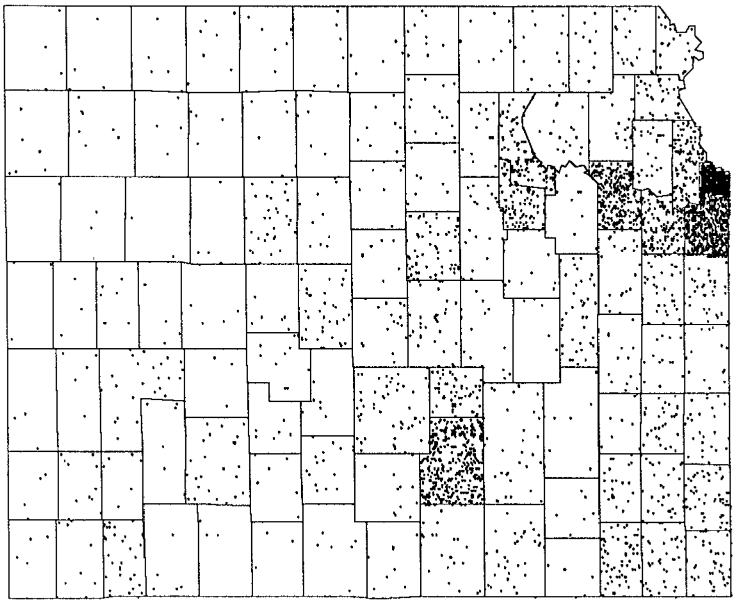


Potential Well Yields in Kansas

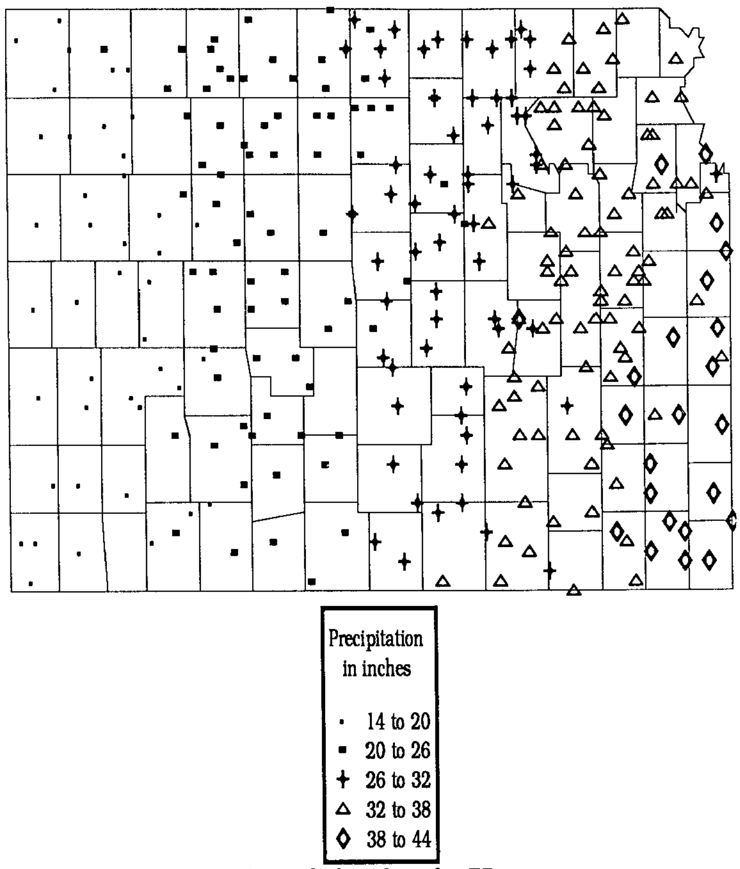
Aquifer Sensitivity Map of Kansas



Areas covered by class I aquifers.
Each dot represents a population center.



Population Density of Kansas
(Dot equals one person per square mile)



Average Annual Precipitation in Kansas

MISSOURI

General Setting

Missouri contains approximately 69,700 square miles. The far southeastern part of the state lies within the Coastal Plain physiographic province, while central and northern parts lie within the Ozark Plateaus and Central Lowland provinces, respectively. The topography varies from gently rolling to rugged, maturely dissected rolling uplands. The Ozark Uplift in the southeastern quarter of the state is the predominant structural feature in Missouri. At the center of the uplift, Precambrian age igneous rocks are exposed and the overlying Paleozoic rocks dip predominantly to the west and northwest. Glacial deposits are present in the northern third of the state and their southern limit roughly parallels the Missouri River. The glacial deposits, which overlie Ordovician to Pennsylvanian age sedimentary rock, range in thickness from 0 to 400 feet.

Missouri is drained principally by the Missouri and Osage river systems, which flow eastward to the Mississippi River. Annual average precipitation ranges from 36 inches in the north to 48 inches in the southeast. Missouri's population, approximately 5.1 million, is concentrated in the Kansas City and St. Louis metropolitan areas. The remainder of the state is lightly populated. About 640 million gallons of fresh ground water are used daily in Missouri.

Unconsolidated Aquifers (Class Ia)

Alluvial and terrace deposits occur along many rivers and tributaries throughout the state. Also included as Class Ia are local glaciofluvial deposits. In the northern part of Missouri these unconsolidated aquifers consist of sand and gravel with variable amounts of silt and clay. Well yields commonly range from 100 to 1,000 gpm, and they may exceed 2,500 gpm. Exposed in far southeastern Missouri are alluvial aquifers that form the Mississippi River flood plain. These unconsolidated deposits consist of Quaternary age sand, gravel, silt, and clay. Well yields commonly range from 1,000 to 2,000 gpm, and may exceed 4,000 gpm. About 18 percent of Missouri is covered by unconsolidated aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Exposed extensively in southern Missouri are Cambrian to Pennsylvanian age carbonate aquifers. These deposits consist of dolomite and limestone with lesser amounts of sandstone and shale. Solution activity has created karstic features, which enhance vertical and lateral permeability of the aquifer. Well yields commonly range from 15 to 700 gpm, and may exceed 1,000 gpm. Approximately 44 percent of the state is underlain by Class Ib aquifers.

Variably Covered Soluble and Fractured Bedrock Aquifers (Class Ib-v)

In eastern and central Missouri Ordovician to Pennsylvanian age carbonate aquifers are overlain by a variable thickness of glacial till. The underlying bedrock consists of limestone and dolomite with lesser amounts of sandstone and shale. Aquifer vulnerability is a function of the overlying low permeability sediments. Well yields commonly range from 15 to 700, and may exceed 1,000 gpm. About 6 percent of the state is occupied by Class Ib-v aquifers.

Semiconsolidated Aquifers (Class Ic)

A relatively small exposure of semiconsolidated sediments occurs in far southeastern Missouri. These Tertiary to Cretaceous age semiconsolidated deposits consist of interbedded sand and clay. Well yields commonly range from 100 to 1600 gpm, and may exceed 2,000 gpm. Only .5 percent of the state is occupied by Class Ic aquifers.

Higher Yield Bedrock Aquifers (Class IIa)

Small local exposures of higher yield bedrock aquifers, consisting of Cambrian age sandstone, occur in the eastern part of the state. Well yields commonly range from 5 to 100 gpm, and they may exceed 250 gpm. Only .7 percent of the state is occupied by higher yield bedrock aquifers.

Lower Yield Bedrock Aquifers (Class IIb)

Occurring in western and, locally, in eastern Missouri are Pennsylvanian age lower yield aquifers, which consist of shale and sandstone with lesser amounts of limestone and coal. Well yields commonly range from 1 to 15 gpm, and may exceed 25 gpm. About 8 percent of the state is covered by Class IIb aquifers.

Variable Covered Lower Yield Bedrock Aquifers (Class IIb-v)

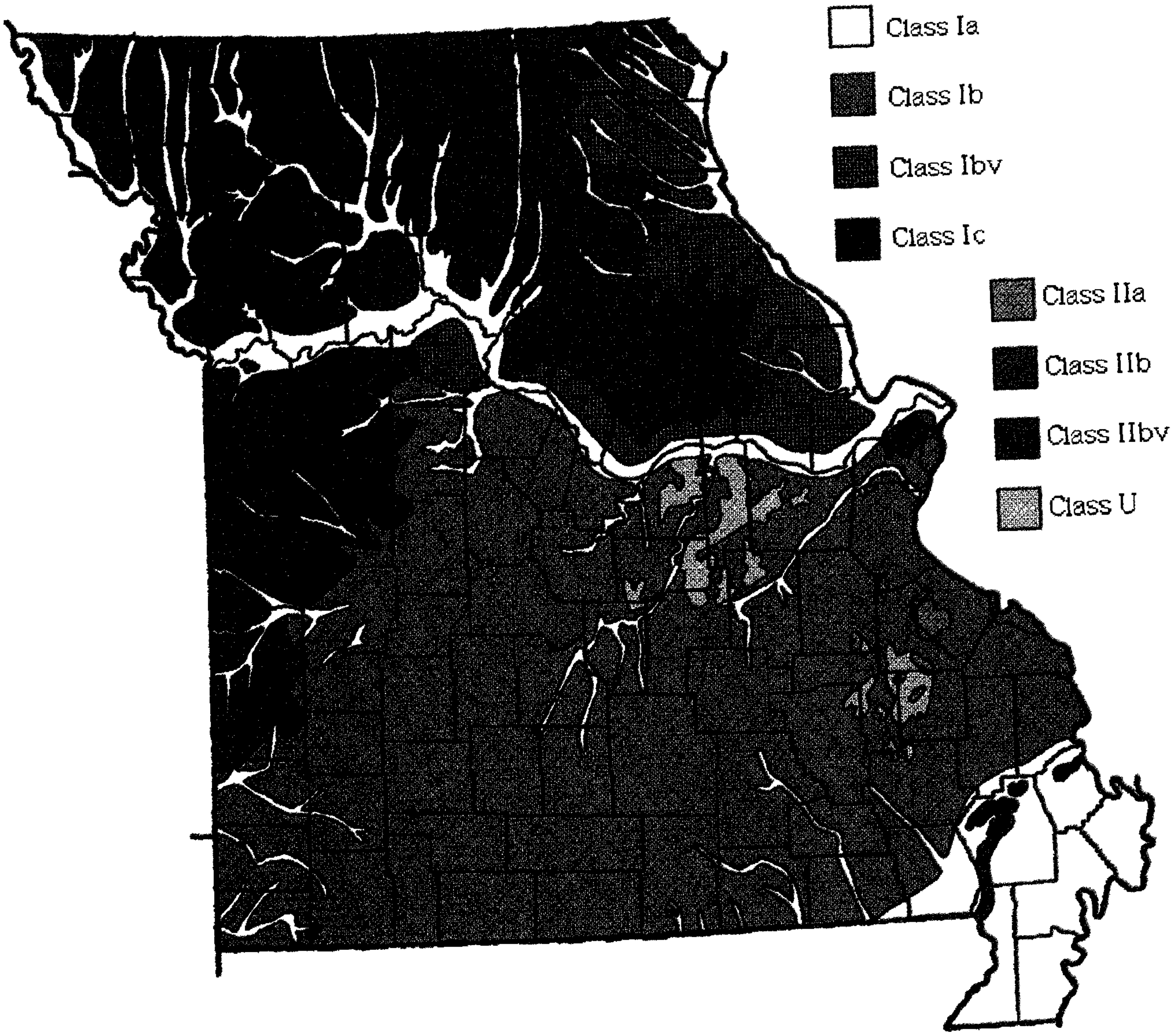
Throughout much of northern Missouri are variably covered lower yield aquifers. The Pennsylvanian age bedrock aquifer, which consists of shale and sandstone with lesser amounts of limestone and coal, is covered by till. The vulnerability of these aquifers is a function of thickness of the overlying glacial till. Well yields commonly range from 1 to 15 gpm, and may exceed 25 gpm. Nearly 21 percent of the state is occupied by Class IIb-v aquifers.

Undifferentiated Aquifers (Class U)

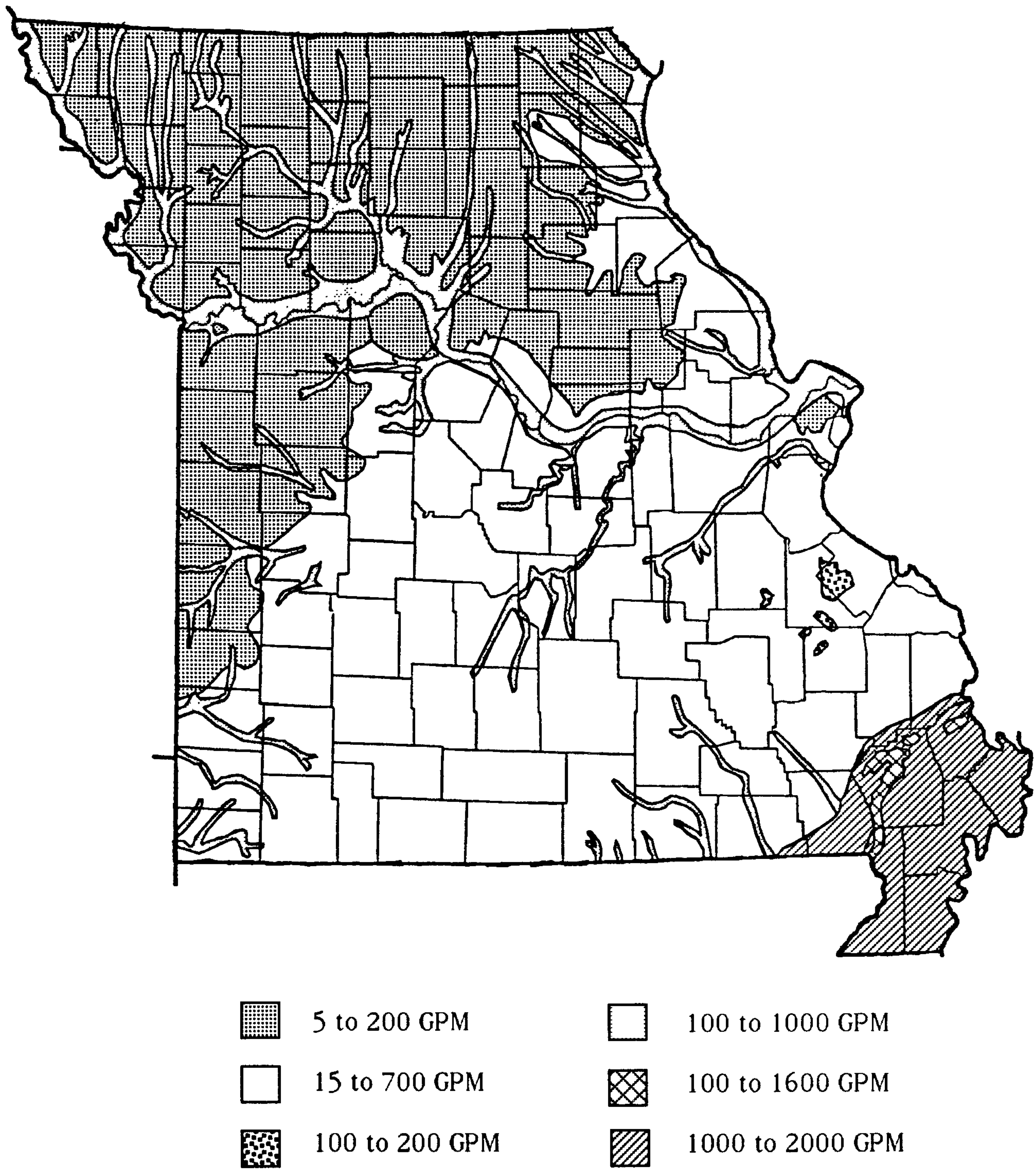
Exposed in east-central Missouri are undifferentiated Pennsylvanian age sedimentary rock. Precambrian age intrusive and extrusive crystalline bedrock occurs in the southwestern part of the state. About 2 percent of Missouri is occupied by undifferentiated aquifers.

Sensitivity

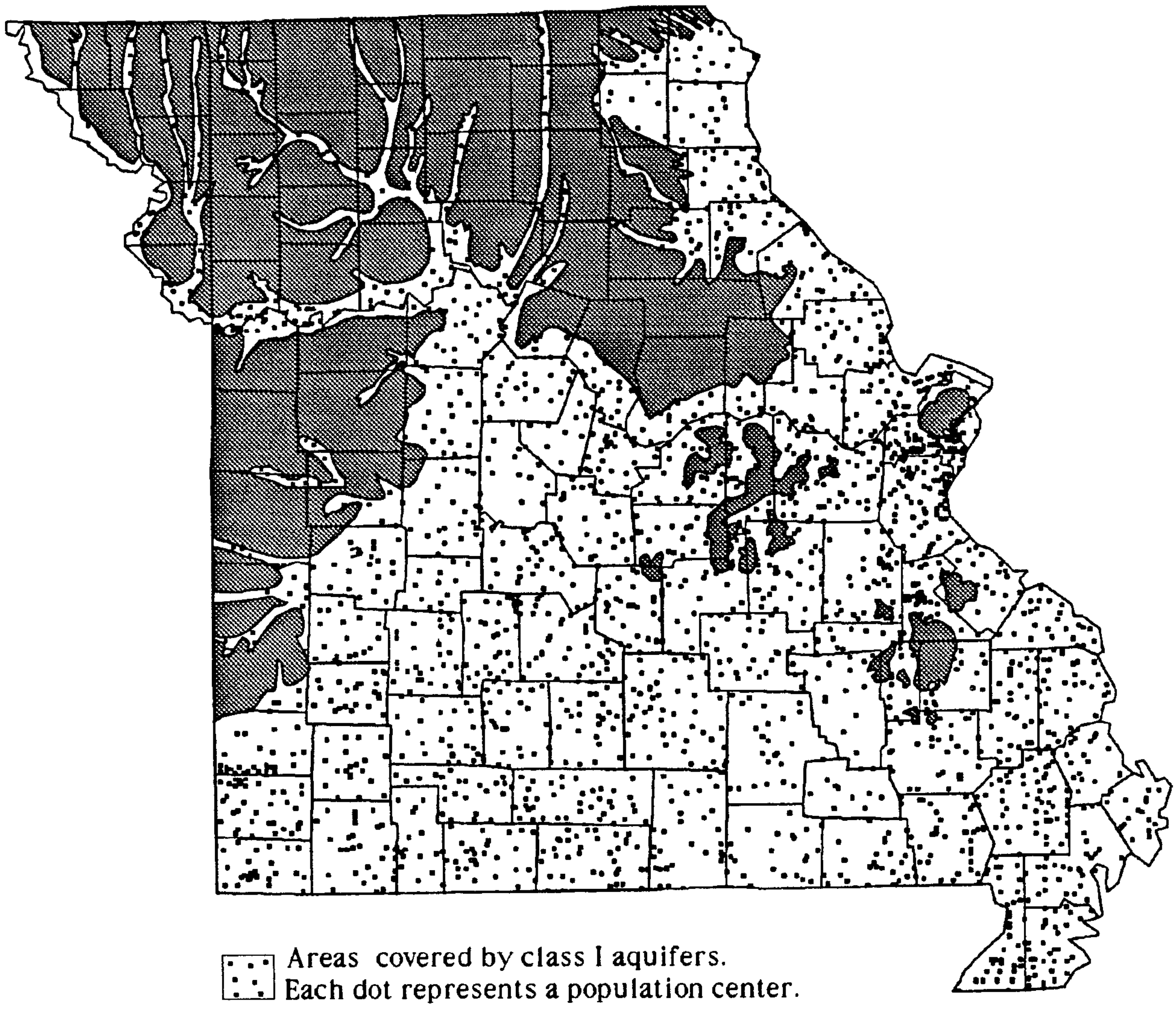
Approximately 68 percent of Missouri consists of vulnerable Class I aquifers. The potential for ground-water contamination from shallow injection wells is high owing to the permeable nature of the rocks in the karst areas. Population centers are rather evenly distributed throughout the state.



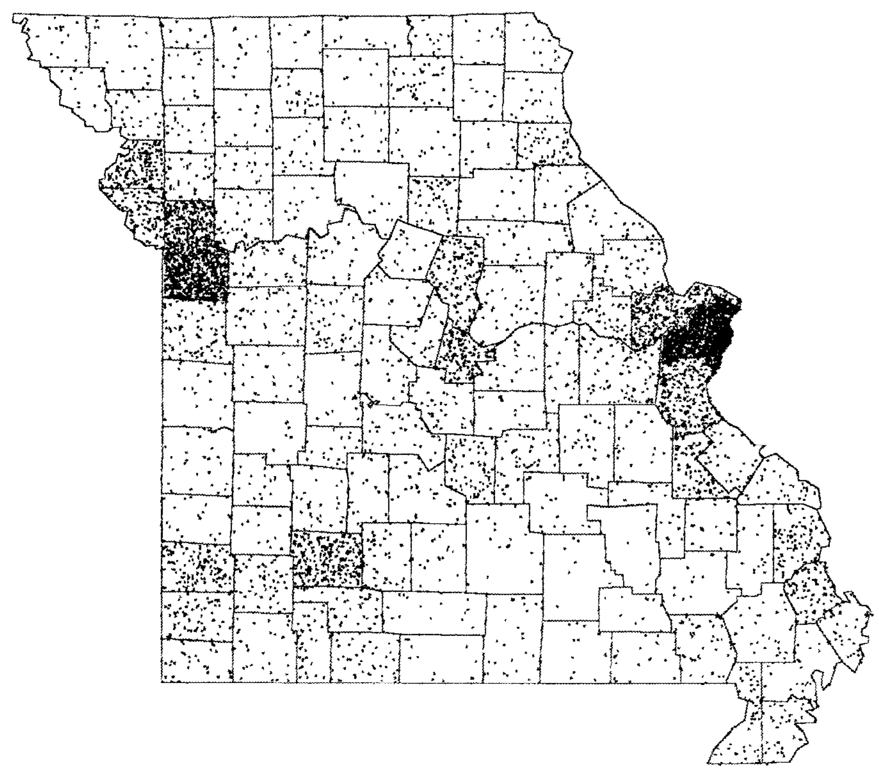
Aquifer Vulnerability Map of Missouri



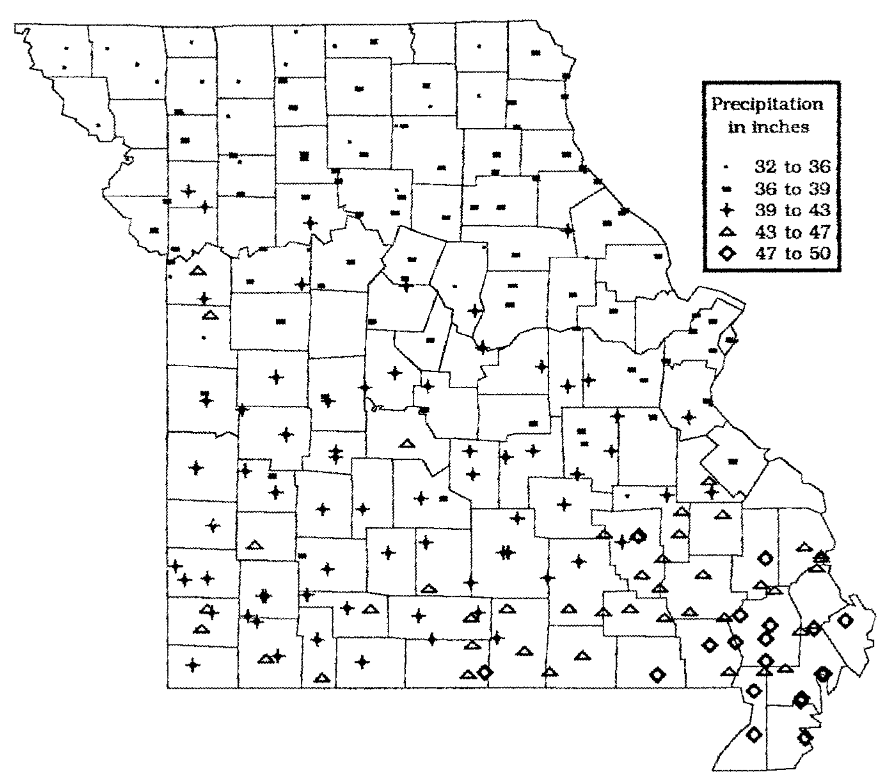
Potential Well Yields in Missouri



Aquifer Sensitivity Map of Missouri



Population Density of Missouri (Dot equals one person per square mile)



Average Annual Precipitation in Missouri

NEBRASKA

General Setting

Nebraska, which contains approximately 77,400 square miles, lies in the dissected plains and rolling hills of the Great Plains and Central Lowland physiographic provinces. Nebraska is underlain by Precambrian and Mesozoic age clastic and carbonate sedimentary rocks that crop out in the eastern part of the state, and dip gently westward into shallow structural basins beneath the Great Plains. These bedrock units are mantled by semiconsolidated, Tertiary age clastic sediments throughout central and western Nebraska, and locally by Quaternary age deposits in eastern Nebraska. Unconsolidated alluvial, eolian, lacustrian, and glacial deposits occur along recent stream and in preglacial bedrock valleys, as well as in other areas throughout the state. Although variable, the thickness of glacial deposits may exceed 400 feet in places (Burchett and others, 1972; Burchett and others, 1975; Dreeszen and others, 1973).

The Missouri River and its many southeastward flowing tributaries drain the entire state. Annual precipitation ranges from less than 16 inches in the west to more than 32 inches in the southeast. The majority of Nebraska's population, approximately 1.6 million, is located in and around metropolitan Omaha and Lincoln. The remainder of the state is sparsely populated. About 5590 million gallons of fresh ground water are used daily in Nebraska.

Unconsolidated Aquifers (Class Ia)

Alluvium and glacial outwash, which occurs along major streams and within paleovalleys throughout the state, forms both vulnerable and productive aquifers. These generally unconfined systems consist of unconsolidated deposits of sand, gravel, silt, and clay that are commonly tens of feet thick. Well yields commonly range from 300 to 1,000 gpm, and locally may exceed 1,500 gpm. About 21 percent of the state is covered by Class Ia aquifers.

Variably Covered Soluble and Fractured Bedrock Aquifers (Class Ib-v)

Karst features are present in fractured, Upper Cretaceous chalk and silty marlstone in eastern Nebraska. These rocks are overlain by a variable thickness of glacial till. The vulnerability of these systems is a function of the thickness of the overlying till, and the occurrence of solutional features and fractures. Well yields commonly range from 300 to 750 gpm, and may exceed 1,000 gpm. Slightly more than 5 percent of the state is underlain by Class Ib-v aquifers.

Semiconsolidated Aquifers (Class Ic)

Exposures of semiconsolidated sediments occur throughout central and western Nebraska, and consist of Tertiary age, poorly- to well-indurated, tuffaceous sand, silt, gravel, and intercalated beds of clay and marl. In many places hydraulically connected Quaternary age glacial and eolian deposits overlie the semiconsolidated sediments and are included in the system. Saturated thicknesses locally exceed 1,000 feet, and well yields commonly range from 500 to 1,000 gpm, and may exceed 2,500 gpm. Surface exposures of semiconsolidated aquifers occupy about 57 percent of the state.

Variably Covered Higher Yield Bedrock Aquifers (Class IIa-v)

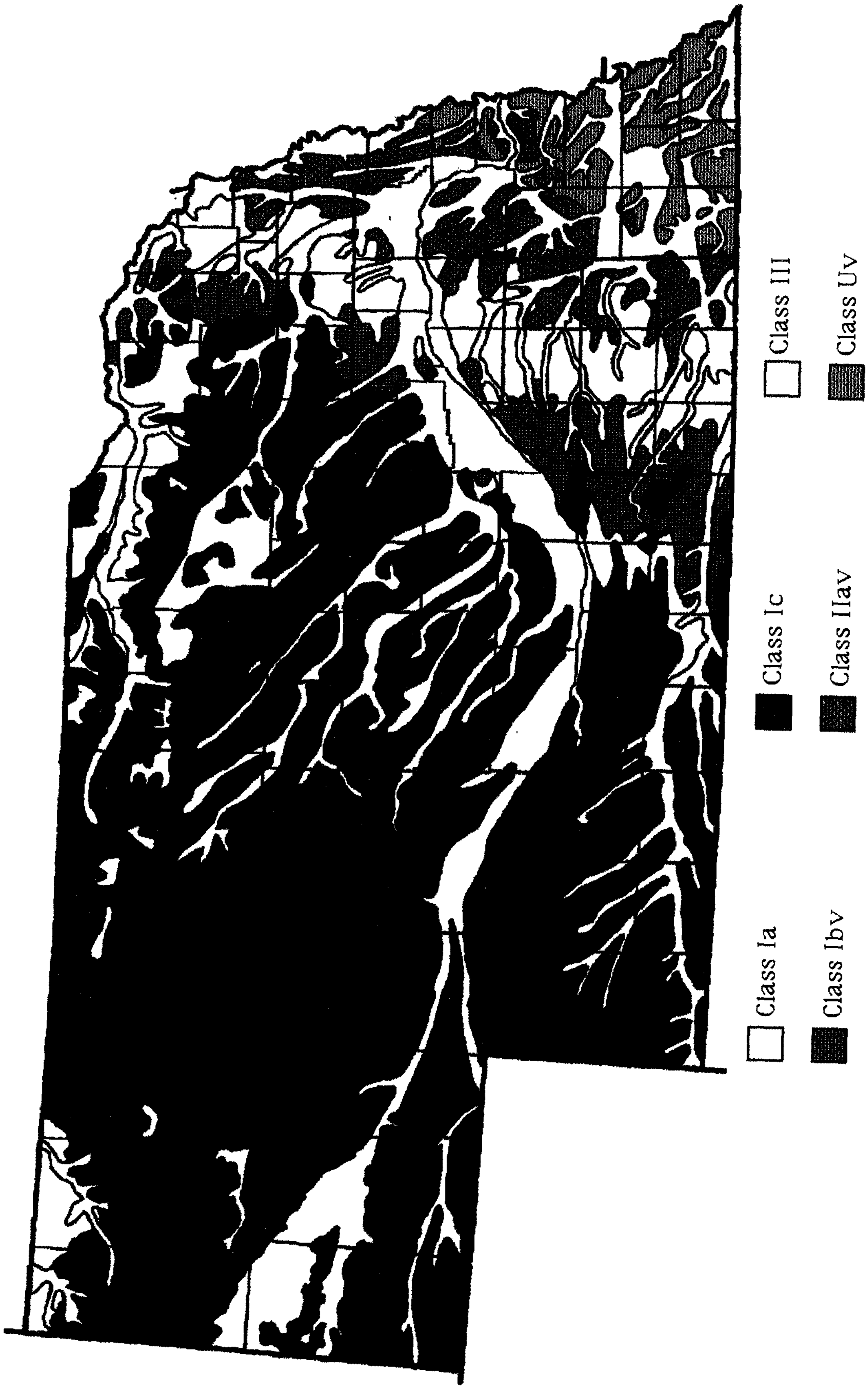
Higher yield bedrock aquifers, composed of Lower Cretaceous sandstone and interbedded clay, occur in eastern Nebraska. These rocks are overlain by a variable thickness of low permeability glacial till. The vulnerability of these systems is a function of the thickness and permeability of the overlying sediments. Well yields commonly range from 300 to 750 gpm, and may exceed 1,000 gpm. About 5 percent of the state is underlain by Class IIa-v aquifers.

Variably Covered Undifferentiated Aquifers (Class U-v)

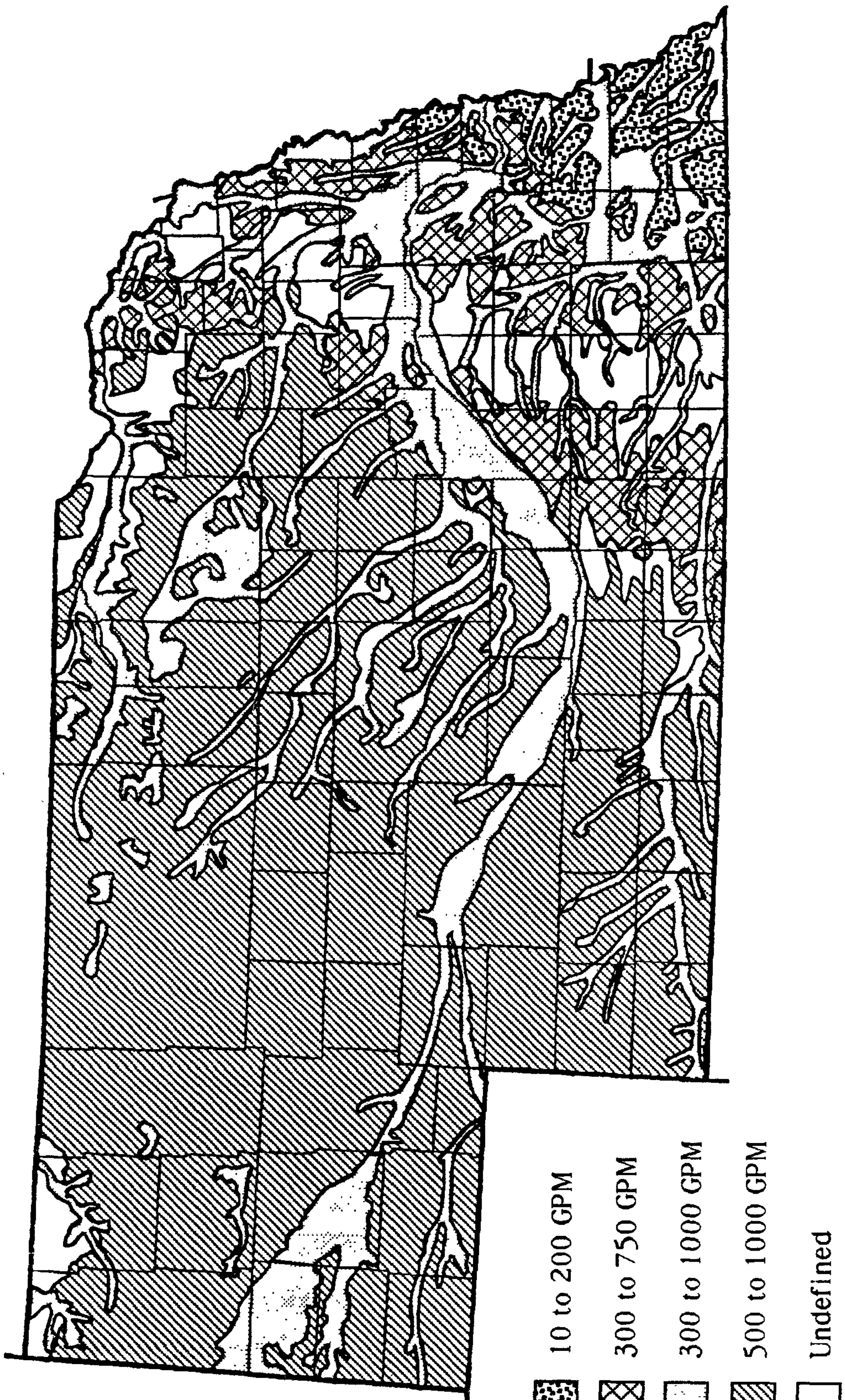
Undivided and lithologically varied Paleozoic age formations occur in southeastern Nebraska, and consist of interbedded shale, limestone, dolomite, sandstone, and evaporite and coal beds. These strata are overlain by a variable thickness of glacial till. The vulnerability of these systems is a function of the thickness and permeability of the overlying sediments. In addition, the lithologic and resultant hydrologic variability of the undivided bedrock formations have not been delineated. A wide range in aquifer permeability and vulnerability should be expected in these areas. About 3.6 percent of the state is underlain by Class U-v aquifers.

Sensitivity

About 83 percent of Nebraska is covered by vulnerable Class I aquifers. The potential for ground-water contamination from shallow injection wells is quite low because of the light population density. Most of the population centers are small and lie along major highways. Consequently, vast expanses are unlikely to be affected.

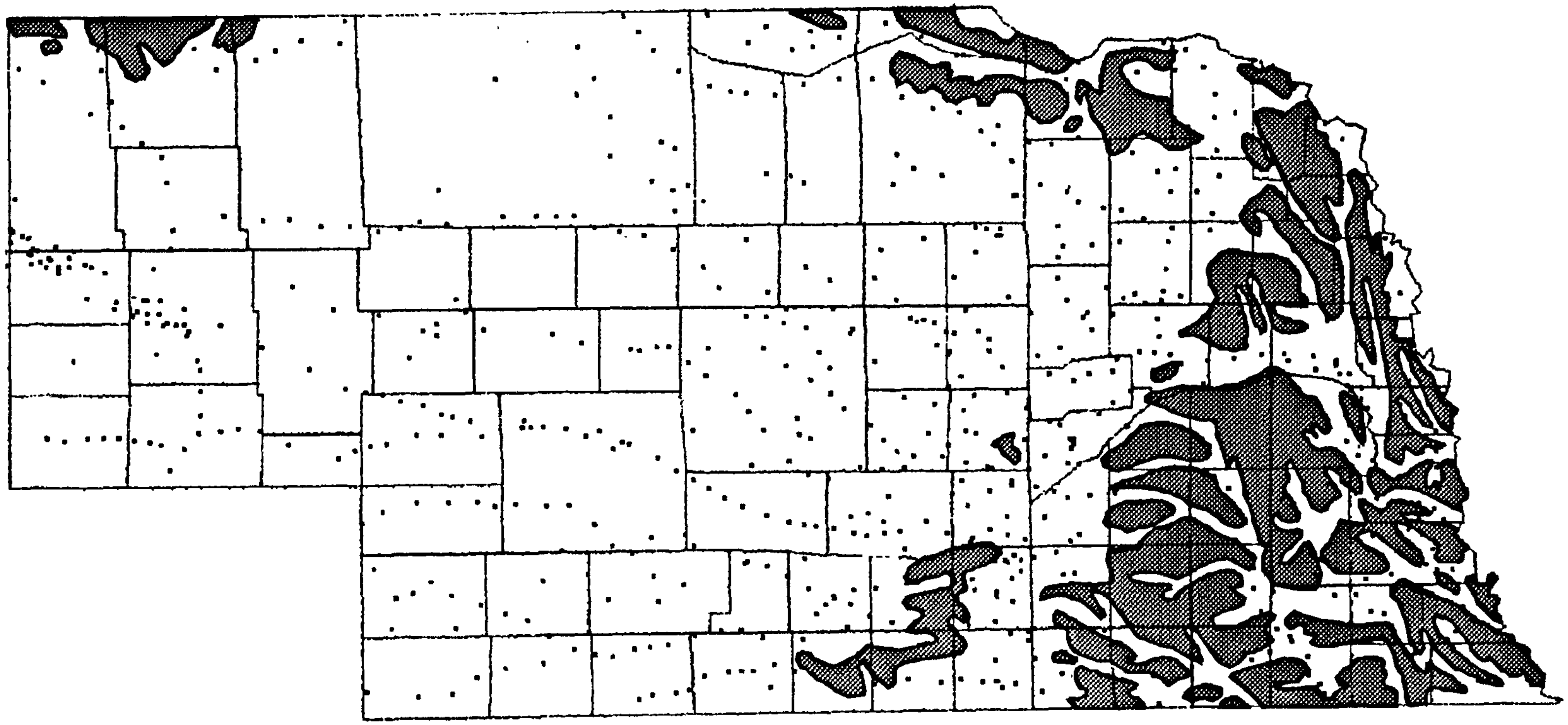


Aquifer Vulnerability Map of Nebraska

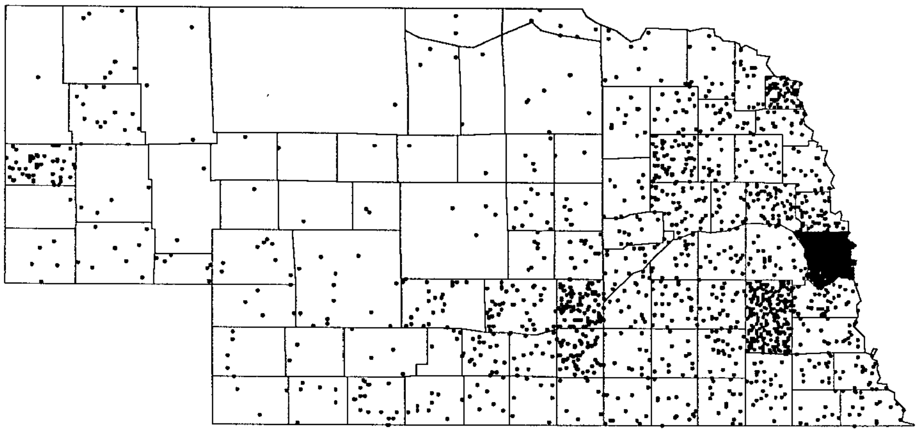


Potential Well Yields In Nebraska

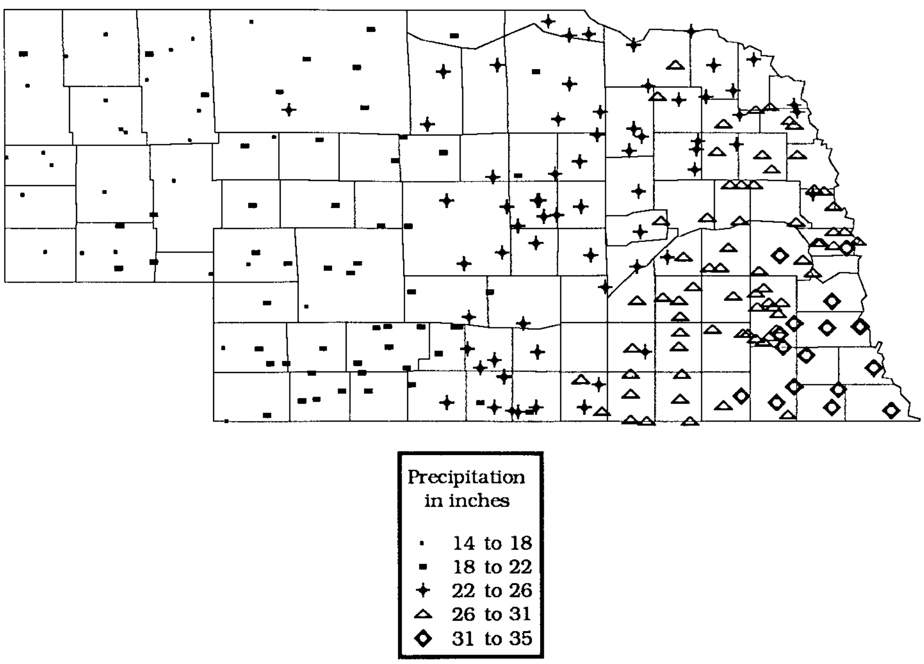
Aquifer Sensitivity Map of Nebraska



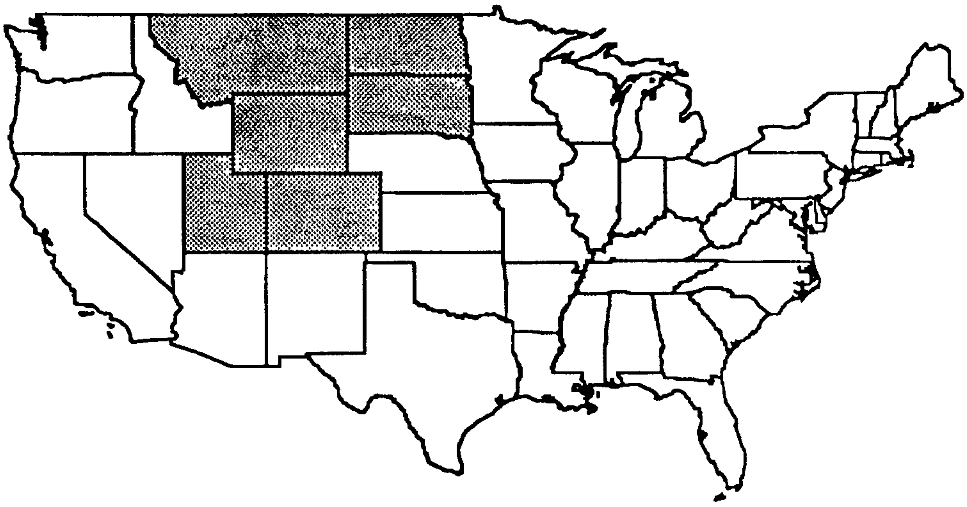
Areas covered by class I aquifers.
Each dot represents a population center.



Population Density of Nebraska (Dot equals one person per square mile)



Average Annual Precipitation in Nebraska



REGION 8

Colorado
Montana
North Dakota
South Dakota
Utah
Wyoming

COLORADO

General Setting

Colorado contains approximately 104,100 square miles, and lies in the high plains, mountains, valleys, and dissected plateaus of the Great Plains, Southern and Middle Rocky Mountains, Wyoming Basin, and Colorado Plateaus provinces. The mountains of central and northern Colorado consist largely of faulted Precambrian age metamorphic and igneous rocks, flanked by steeply dipping Paleozoic and Mesozoic age clastic and carbonate sedimentary units. The mountains of southern and west-central Colorado are composed of Tertiary age volcanic and granitic rocks, as well as Paleozoic and Mesozoic age clastic and carbonate sediments. The plateaus and plains of western and eastern Colorado are underlain by relatively flat lying, consolidated to semiconsolidated, Mesozoic and Cenozoic age clastic rocks. Unconsolidated alluvial, eolian, and glacial deposits occur throughout the state. The eastern half of Colorado is drained by the east-flowing South Platte and Arkansas rivers, and their many tributaries. The western half of the state is drained by the Colorado River and several other smaller systems.

Annual precipitation ranges from less than 8 inches in south-central and western Colorado to about 40 inches in the Rocky Mountains. Extreme variations in monthly precipitation are the result of regional climatic variations and orographic effects. The majority of Colorado's population, approximately 3.3 million, is located along the eastern front of the Rocky Mountains. The remainder of the state is sparsely populated. About 2310 and 32 million gallons of fresh and saline ground water, respectively, are used each day in Colorado.

Unconsolidated Aquifers (Class Ia)

Alluvial, lacustrine, and glacial deposits occur in river valleys and basins throughout the state, and form vulnerable and productive aquifers. These generally unconfined systems consist of unconsolidated Late Tertiary and Quaternary age gravel, sand, silt, and clay. Glacial material includes cobbles and boulders. Volcanic rock interbeds occur within basin-fill deposits in southern Colorado. Well yields in river valley deposits commonly range from 100 to 1,500 gpm, and may exceed 3,000 gpm. Well yields in basin-fill deposits of the San Luis Valley in southern Colorado commonly range from 500 to 1,200 gpm, and may exceed 2,000 gpm. Nearly 10 percent of the state is covered by Class Ia aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Limited exposures of solutional features are present in fractured Devonian and Mississippian age limestone and dolomite in the west-central Rocky Mountains. Sandstone and chert interbeds occur within these units. Where present, solutional features and fractures contribute to the vertical and lateral permeability of the rock. Well yields in this largely undeveloped aquifer may exceed 500 gpm. Class Ib aquifers occupy about .2 percent of the state.

Semiconsolidated Aquifers (Class Ic)

Exposures of semiconsolidated sediments occur throughout eastern Colorado, and as isolated units in central and western parts of the state. These generally unconfined systems consist of poorly- to moderately- consolidated Tertiary and Quaternary age gravel, sand, silt, and clay with thin beds of caliche and limestone. Calcite is a common cementing agent. In northeastern Colorado, the semiconsolidated High Plains Aquifer reaches a thickness of 400 feet (Pearl, 1974). Semiconsolidated sediments locally are overlain by eolian and alluvial deposits. Well yields in the High Plains Aquifer commonly range from 350 to 2,000 gpm, and may exceed 2,500 gpm. Surface exposures of semiconsolidated aquifers occupy about 16 percent of the state.

Higher Yield Bedrock Aquifers (Class IIa)

Higher yield bedrock aquifers crop out in northern and southern parts of western Colorado and in the east-central part of the state. These systems consist of Cretaceous and Tertiary age sandstone and conglomerate with interbedded shale, siltstone, coal, and fractured dolomitic marlstone. Well yields in northwestern and east-central Colorado commonly range from 5 to 500 gpm, and may exceed 2,000 gpm; well yields in the southwest generally range from 5 to 1,000 gpm, and may exceed 1,500 gpm. Surface exposures of higher yield bedrock aquifers occupy nearly 6 percent of the state.

Lower Yield Bedrock Aquifers (Class IIb)

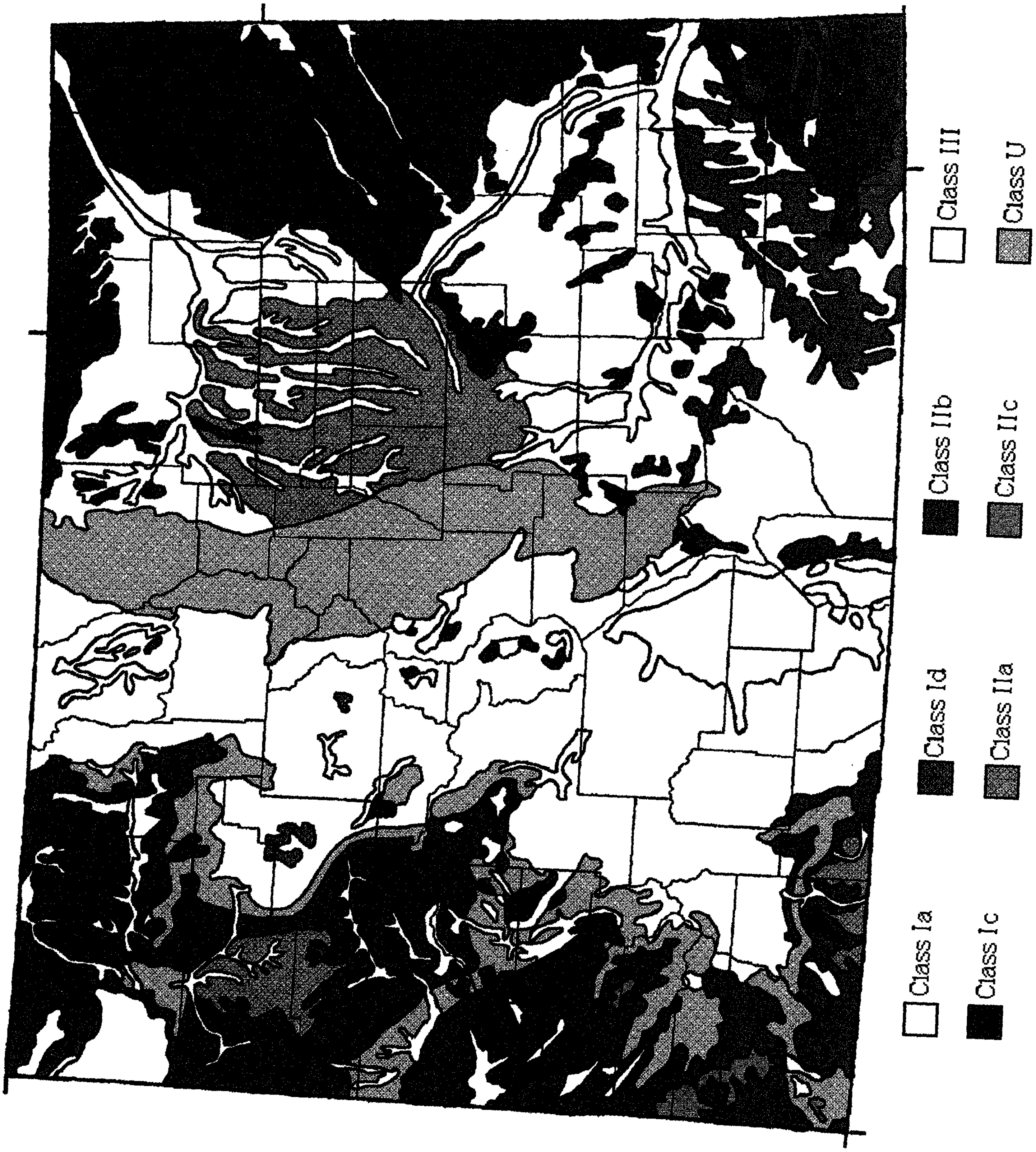
Lower yield bedrock aquifers, which crop out throughout western and parts of southeastern Colorado, consist of Mesozoic and Early Tertiary age sandstone with interbedded shale, siltstone, and conglomerate. Well yields in western Colorado commonly range from 1 to 25 gpm, and may exceed 500 gpm; moderate well yields are reported for similar units in southeastern Colorado (McGuinness, 1963). Surface exposures of Class IIb aquifers occupy about 19 percent of the state.

Undifferentiated Aquifers (Class U)

Precambrian age igneous and metamorphic rocks are exposed throughout the Rocky Mountains, and function as aquifers only in areas where faulting and jointing have produced fractures. An incomplete understanding of the distribution and hydrologic behavior of fractures results in a wide range in aquifer productivity and vulnerability. Well yields from crystalline aquifers along the Front Range commonly range from 0.5 to 5 gpm, and may exceed 15 gpm. Similar hydrologic conditions within other crystalline rocks may exist outside those areas documented. Undivided and lithologically varied Cretaceous age rocks, which crop out throughout western Colorado, consist of interbedded shale, sandstone, and limestone. The lithologic and resultant hydrologic variability of these undivided units has not been delineated. Well yields in locally weathered or fractured producing zones commonly range from 1 to 10 gpm, and may exceed 25 gpm. Surface exposures of undifferentiated aquifers occupy about 12 percent of the state.

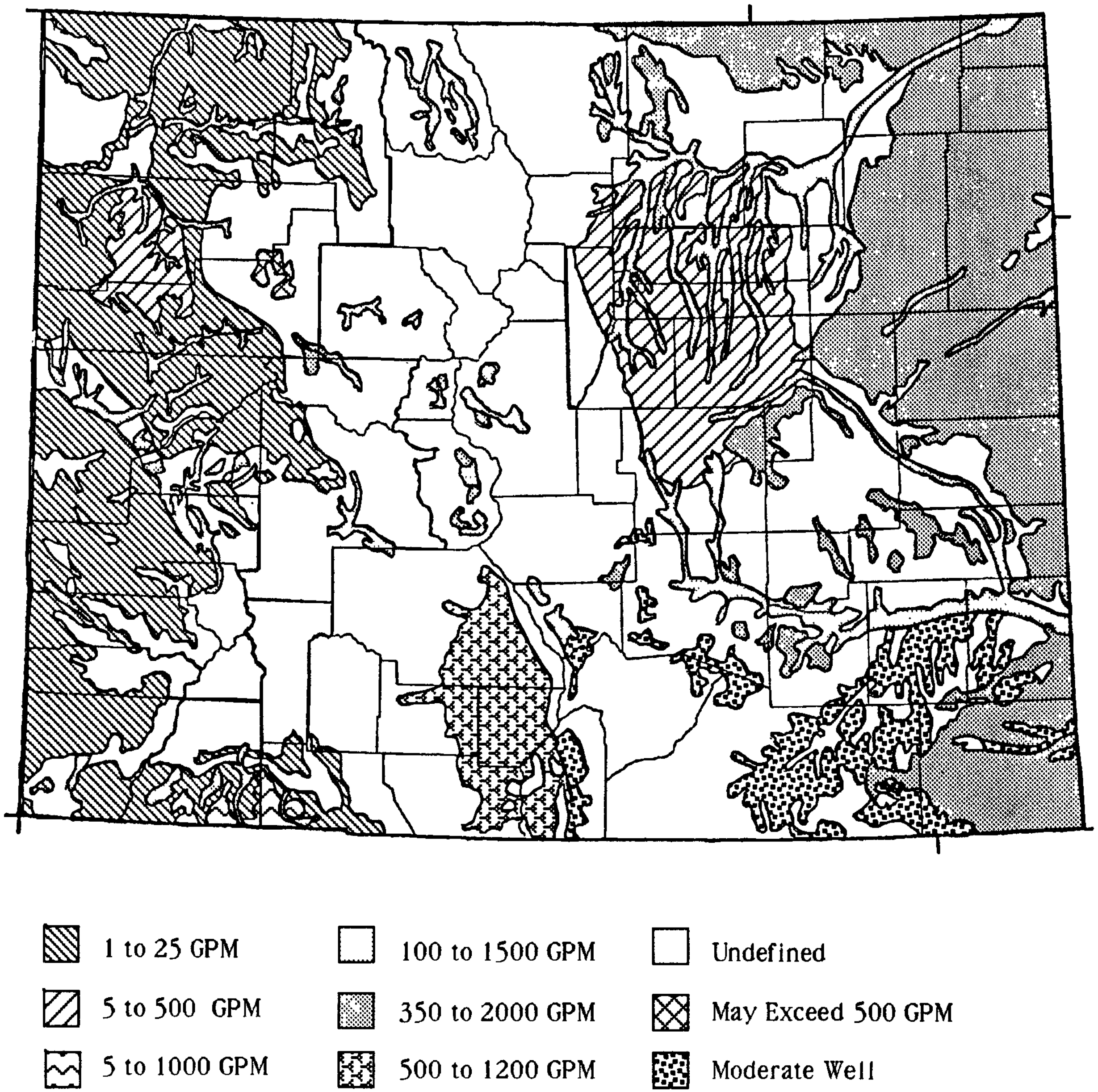
Sensitivity

Nearly 26 percent of Colorado consists of Class I aquifers. Aquifer sensitivity in most places in Colorado is quite low owing to the low population density. The greatest number of population centers occurs along major highways in the eastern quarter of the state. Several of the highways follow major water courses, such as along the South Platte and Arkansas rivers.

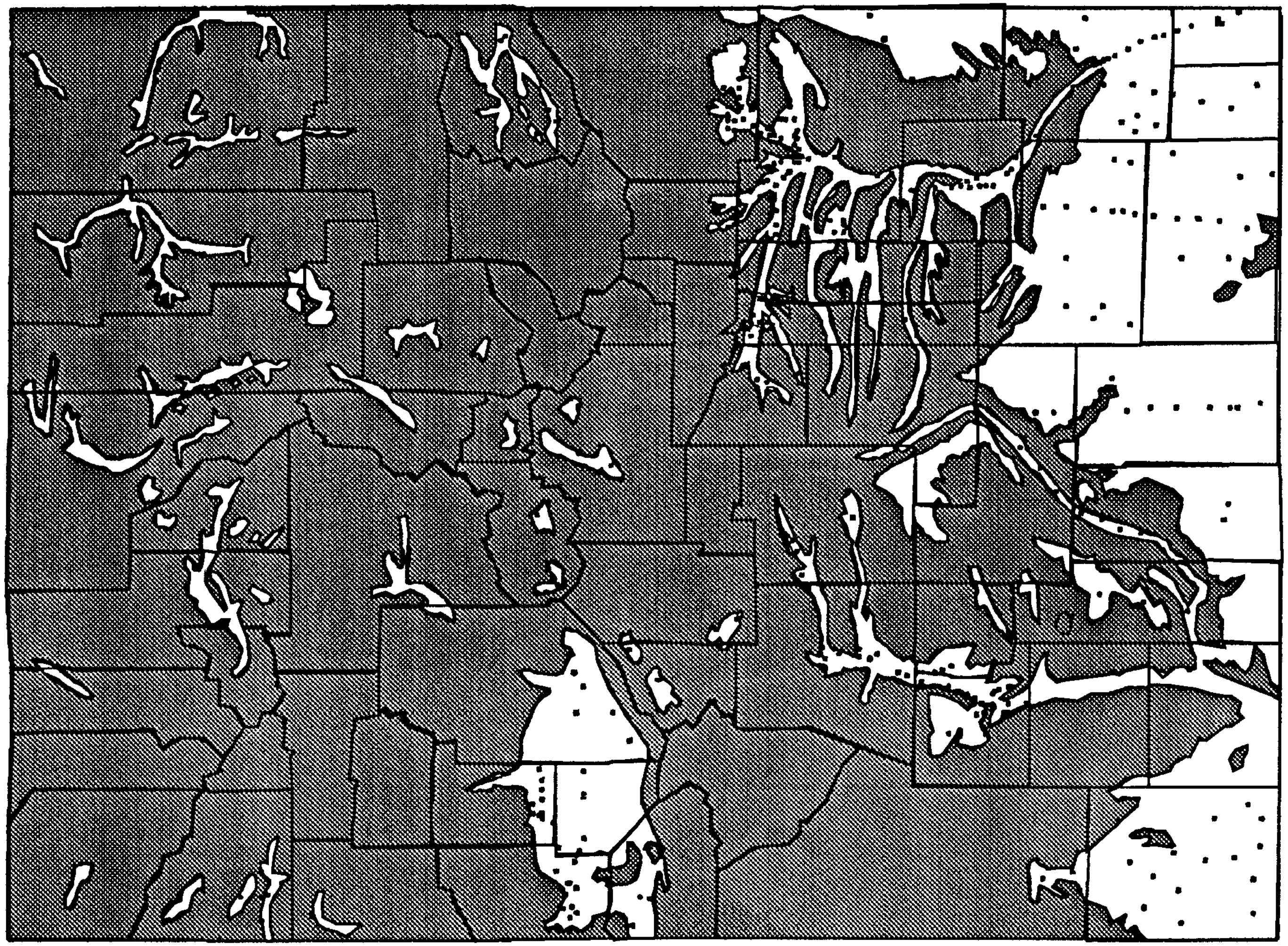


Aquifer Vulnerability Map of Colorado

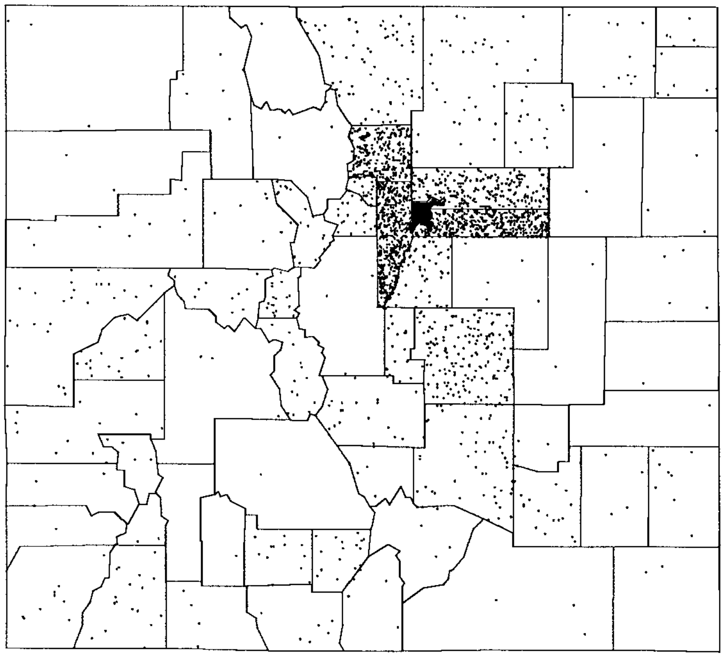
Potential Well Yields In Colorado



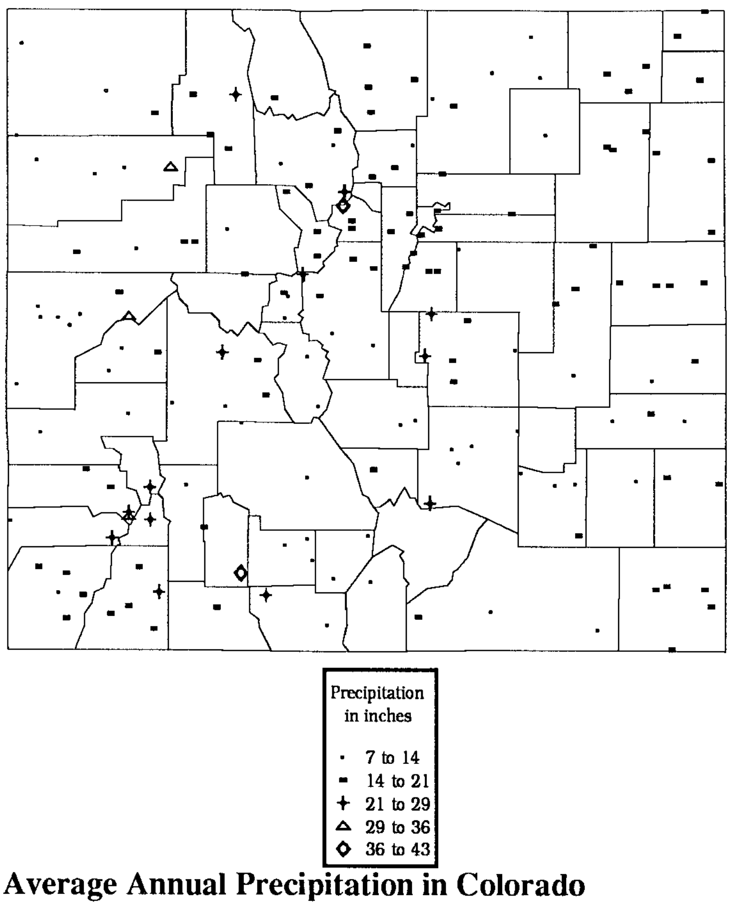
Aquifer Sensitivity Map of Colorado



Areas covered by class I aquifers.
Each dot represents a population center.



Population Density of Colorado (Dot equals one person per square mile)



Average Annual Precipitation in Colorado

MONTANA

General Setting

Montana contains approximately 147,000 square miles, and lies in the mountains, valleys, and dissected plains of the Northern and Middle Rocky Mountain and the Great Plains physiographic provinces. The mountains of western and southwestern Montana are underlain by folded and faulted Precambrian to Paleozoic age metamorphic and sedimentary rocks that, locally, are intruded by Precambrian, Cretaceous, and Tertiary age basic and acidic bodies. The remainder of the state is underlain by gently dipping Paleozoic to Tertiary age marine and nonmarine sediments, locally intruded by minor Tertiary age granitic bodies. Alluvial and glacial deposits occur along rivers and within intermontane valleys.

Except for northwestern Montana, the entire state is drained by the east-flowing Missouri and Yellowstone rivers. Kootenai and Clark Fork rivers drain northwestern Montana. Annual precipitation ranges from 8 to 120 inches in the west, and from 12 to 30 inches in the eastern plains. The majority of Montana's precipitation is received from April to September. The majority of Montana's population, approximately 805,000, is located in Cascade, Silver Bow, Missoula, and Yellowstone counties. The remainder of the state is sparsely populated. Daily use of fresh ground water amounts to about 203 million gallons.

Unconsolidated Aquifers (Class Ia)

Alluvial and glacial-outwash deposits occur throughout the state, and form vulnerable and productive aquifers. These generally unconfined systems consist of Late Tertiary and Quaternary age unconsolidated sand, gravel, silt, and clay. Outwash deposits generally include cobbles and boulders. Well yields commonly range from 5 to 50 gpm, and may exceed 3,500 gpm. About 16.4 percent of the state is covered by Class Ia aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Solutional features are present in Paleozoic age limestone units exposed in west-central and southwestern Montana. Dolomite, anhydrite, and halite interbeds occur within this system. Where present, solutional features contribute to the vertical and lateral permeability of the rock, creating highly productive and vulnerable aquifers. Well yields may exceed 1,000 gpm. Class Ib aquifers occupy about 5.2 percent of the state.

Semiconsolidated Aquifers (Class Ic)

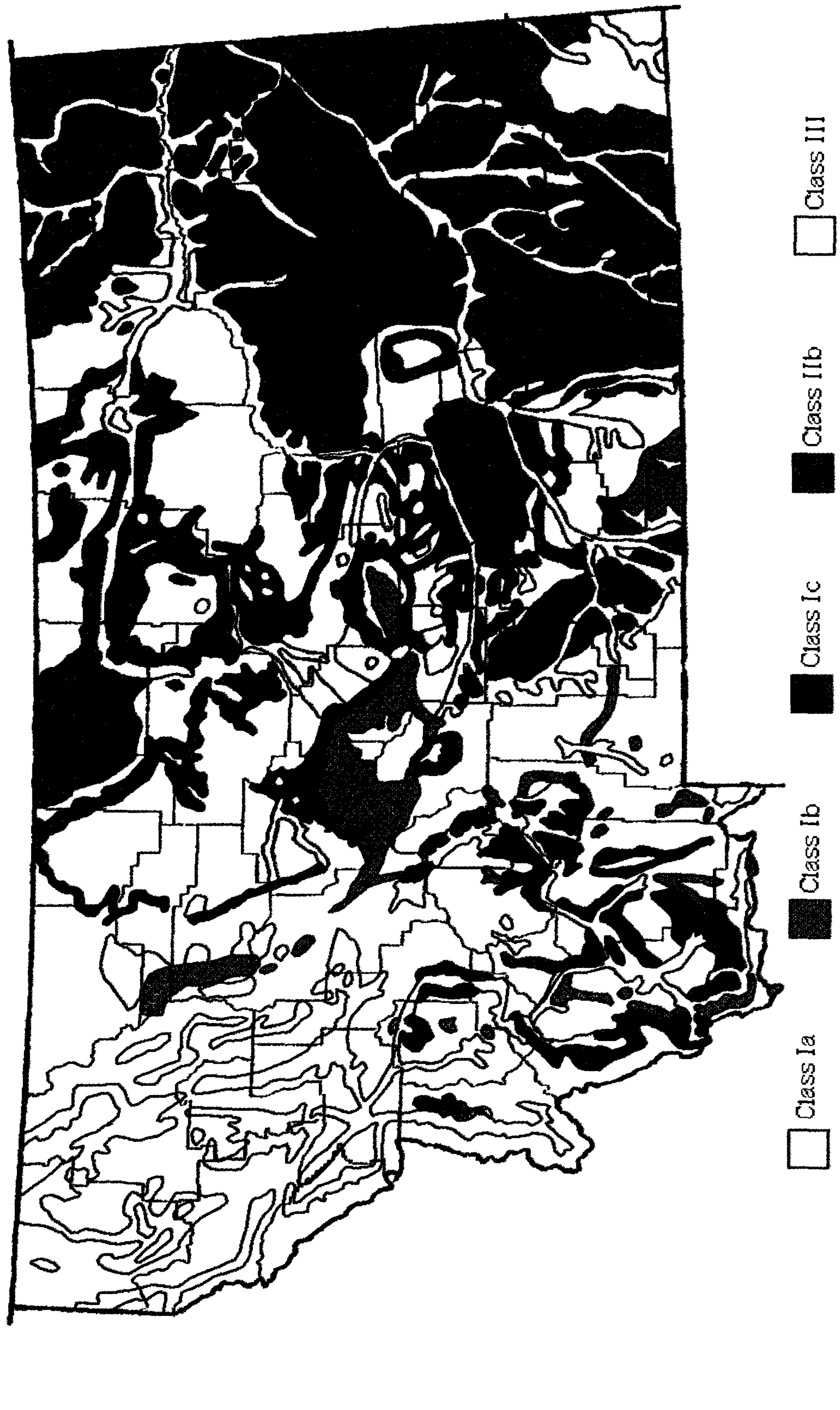
Exposures of semiconsolidated sediments occur throughout northeastern and southwestern Montana, and consist of poorly to moderately consolidated, interbedded, Tertiary age gravel, sand, silt, clay, tuffaceous material, and lenses of lignite. Well yields range from 15 to 25 gpm, and may exceed 100 gpm. Surface exposures of semiconsolidated aquifers occupy about 5.7 percent of the state.

Lower Yield Bedrock Aquifers (Class IIb)

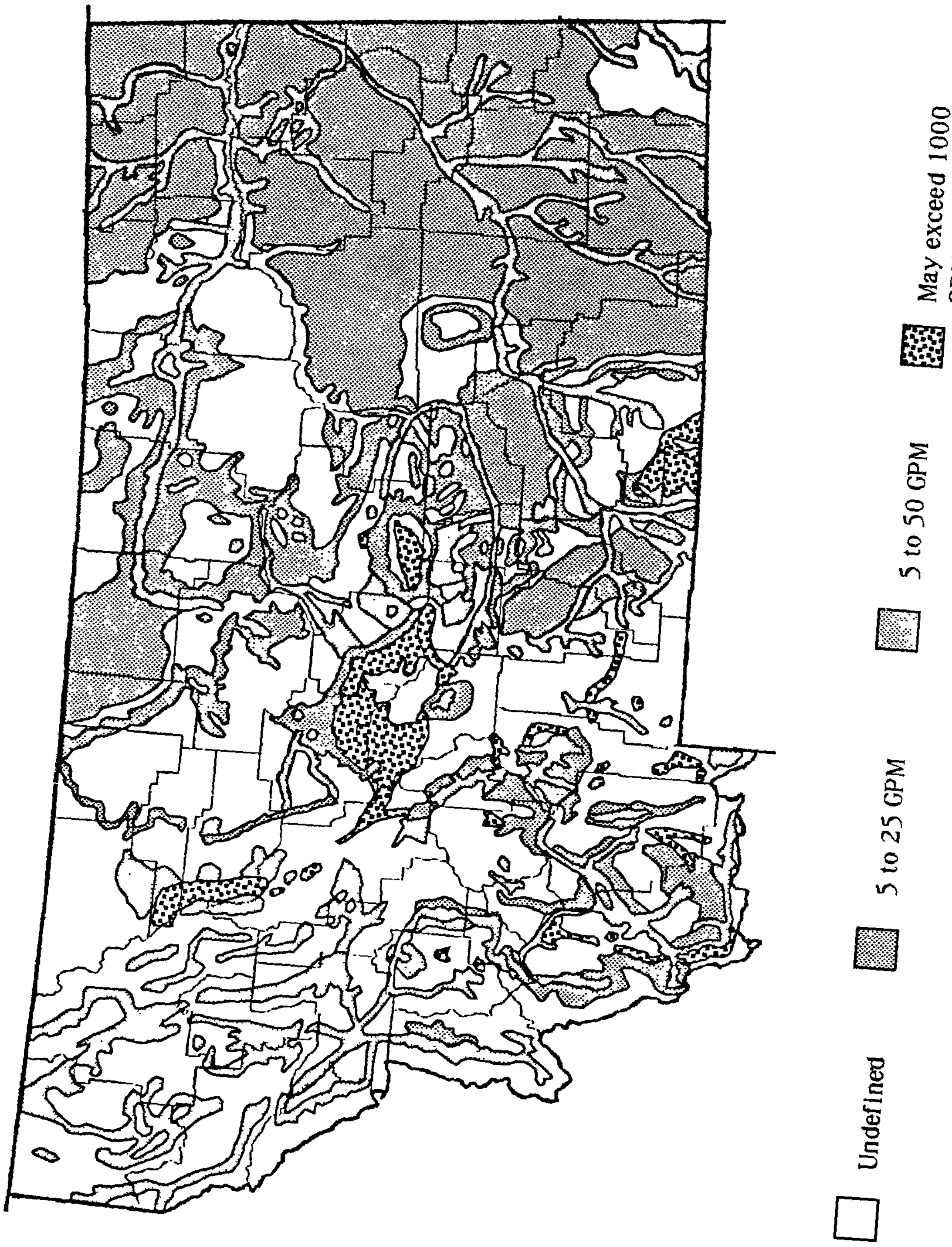
Lower yield bedrock aquifers, consisting primarily of Cretaceous and Paleocene age sandstone, occur throughout the eastern two-thirds of the state. Sandstone aquifers contain variable amounts of siltstone, shale, lignite, and limestone, and are unconfined in the outcrop area. Well yields range from 5 to 25 gpm, and may exceed 200 gpm.

Sensitivity

Although about 27 percent of Montana is covered by Class I aquifers, the potential for ground-water contamination from shallow injection wells is relatively small owing to Montana's low population density. Population centers generally follow the trend of major river valleys and highways. Elsewhere there are only a few relatively isolated towns.



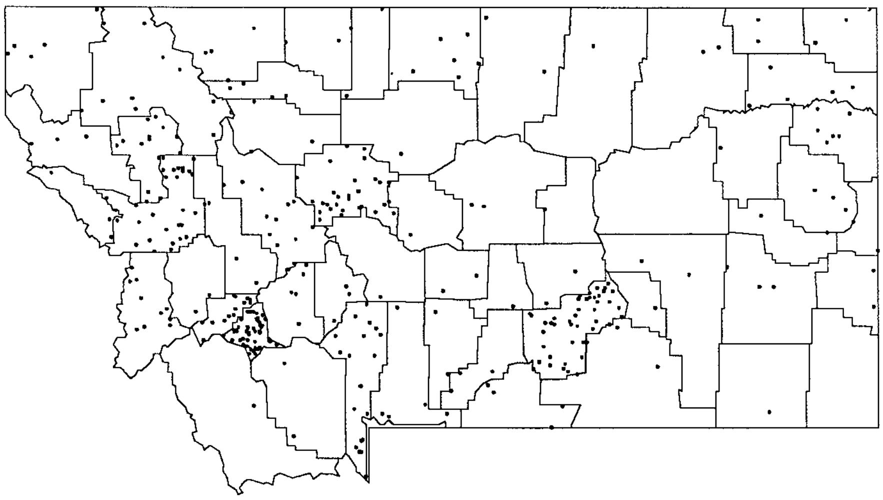
Aquifer Vulnerability Map of Montana



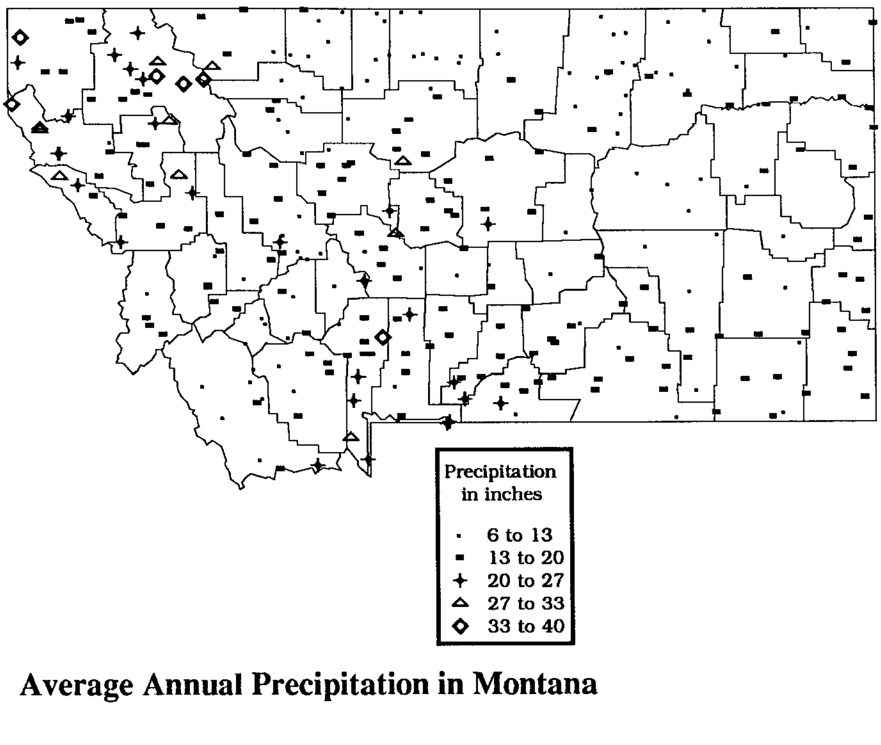
Potential Well Yields in Montana

Aquifer Sensitivity Map of Montana

Areas covered by class I aquifers.
Each dot represents a population center.



Population Density of Montana (Dot equals one person per square mile)



Average Annual Precipitation in Montana

NORTH DAKOTA

General Setting

North Dakota, which contains approximately 70,700 square miles, lies in the rolling to hilly, largely glaciated prairies of the Great Plains and Central Lowland physiographic provinces. The Badlands of southwestern North Dakota contain rugged hills along the Little Missouri River. All but the southwestern quarter of North Dakota is covered with unconsolidated glacial deposits of Quaternary age. These sediments range from less than 10 to more than 600 feet in thickness(Bluemle, 1986). The glacial boundary roughly parallels the present course of the Missouri River. The Williston structural basin in western North Dakota contains thick accumulations of Paleozoic to Tertiary age limestone, sandstone, siltstone, and shale. These deposits gradually thin toward the margins of the basin, and Precambrian age granitic rocks locally underlie glacial deposits in the eastern part of the state.

The Great Plains province is drained by the Missouri River and its five principal tributaries, and the Little Missouri River. The north-flowing Red and Souris rivers drain most of the Central Lowlands province. Poorly defined drainage patterns over much of the province reduce surface runoff to rivers. North Dakota has a semiarid continental climate with extremes in winter and summer temperatures. Annual precipitation ranges from about 13 inches in the west to more than 22 inches in the east. The majority of North Dakota's population, approximately 667,000, is located in Burleigh, Morton, Cass, and Ward counties. The remainder of the state is sparsely populated. Daily use of fresh ground water amounts to about 127 million gallons.

Unconsolidated Aquifers (Class Ia)

Glacial outwash and alluvial deposits form the most productive and vulnerable aquifers in the state. Glacial outwash deposits consist of unconsolidated, interbedded, linear bodies of sand, gravel, silt, and clay. These deposits occur throughout much of the state and locally exceed 100 feet in thickness. Alluvial deposits, consisting of unconsolidated sand, gravel, and silt are best developed along the Missouri River and its tributaries, and the Little Missouri River. Well yields in glacial outwash and alluvial aquifers range from about 1 to 1,000 gpm, and may exceed 1,500 gpm. About 13 percent of the state is covered by glacial outwash and alluvial deposits.

Higher Yield Bedrock Aquifers (Class IIa)

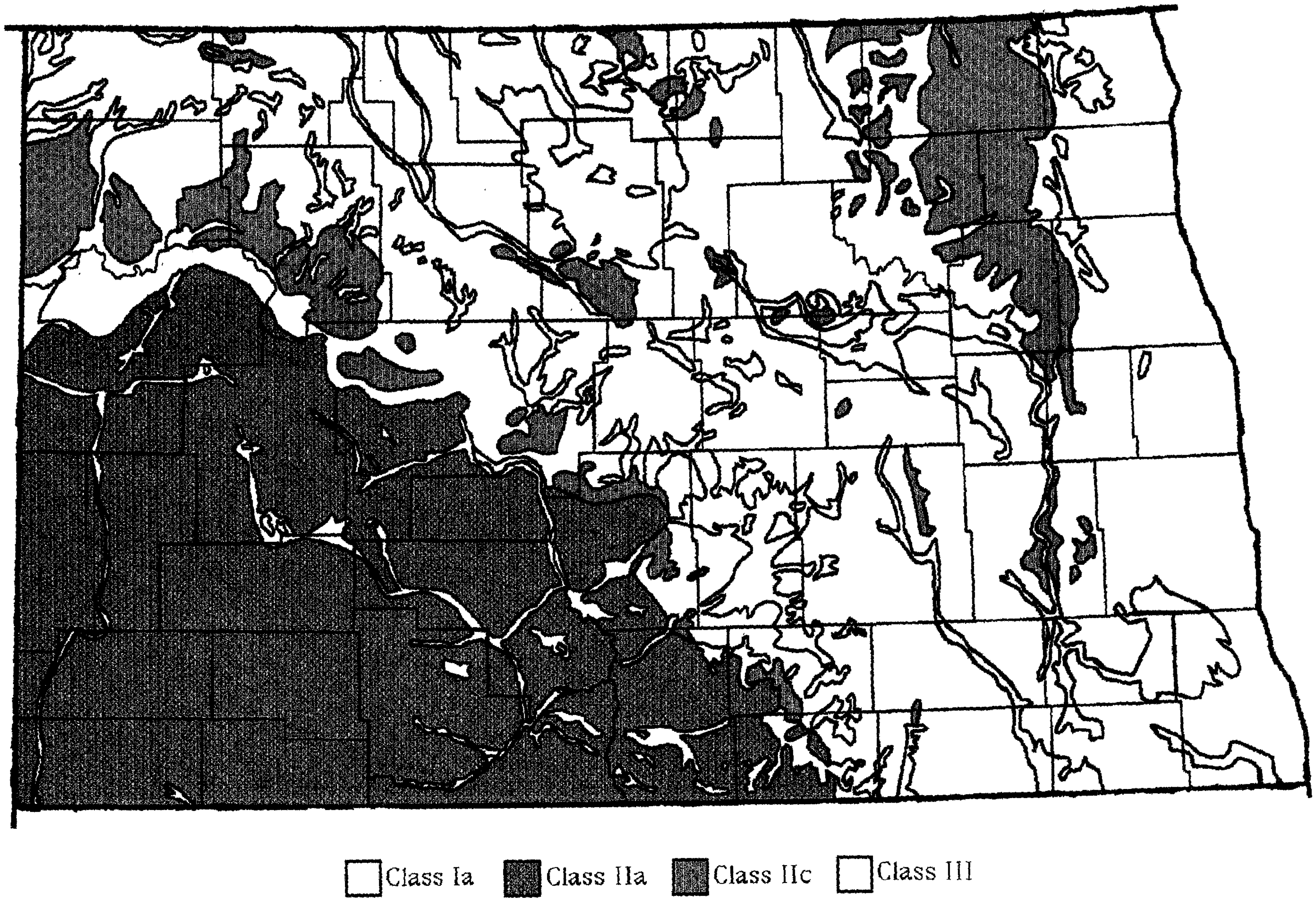
Higher yield bedrock aquifers, consisting of interbedded sandstone, siltstone, claystone, and shale of Cretaceous and Tertiary age, crop out throughout the unglaciated southwestern part of the state. Well yields range from 1 to 150 gpm, and may exceed 300 gpm. Surface exposures of higher yield bedrock aquifers occupy 27 percent of the state.

Covered Bedrock Aquifers (Class IIc)

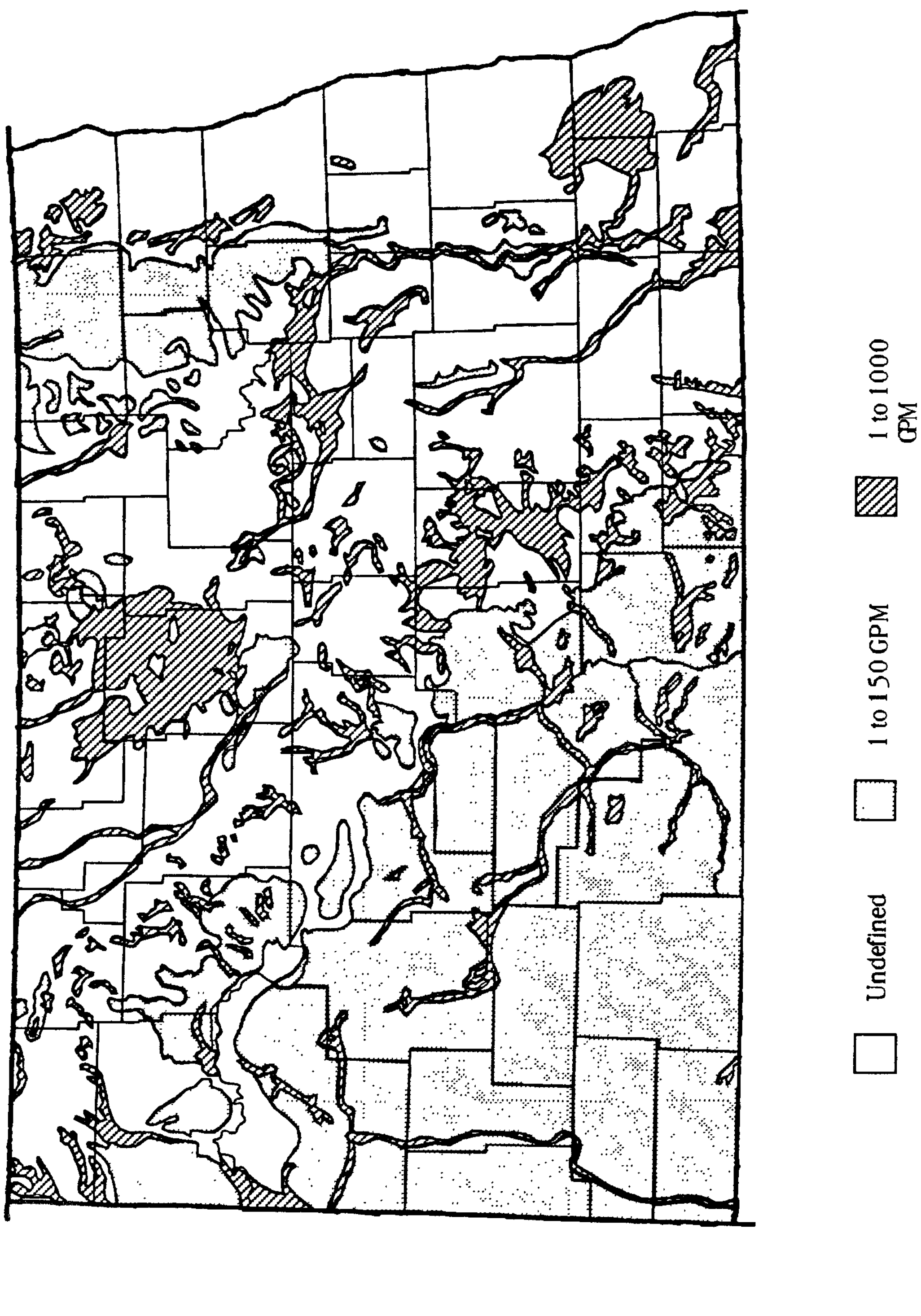
Higher yield bedrock aquifers of Cretaceous and Tertiary age, overlain by less than 50 feet of glacial till, occur sporadically throughout the glaciated part of the state. Well yields commonly range from 1 to 150 gpm. Class IIc aquifers occupy 9 percent of the state.

Sensitivity

Although 15 percent of the state is covered by Class I aquifers, the potential for shallow ground-water contamination from shallow injection wells is very low due to North Dakota's low population density. Population centers that lie on Class I aquifers are very few and these generally occur along major highways.

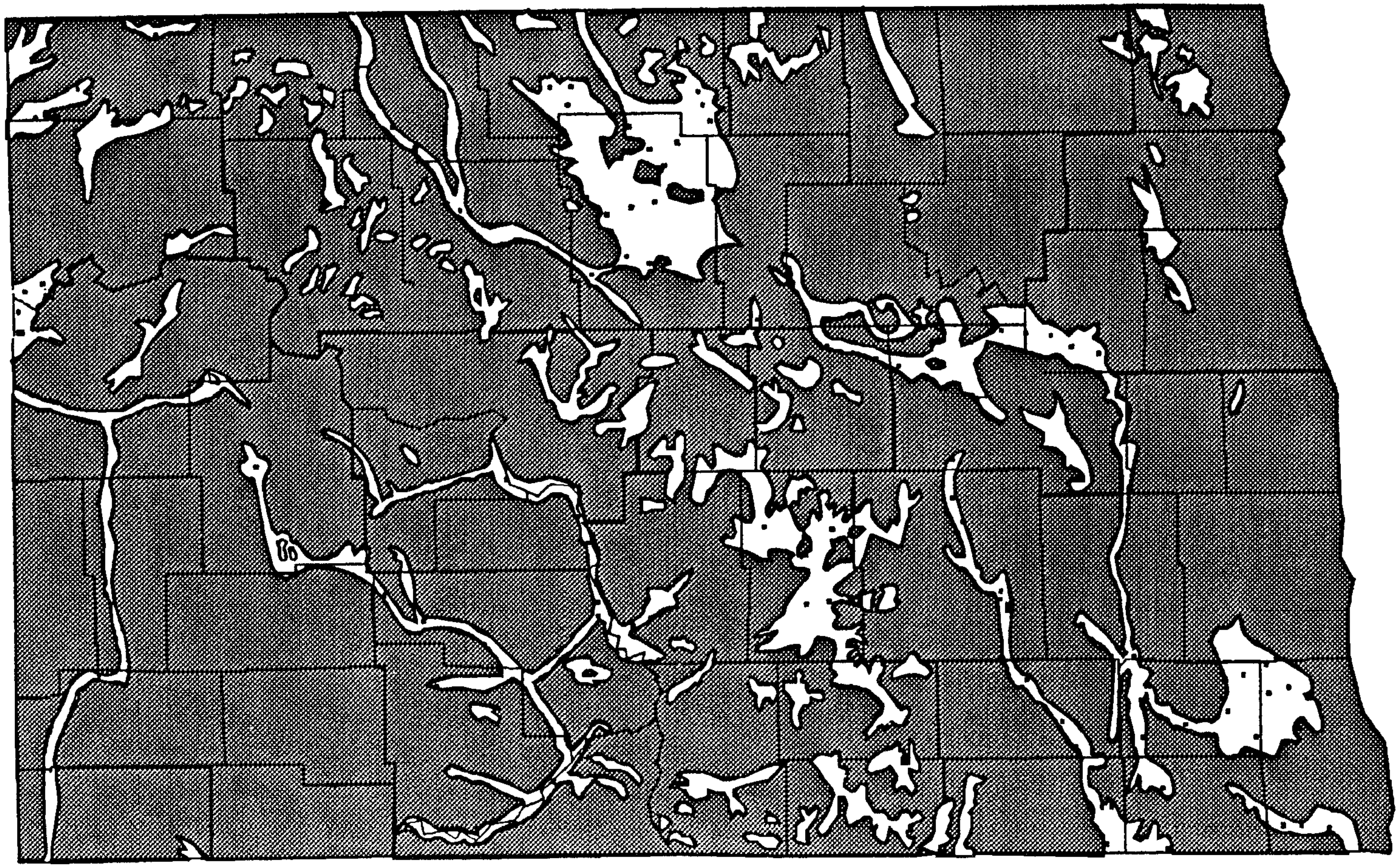


Aquifer Vulnerability Map of North Dakota

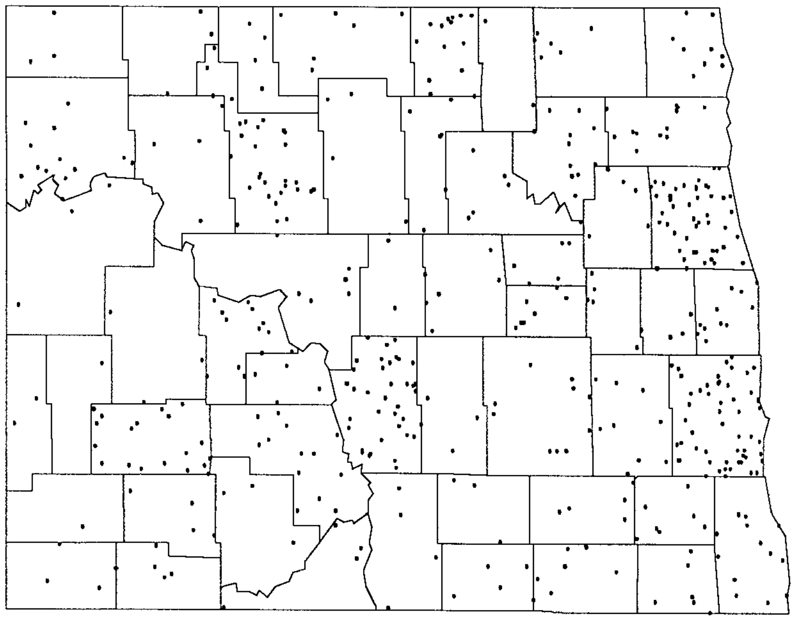


Potential Well Yields In North Dakota

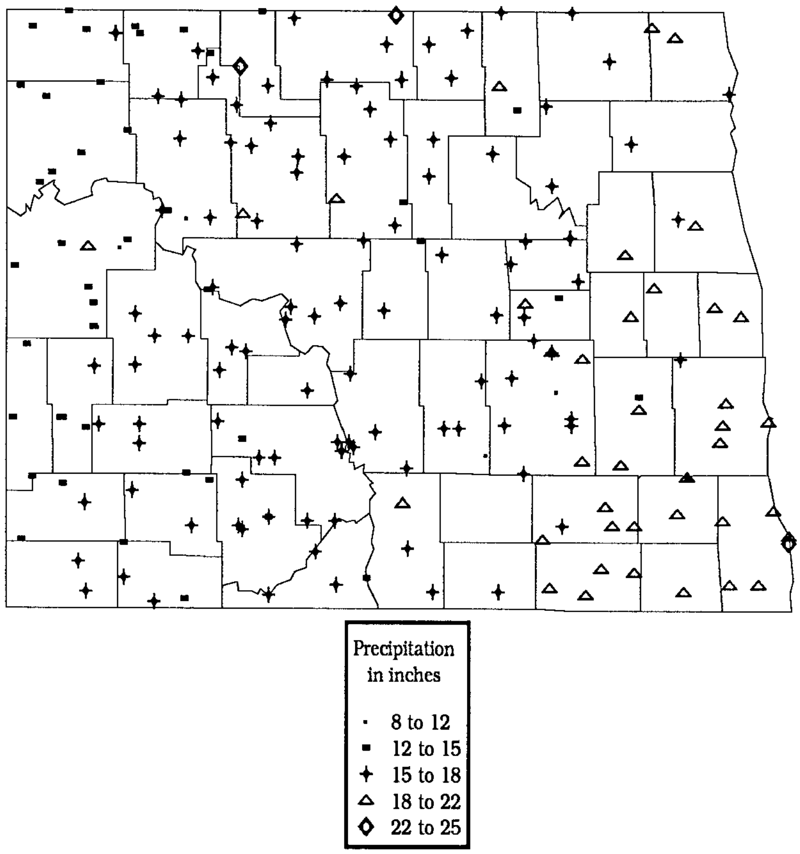
Aquifer Sensitivity Map of North Dakota



Areas covered by class I aquifers.
Each dot represents a population center.



Population Density of North Dakota (Dot equals one person per square mile)



Average Annual Precipitation in North Dakota

SOUTH DAKOTA

General Setting

South Dakota contains approximately 77,100 square miles, and is divided into two physiographic provinces by the Missouri River. The area west of the Missouri lies in the Great Plains province and is characterized by deep valleys and canyons, buttes, and broad flat uplands. East of the Missouri River, low rolling hills and potholes typify the glaciated part of the Central Lowland province. South Dakota is underlain by gently dipping, Paleozoic and Mesozoic age limestone, shale, and sandstone. These rocks are locally overlain by Tertiary age semiconsolidated to consolidated sandstone, silt, and clay in the western two-thirds of the state, and by Quaternary age glacial deposits in the eastern third of the state. Glacial deposits average about 150 feet in thickness, but may be as much as 800 feet thick in the northeast part of the state (U.S.G.S., 1986). Precambrian age metamorphic and igneous rocks crop out in the Black Hills in western South Dakota, and along the partially buried Sioux Uplift in the east. Unconsolidated Quaternary age alluvial and terrace deposits lie along all of South Dakota's major rivers.

South Dakota is drained by the southeast-flowing Missouri River and its seven principal tributaries. The state has a continental climate with extreme summer heat, extreme winter cold, and rapidly changing temperatures. Annual precipitation commonly ranges from 13 inches in the northwest to 25 inches in the southeast. The majority of South Dakota's population, approximately three-quarters of a million, is located in Minnehaha and Pennington counties. The remainder of the state is sparsely populated. About 249 million gallons of fresh ground water are used daily.

Unconsolidated Aquifers (Class Ia)

Alluvial deposits occur in narrow bands along larger streams, and form some of the most vulnerable aquifers in the state. These unconfined systems generally consist of unconsolidated sand, gravel, and silt. Glacial outwash aquifers, consisting of unconsolidated sand, gravel, and silt occur throughout the glaciated eastern third of the state. Well yields commonly range from 3 to 50 gpm, and may exceed 2,000 gpm. About 28.5 percent of the state is covered by Class Ia aquifers.

Semiconsolidated Aquifers (Class Ic)

The High Plains Aquifer, located in south-central South Dakota, consists of the lower part of the Ogallala and the Arikaree Formation of Miocene age. The Ogallala is composed of semiconsolidated to consolidated sand and silt, while the Arikaree consists of semiconsolidated to consolidated sand, clay, and silt. Sediments associated with the largely unconfined High Plains Aquifer are as much as 700 feet thick. Well yields commonly range from 5 to 100 gpm, and may locally exceed 1,500 gpm. Surface exposures of semiconsolidated aquifers occupy nearly 10 percent of the state.

Higher Yield Bedrock Aquifers (Class IIa)

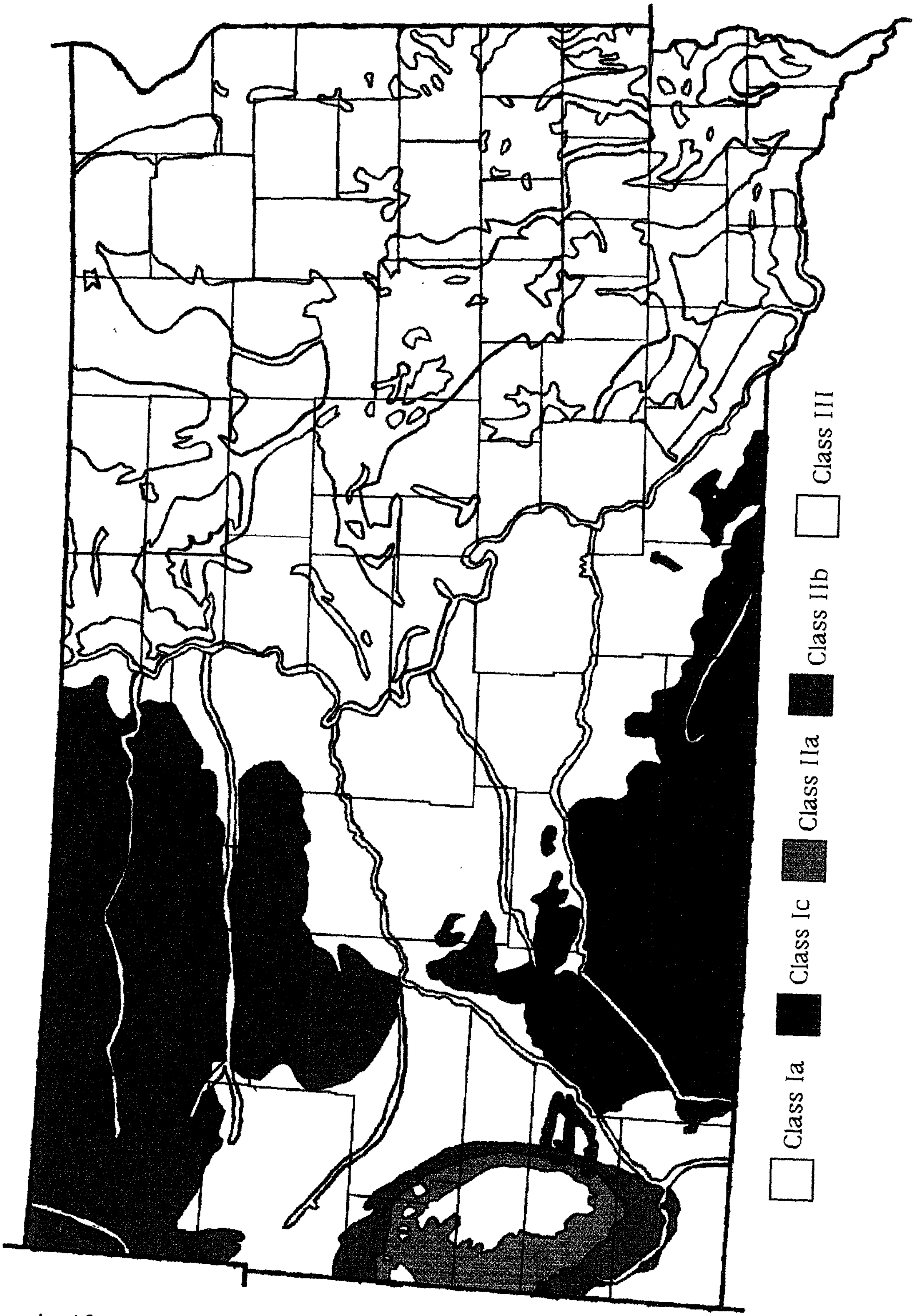
Higher yield bedrock aquifers, consisting of a variety of interbedded lithologies including sandstone, shale, siltstone, limestone, dolomite, and evaporites, are exposed around the Black Hills in western South Dakota. Well yields commonly range from 3 to 100 gpm but as much as 4,000 gpm are obtainable locally in areas of significant artesian pressure. Surface exposures of higher yield bedrock aquifers occupy nearly 2 percent of the state.

Lower Yield Bedrock Aquifers (Class IIb)

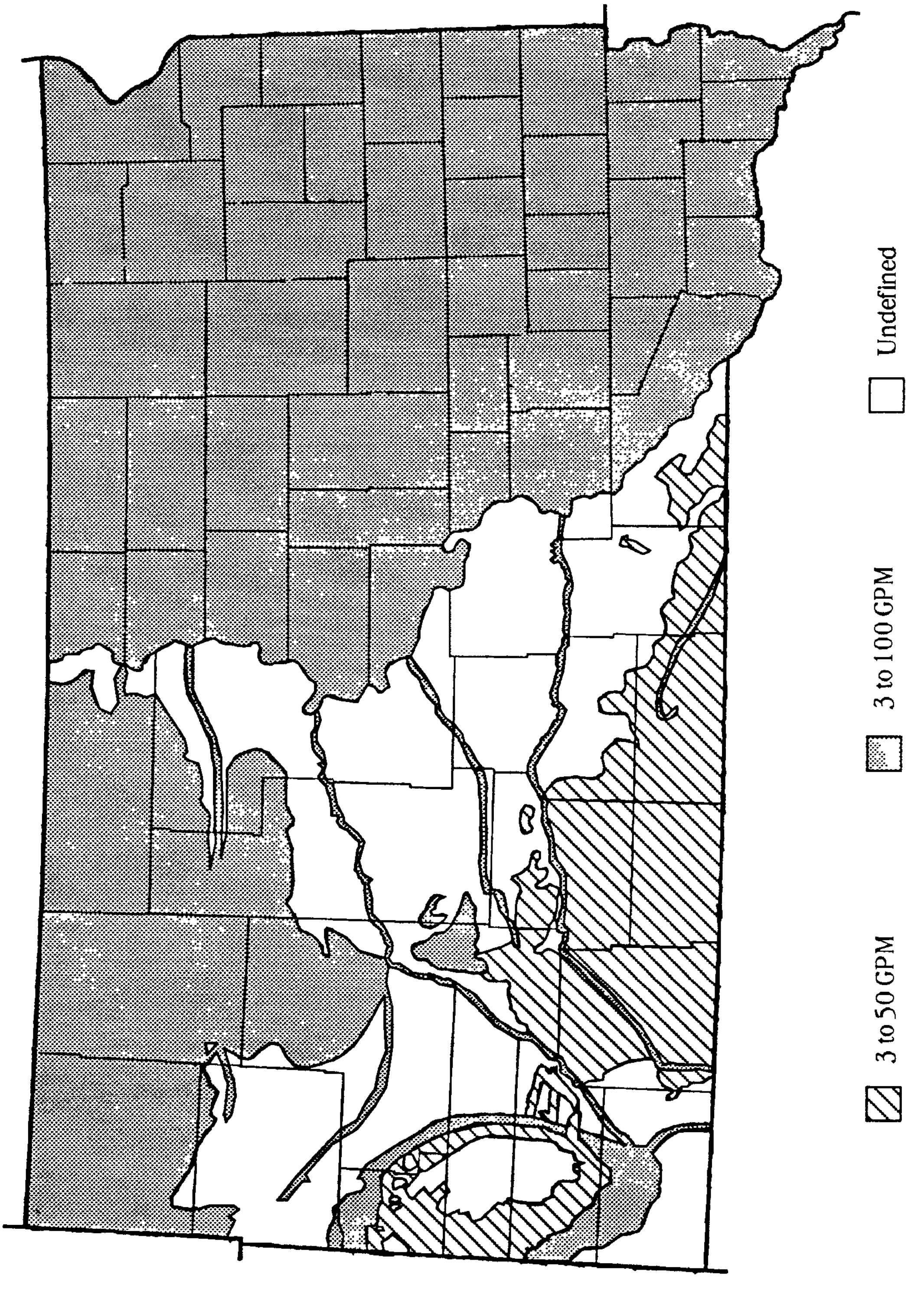
Lower yield bedrock aquifers, consisting of sandstone that is interbedded with shale, siltstone, and lignite, occur in the western and northwestern parts of the state. Sandstone aquifers are unconfined in the outcrop area. Well yields range from 2 to 50 gpm, and may exceed 1,500 gpm. Surface exposures of lower yield bedrock aquifers occupy about 15.4 percent of the state.

Sensitivity

About 38 percent of South Dakota is covered by Class I aquifers. The potential for ground-water contamination from shallow injection wells is small owing to low population density. In the Class I areas in the eastern part of the state, most of the population centers lie along major highways and the towns are small.

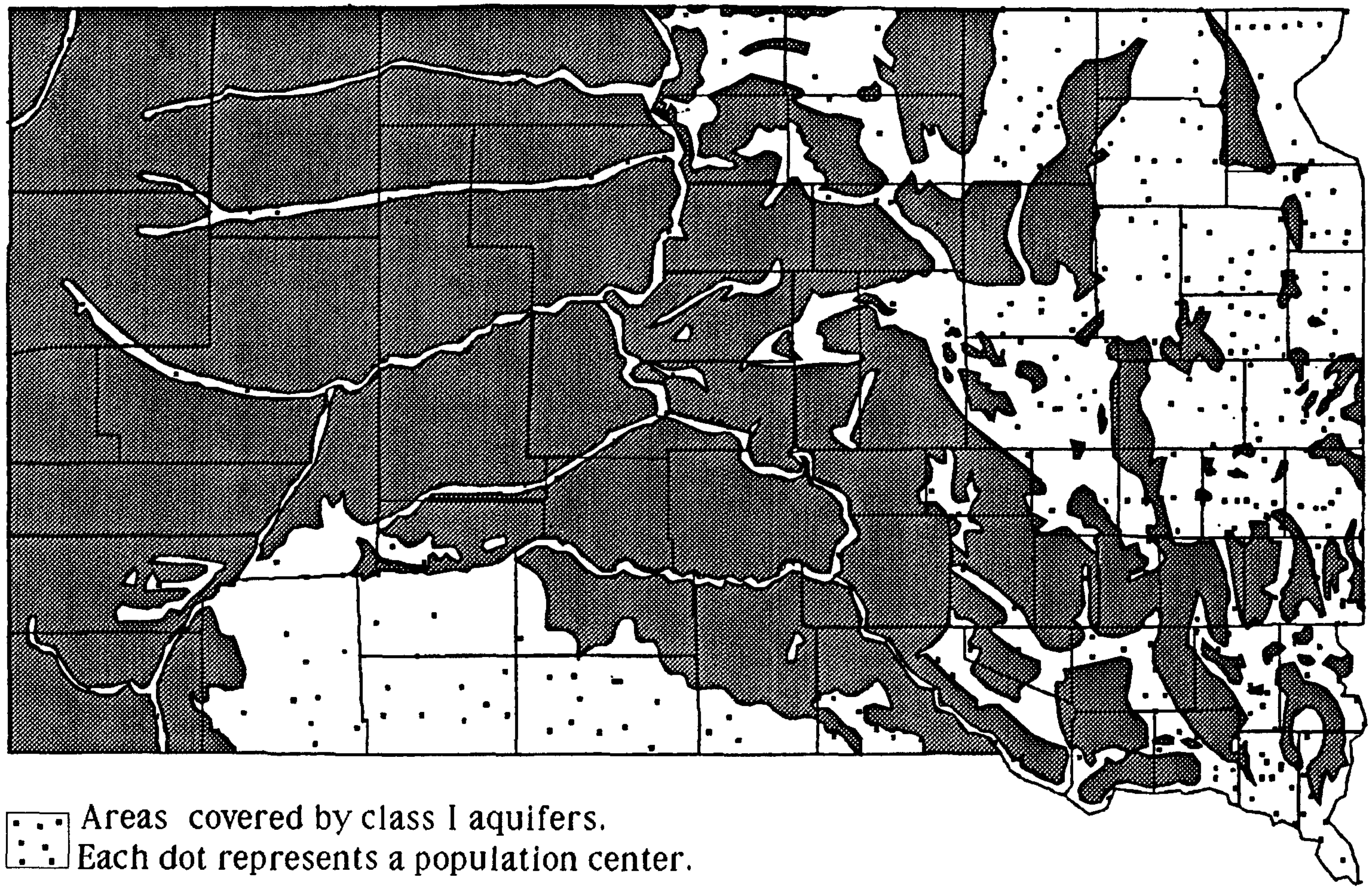


Aquifer Vulnerability Map of South Dakota

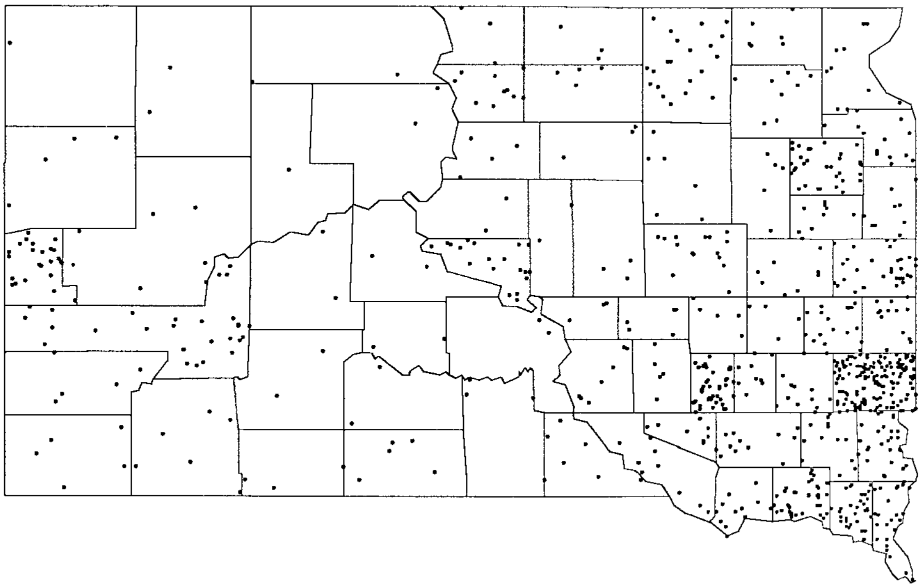


Potential Well Yields In South Dakota

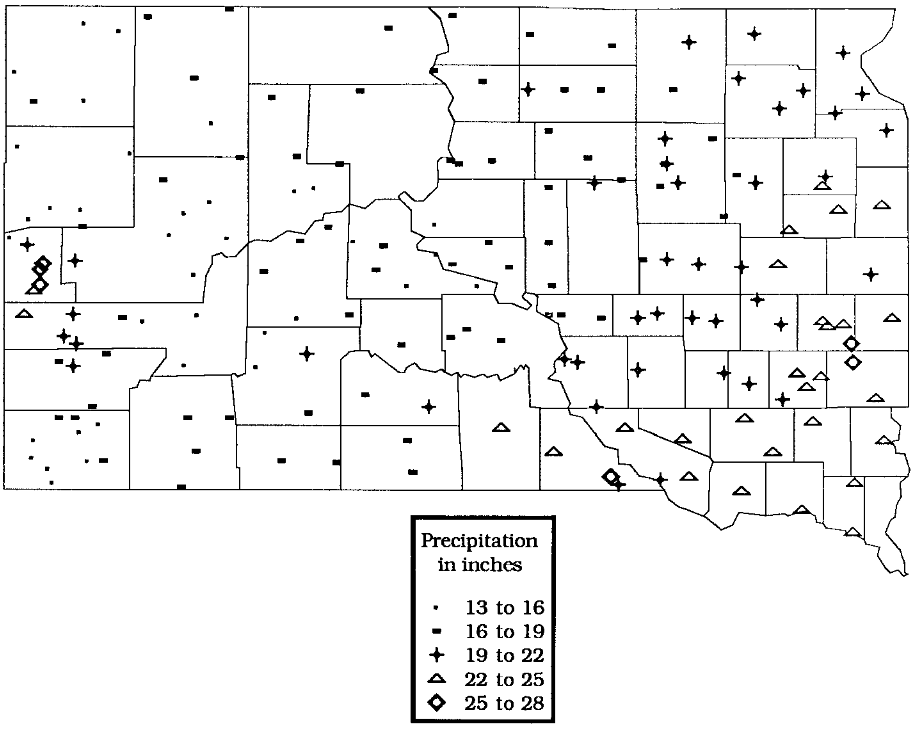
Aquifer Sensitivity Map of South Dakota



Areas covered by class I aquifers.
Each dot represents a population center.



Population Density of South Dakota (Dot equals one person per square mile)



Average Annual Precipitation in South Dakota

UTAH

General Setting

Utah contains approximately 84,900 square miles, and lies in the mountains, intermountain basins, and dissected plateaus of the Basin and Range, Middle Rocky Mountains, and Colorado Plateaus physiographic provinces. The mountains of northern and western Utah consist largely of folded and faulted, metamorphic, clastic, and carbonate rocks that range from Paleozoic to Precambrian in age. Tertiary age granitic and volcanic rocks form mountains in parts of western Utah. Paleozoic and Mesozoic age clastic and carbonate sediments flank the northern mountains and crop out in large areas of the Colorado Plateaus to the south. Basin and valley fill generally consists of thick accumulations of Cenozoic age alluvial, playa, and volcanic deposits.

Eastern Utah is drained by the Colorado River system. Most of the rivers in western Utah terminate in closed basins. Annual precipitation ranges from less than 10 inches in the west to more than 40 inches in the mountains of north and southwest Utah. The distribution of precipitation is relatively uniform throughout the year. The majority of Utah's population, nearly 1.7 million, is located in the north-central part of the state. Elsewhere the state is sparsely populated. The daily use of fresh and saline ground water in Utah is about 790 and 25 million gallons, respectively.

Unconsolidated Aquifers (Class Ia)

Quaternary age valley-fill and basin-fill deposits form vulnerable and productive aquifers, and constitute the principal source of ground water in Utah. These unconfined to confined systems consist of interbedded, unconsolidated deposits of clay, sand, silt, gravel, and boulders. Evaporite and volcanic deposits occur locally. Valley-fill, alluvial, colluvial, and glacial deposits, which generally extend from southwestern to northeastern Utah, commonly reach thicknesses of several hundred feet. Well yields usually range from 10 to 750 gpm, and may exceed 2,000 gpm. Basin-fill deposits occur throughout western Utah, where they reach thicknesses of several thousand feet. Well yields commonly range from 200 to 1,000 gpm, and may exceed 6,000 gpm. About 13.3 percent of the state is covered by permeable, unconsolidated sediments.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Solutional features and fractures are present in folded and faulted limestone and dolomite units that range in age from Middle Cambrian to Triassic in western, central, and northeastern Utah. Sandstone and shale interbeds occur within these units. Where present, solutional features and fractures contribute to the vertical and lateral permeability of the rock, creating productive and vulnerable aquifers. Well yields in this largely undeveloped aquifer system are generally less than 10 gpm, but may exceed 200 gpm. Solutional features also are present in the Tertiary age limestone units that are exposed across southwestern and south-central Utah. Fractured volcanic rock aquifers, composed of Tertiary and Quaternary age basalt and rhyolite, have been documented in central and northern Utah. Ground-water yield and movement are controlled by the density of joints and fractures. Well yields usually are less than 10 gpm. Similar hydrologic conditions within other volcanic units may exist outside those areas documented. Fractured rock aquifers also are present in the Pennsylvanian age quartzite exposed along the Wasatch Front in north-central Utah. Class Ib aquifers occupy about 10.7 percent of the state.

Semiconsolidated Aquifers (Class Ic)

Exposures of semiconsolidated sediments occur in isolated areas throughout Utah, and consist of Tertiary and Quaternary age poorly- to well-indurated, tuffaceous sand, gravel, and intercalated layers of clay. Calcium carbonate is a common cementing agent. Low to moderate permeabilities are reported for these sediments (Hood and Waddell, 1969; Hood, 1972). Surface exposures of semiconsolidated aquifers occupy about 7 percent of the state.

Higher Yield Bedrock Aquifers (Class IIa)

Higher yield bedrock aquifers, composed of Pennsylvanian, Permian, and Mesozoic age fine to coarse-grained sandstone, with some shale, coal, and limestone, crop out in southern, eastern, and northeastern Utah. Well yields commonly range from 50 to 500 gpm, and may exceed 3,000 gpm. Higher yield Late Cretaceous and Tertiary age aquifers, which are composed of sandstone interbedded with shale, conglomerate, and coal, crop out across central and east-central Utah. Well yields commonly range from 25 to 100 gpm (Waddell and others, 1981). Maximum well yields are associated with local fracturing. Surface exposures of Class IIa aquifers occupy about 27 percent of the state.

Variably Covered Aquifers (Class IIa-v)

Higher yield bedrock aquifers that are overlain by an undetermined thickness of low permeability material, occur throughout southeastern Utah. The vulnerability of these systems is a function of the thickness of the overlying sediments. Variably covered, higher yield bedrock aquifers occupy about 2 percent of the state.

Lower Yield Bedrock Aquifers (Class IIb)

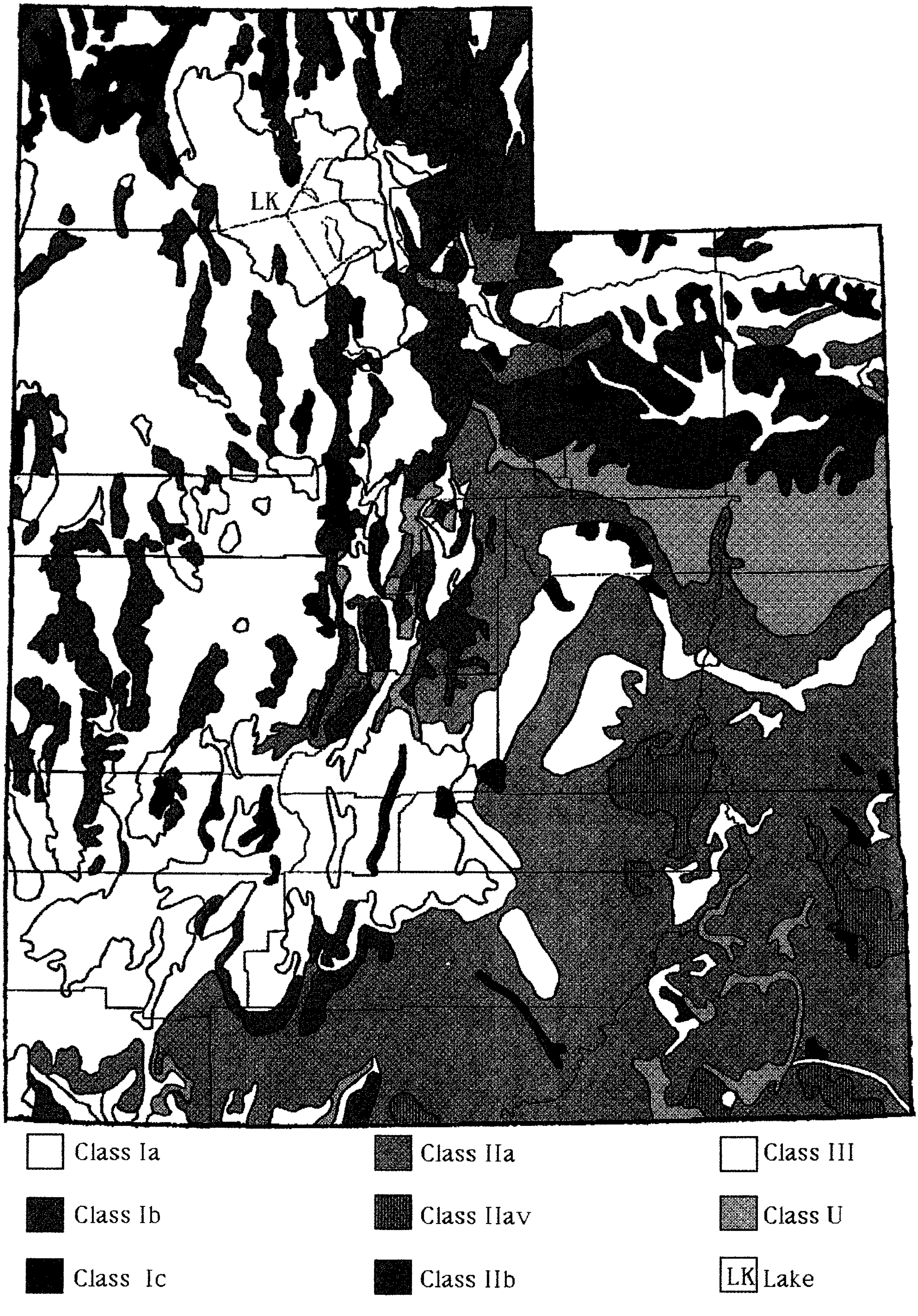
Lower yield bedrock aquifers of Tertiary age that are composed of sandstone, conglomerate, and shale, crop out in northern and northeastern Utah. Limited amounts of ground water are produced from wells and springs in these units (Taylor and others, 1986; Holmes, 1987). Maximum well yields are associated with local fracturing. Surface exposures of Class IIb aquifers occupy about 6.6 percent of the state.

Undifferentiated Aquifers (Class U)

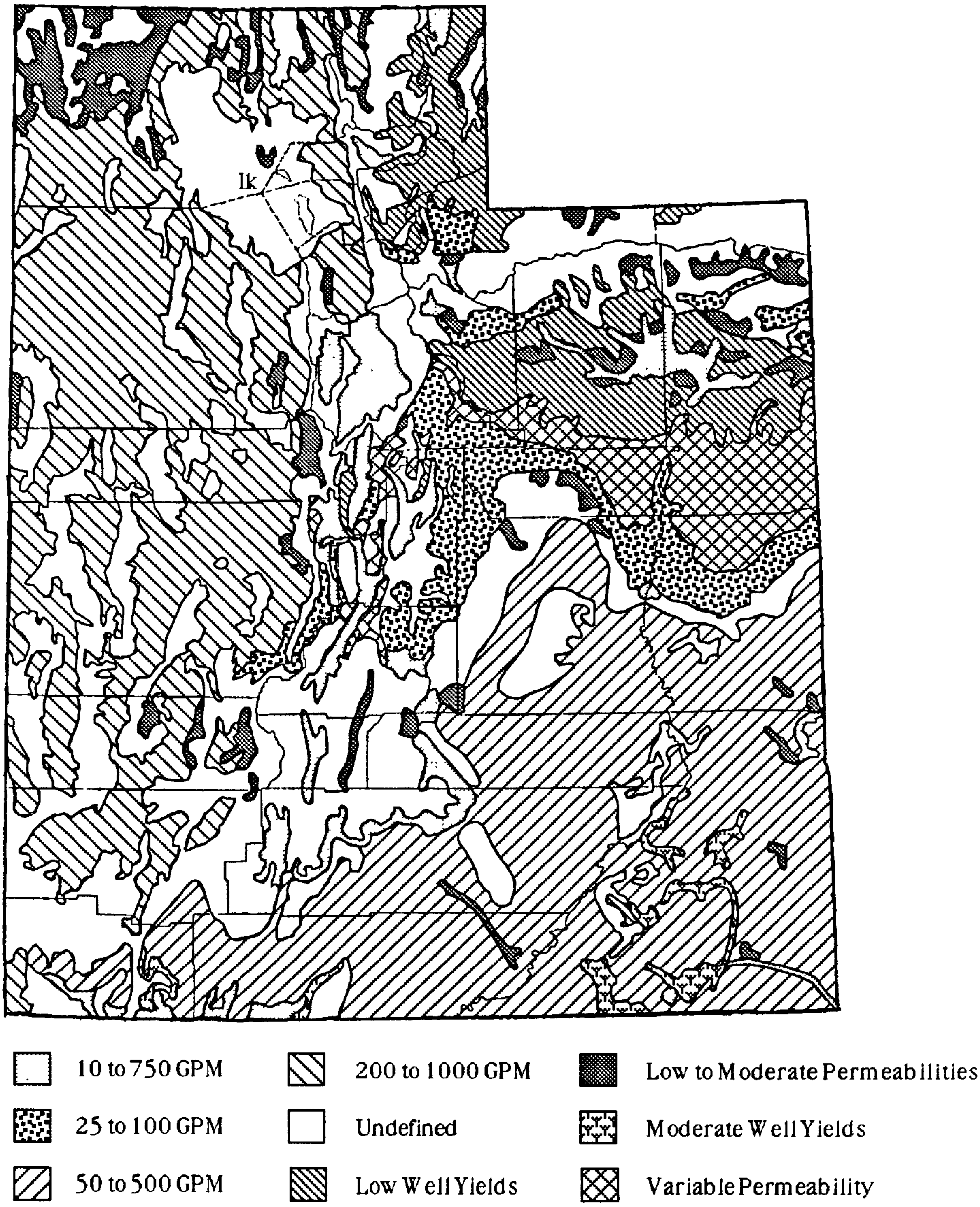
Undivided and lithologically varied Pennsylvanian, Permian, and Triassic age strata crop out in parts of southeastern and southwestern Utah. They consist of interbedded limestone, shale, sandstone, and conglomerate. Moderate amounts of ground water are produced from the Triassic sandstone and conglomerate units (McGuinness, 1963; Goode, 1966); Paleozoic limestones are known to yield water to wells (McGuinness, 1963). Undivided and lithologically varied Cretaceous and Eocene age formations crop out across eastern and south-central Utah, and consist of shales that contain permeable sandstone and limestone interbeds (Waddell and others, 1981; Taylor and others, 1986; Holmes, 1987). Maximum well yields are associated with local fracturing. Surface exposures of undifferentiated aquifers occupy about 12 percent of the state.

Sensitivity

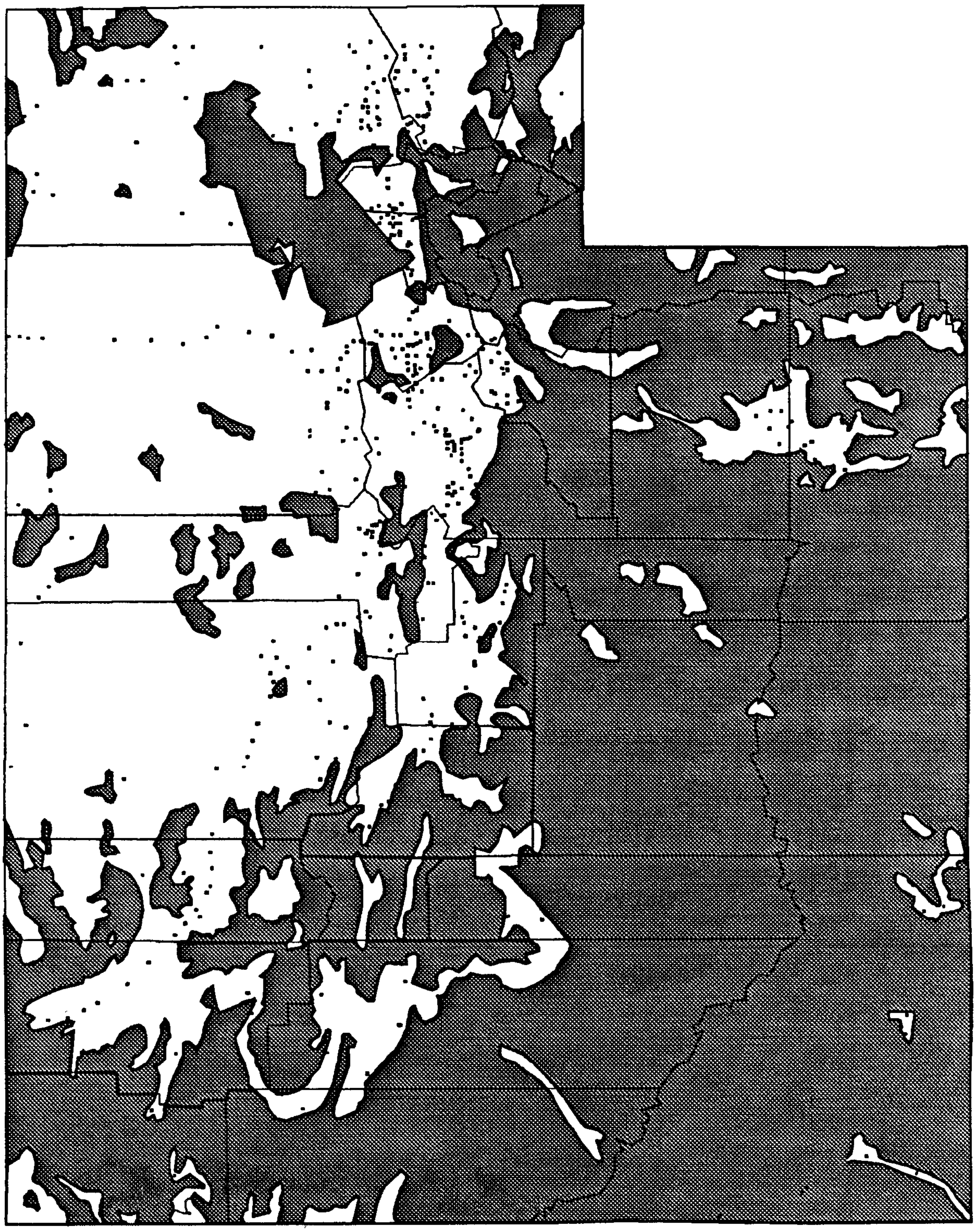
Although nearly 31 percent of Utah consists of Class I units, aquifer sensitivity is very low because of the light population density. Most of the population centers that lie on Class I aquifers occur along major highways.



Aquifer Vulnerability Map of Utah

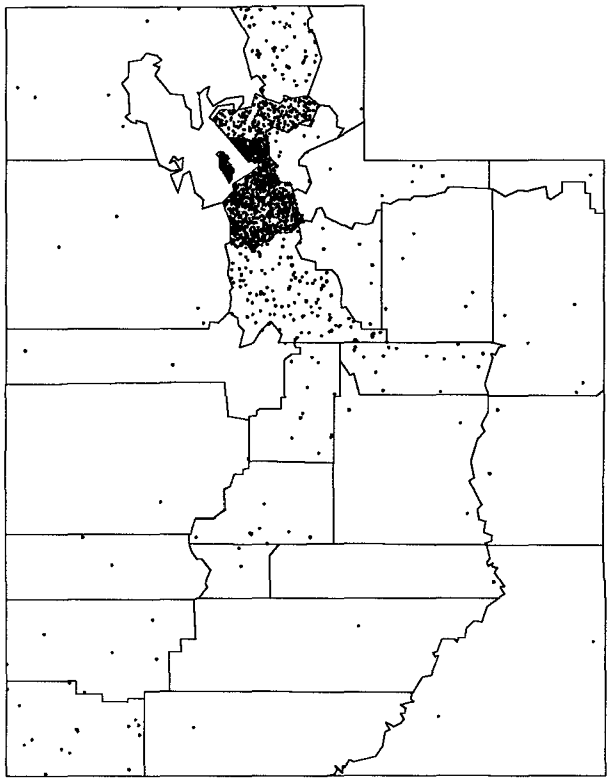


Potential Well Yields In Utah

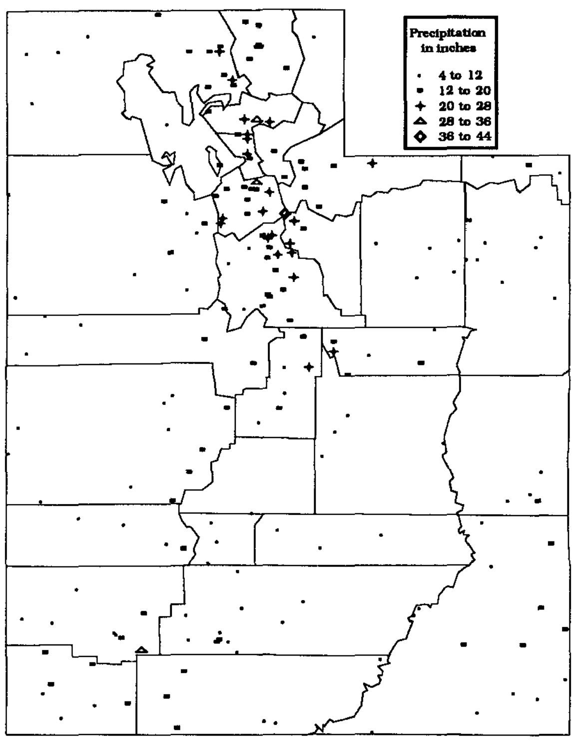


Areas covered by class I aquifers.
Each dot represents a population center.

Aquifer Sensitivity Map of Utah



Population Density of Utah (Dot equals one person per square mile)



Average Annual Precipitation in Utah

WYOMING

General Setting

Wyoming, which contains approximately 97,800 square miles, lies in the high plains, basins, and mountains of the Great Plains, Wyoming Basin, Middle and Southern Rocky Mountains physiographic provinces. Wyoming's mountains consist of exposed cores of Precambrian age metamorphic and igneous rocks, flanked by Paleozoic and Mesozoic age carbonate and clastic strata that dip steeply into adjacent structural basins. Semiconsolidated to consolidated Tertiary age clastic deposits comprise the majority of the basin fill. Alluvial, glacial, and eolian deposits occur along rivers, and within intermontane valleys.

The northern half of Wyoming is drained by the west-flowing Snake River and the north- and east-flowing Yellowstone, Bighorn, Powder, Belle Fourche, and Cheyenne rivers and their tributaries. The southern half of the state is drained by the south- and east-flowing Green and North Platte rivers. Annual precipitation ranges from less than 8 inches at lower elevations to more than 24 inches in the western mountains (McGuinness,1963). Approximately 50 percent of the state receives less than 12 inches per year. The majority of Wyoming's population, approximately 479,000, is located in Natrona, Cheyenne, Laramie, and Kemmerer Counties. The remainder of the state is sparsely populated. About 504 and 23 million gallons of fresh and saline ground water, respectively, are used daily in Wyoming.

Unconsolidated Aquifers (Class Ia)

Alluvial and outwash deposits, which occur throughout the state, form vulnerable and productive aquifers. These generally unconfined systems consist of Quaternary age gravel, sand, silt, and clay. Glacial outwash locally contains boulders. Alluvial aquifers generally are less than 50 feet thick, but may exceed 200 feet in the Bear and Snake River structural basins. Well yields commonly range from 50 to 100 gpm, and may exceed 3,000 gpm. About 14 percent of the state is covered by Class Ia aquifers.

Semiconsolidated Aquifers (Class Ic)

Exposures of semiconsolidated sediments, which occur throughout the southern half of Wyoming, consist of poorly- to moderately-consolidated, interbedded, Tertiary and Quaternary age tuffaceous sand, clay, silt, and gravel. Thicknesses are generally less than 400 feet, but may locally exceed 1,000 feet. Semiconsolidated sediments are locally overlain by eolian deposits. Well yields commonly range from 150 to 800 gpm, and may exceed 2,000 gpm. Surface exposures of semiconsolidated aquifers occupy about 13 percent of the state.

Lower Yield Bedrock Aquifers (Class IIb)

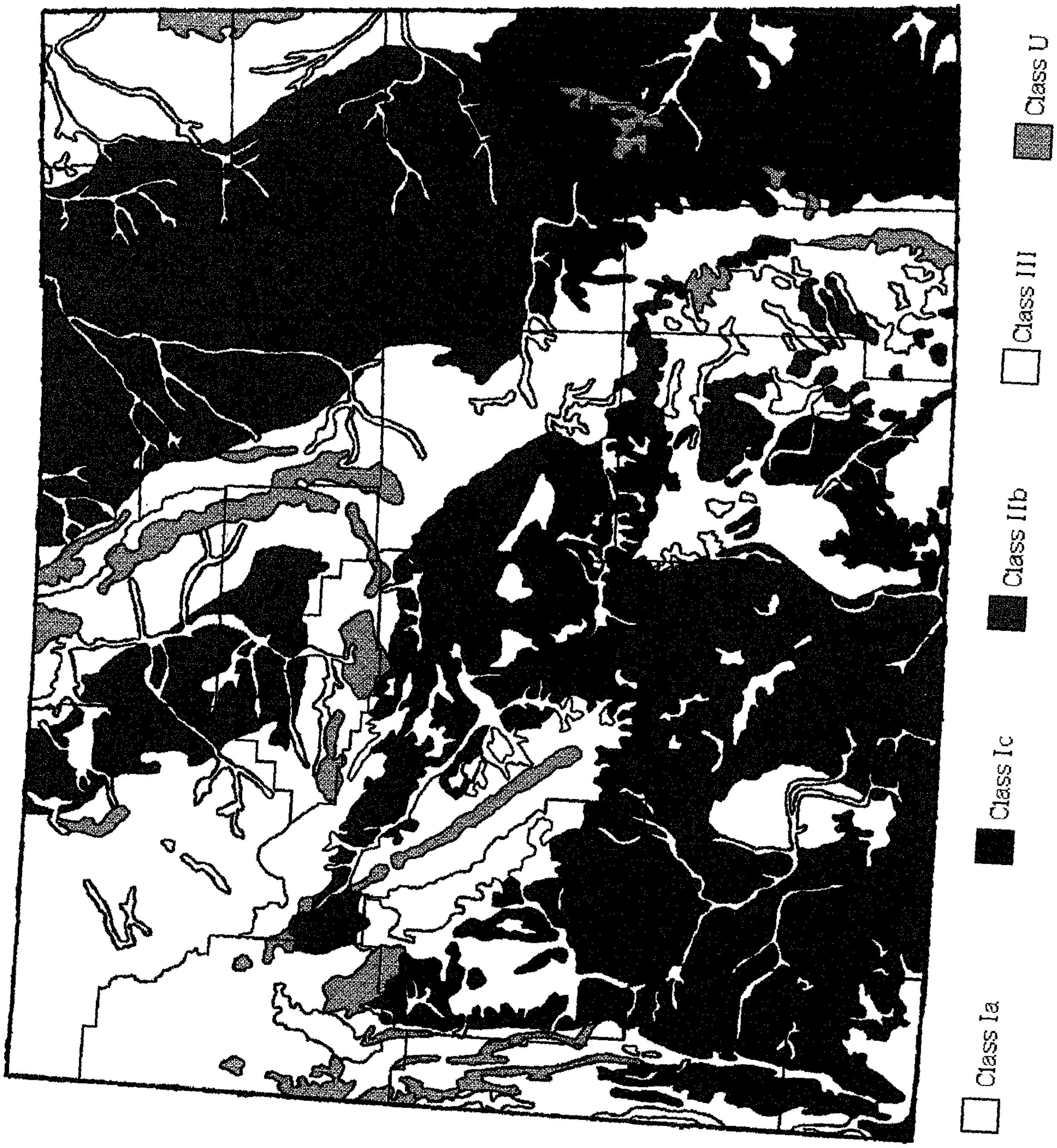
Lower yield bedrock aquifers occur within structural basins across the state, and consist of interbedded, Late Cretaceous and Tertiary age sandstone, shale, claystone, siltstone, marlstone, coal beds, and conglomerate. Sandstones are commonly arkosic and tuffaceous; coal beds may contain oil. Locally in southwestern Wyoming, these units are overlain by eolian deposits. Well yields commonly range from 1 to 50 gpm, but may exceed 1,000 gpm. Surface exposures of lower yield bedrock aquifers occupy 37 percent of the state.

Undifferentiated Aquifers (Class U)

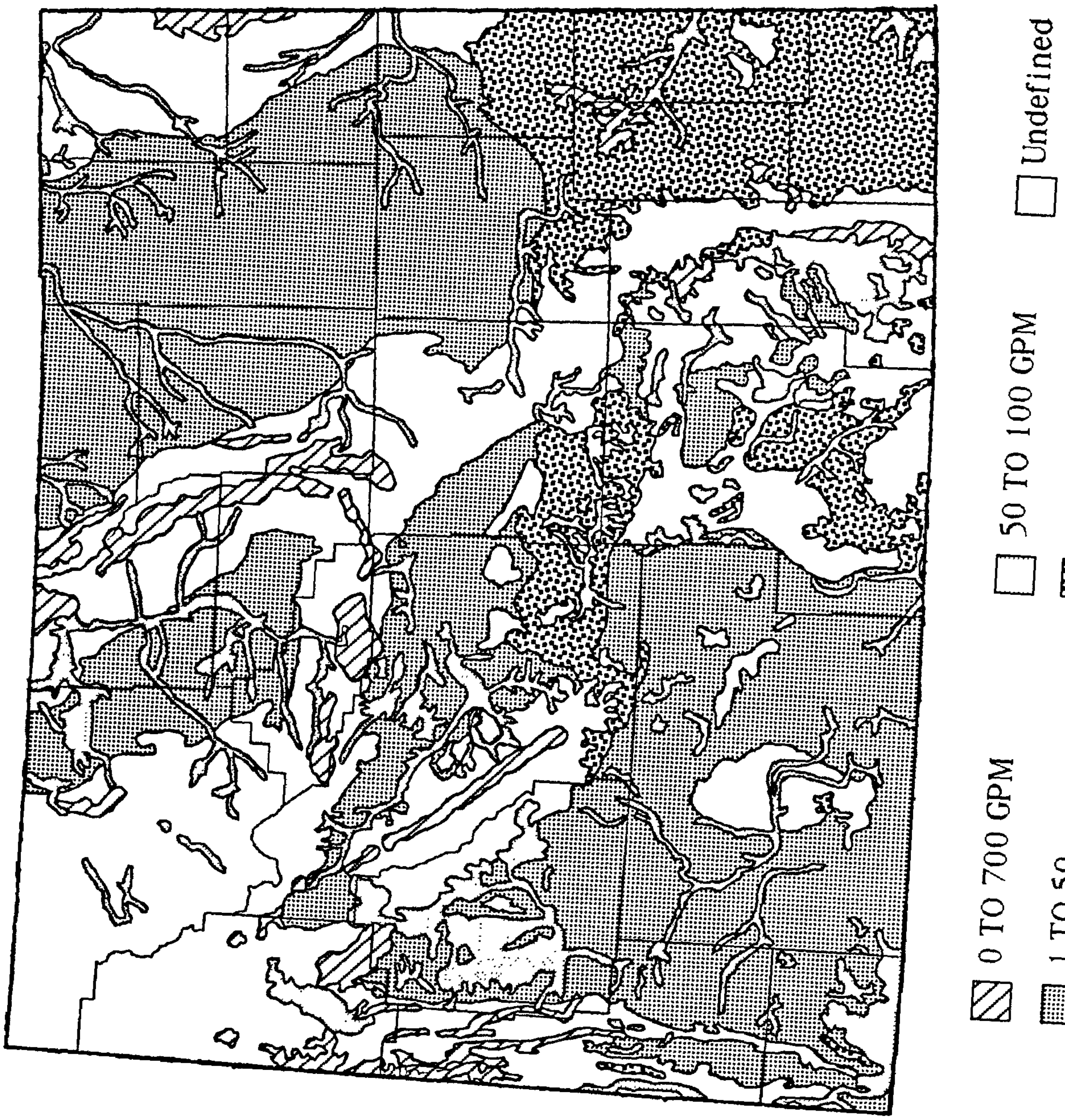
Several undivided and lithologically varied Paleozoic and Triassic age formations crop out along the flanks of mountains throughout the state, and consist of interbedded limestone, dolomite, sandstone, shale, siltstone, phosphorite, gypsum, and halite. The lithologic and resultant hydrologic variability of these undivided formations has not been delineated. A wide range in aquifer productivity and vulnerability should be expected in these areas. Surface exposures of undifferentiated aquifers occupy about 32 percent of the state.

Sensitivity

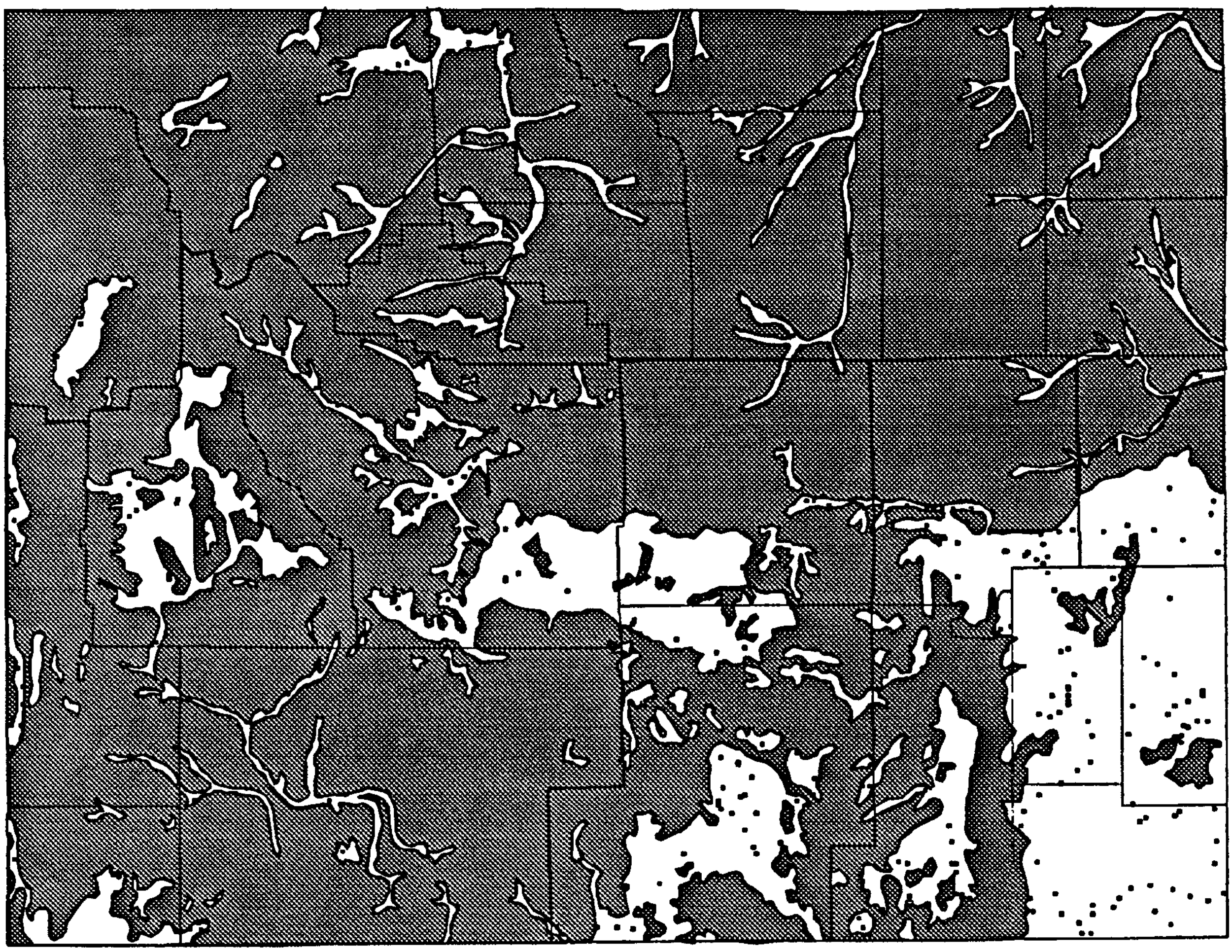
Although nearly 27 percent of Wyoming is covered by Class I aquifers, the potential for shallow ground-water contamination from shallow injection wells is relatively small due to Wyoming's low population density. Even in the most vulnerable areas, population centers are quite widely distributed, and most lie along major highways.



Aquifer Vulnerability Map of Wyoming

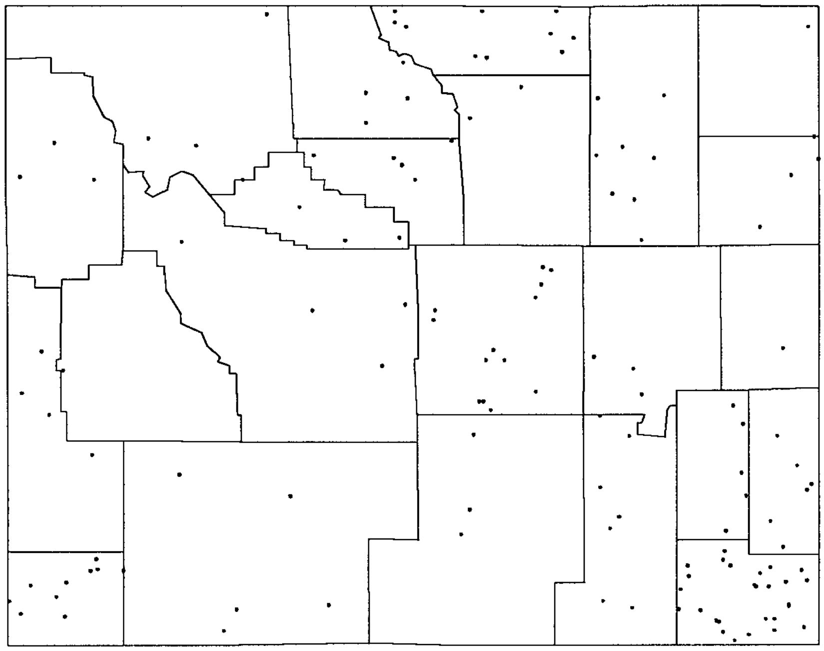


Potential Well Yields In Wyoming

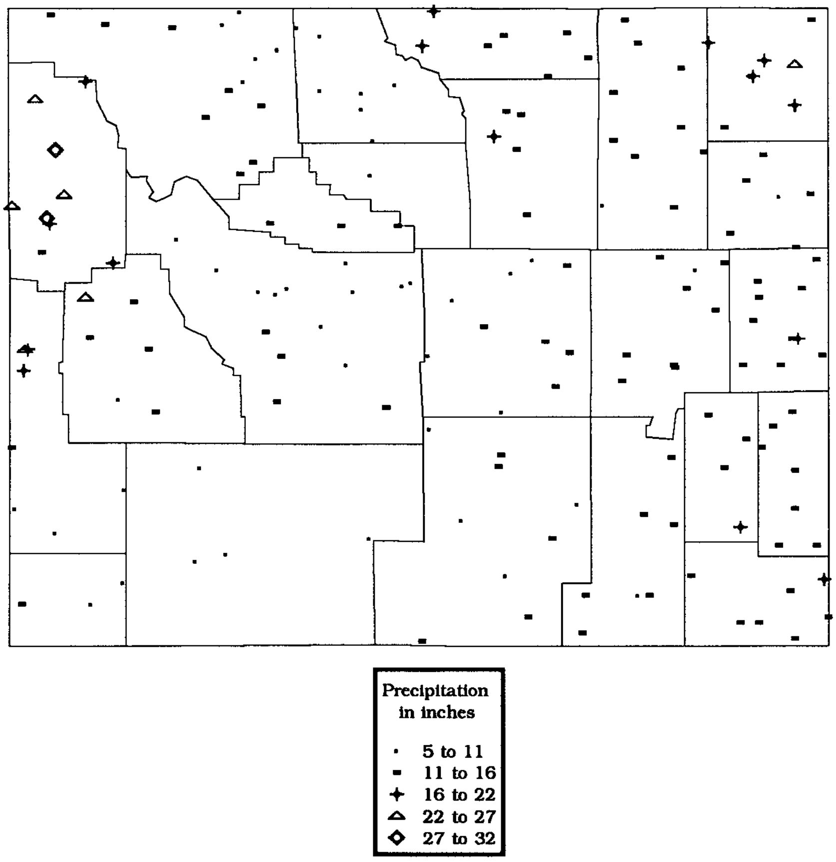


Areas covered by class I aquifers.
Each dot represents a population center.

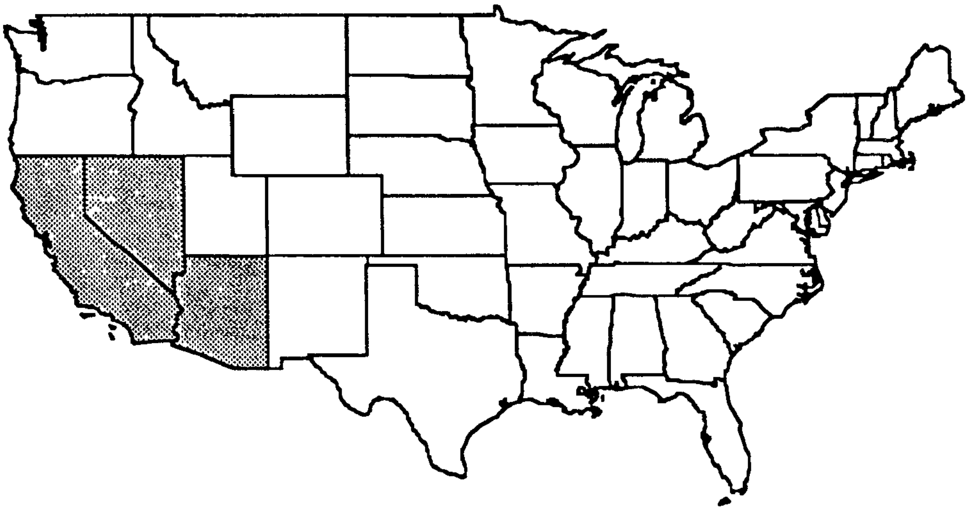
Aquifer Sensitivity Map of Wyoming



Population Density of Wyoming (Dot equals one person per square mile)



Average Annual Precipitation in Wyoming



REGION 9

Arizona
California
Nevada

ARIZONA

General Setting

Arizona, which contains approximately 114,000 square miles, lies in the dissected plateaus, mountains, and intermountain basins of the Colorado Plateaus and Basin and Range physiographic provinces.The mountains of central and southern Arizona consist largely of Precambrian and Cenozoic age metamorphic, sedimentary, and igneous extrusive and intrusive rocks. Similar rocks of Paleozoic and Mesozoic age crop out locally in the mountains of western and southeastern Arizona. Intermountain basins contain thick accumulations of variably indurated, Cenozoic age alluvial, eolian, lacustrine, and volcanic deposits. The northern and northeastern parts of the state are underlain by thick sequences of flat lying Paleozoic and Mesozoic age clastic and carbonate rocks. These units are locally overlain by Cenozoic age volcanic and sedimentary deposits.

The entire state is drained by the Colorado River and its west-flowing tributaries. Annual precipitation ranges from less than 5 inches in the southwest to more than 25 inches at higher elevations across the state. July and August are the wettest months of the year; May and June are the driest. The majority of Arizona's population, nearly 3.5 million, is located in and around metropolitan Phoenix and Tucson. The remainder of the state is sparsely populated. Daily use of fresh and saline ground water amounts to 3090 and 8.4 million gallons, respectively.

Unconsolidated Aquifers (Class Ia)

Alluvial, eolian, and lacustrine deposits occur throughout the basins of southern Arizona, and within isolated depressions in the north, forming sensitive and productive aquifers that constitute the state's major ground-water reservoirs. These unconfined to confined systems consist of Quaternary age unconsolidated sand, silt, clay, and volcanic material, that range from a few hundred to about 10,000 feet in thickness. Well yields of 1,000 gpm are common and locally they may exceed 2,500 gpm. About 28 percent of the state is covered by unconsolidated basin-fill deposits.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Solutional features are present in fractured, sandy, Permo-Triassic age limestone units exposed in north-central and northwestern Arizona. Where present, solutional features and fractures contribute to the vertical and lateral permeability of the rock. Although ground water is not currently being obtained from these rocks, reports indicate that there is a potential for development (Arizona Geological Survey, oral. communication, 1990). Class Ib aquifers occupy about 7 percent of the state.

Semiconsolidated Aquifers (Class Ic)

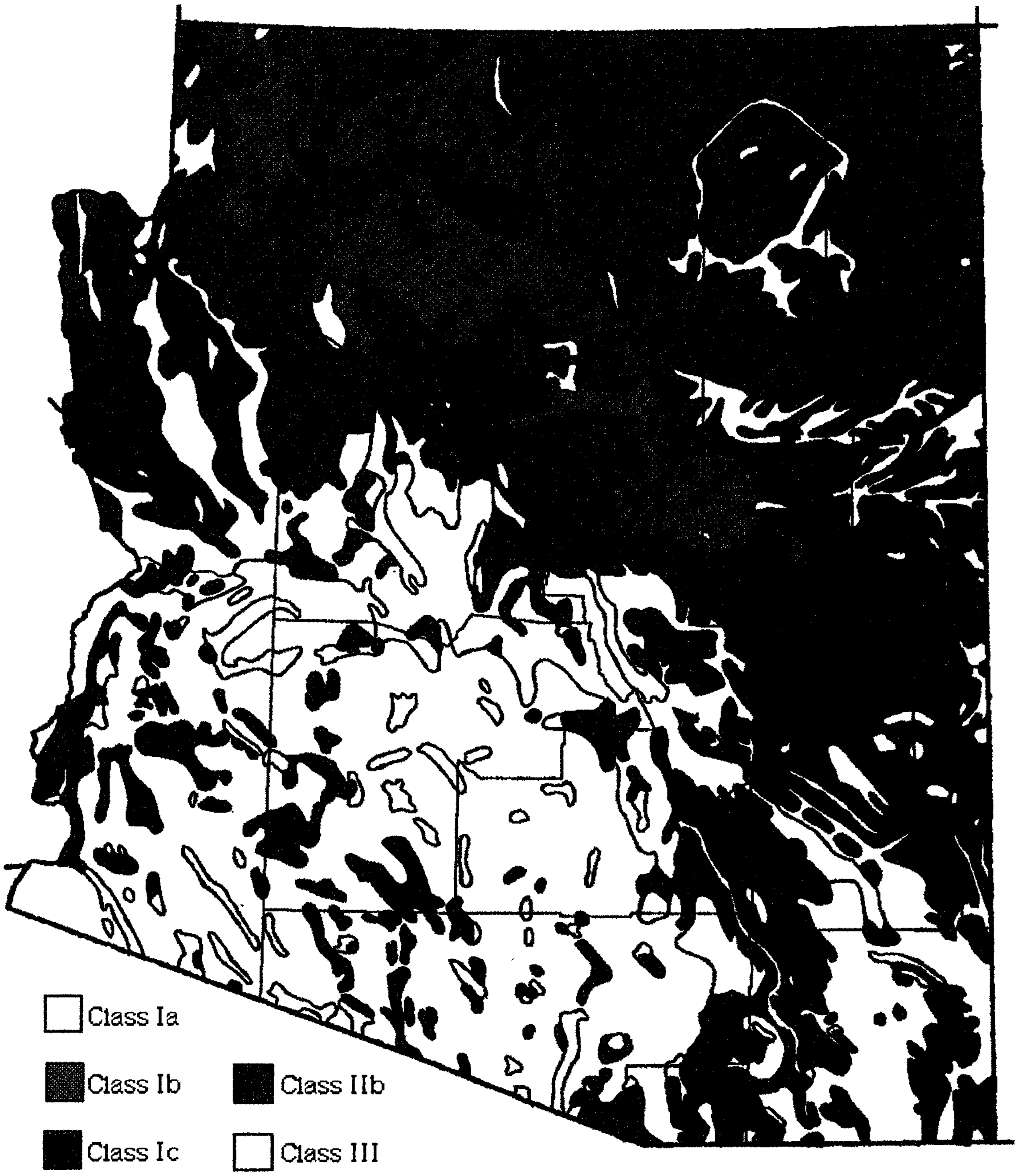
Exposures of semiconsolidated sediments, which occur within intermountain basins in west-central and southeastern Arizona, consist of poorly- to well-indurated, Tertiary and Quaternary age gravel, sand, silt, clay, gypsum, limestone, diatomite, and some intercalated basalt flows and felsic tuff beds. Well yields of 1,000 gpm are common, and locally they may exceed 2,500 gpm. Surface exposures of semiconsolidated aquifers occupy about 9 percent of the state.

Lower Yield Bedrock Aquifers (Class IIb)

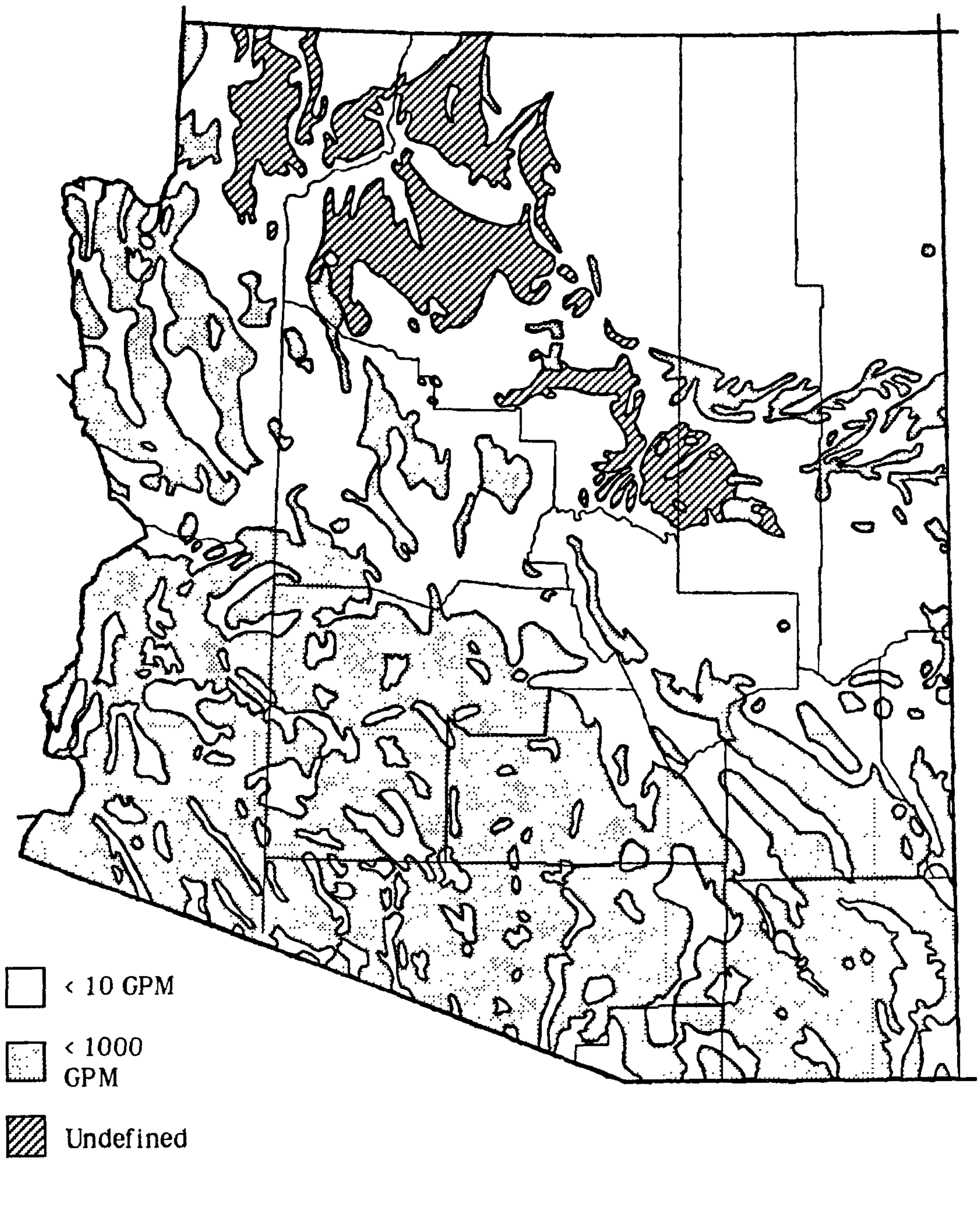
Lower yield bedrock aquifers, composed of sedimentary and igneous rocks, occur throughout the state. Throughout northern Arizona, these units consist of Paleozoic and Mesozoic age fine-grained sandstone and interbedded siltstone, shale, and carbonate rocks. Elsewhere Late Mesozoic and Cenozoic age, interbedded basalt and rhyolite flows, agglomerate, and variable welded pyroclastic material are exposed. Well yields for sedimentary and volcanic aquifers commonly range from 0.5 to 2 gpm, but they may exceed 200 gpm. Maximum well yields, and increased aquifer vulnerability are associated with the density of joints and fractures, and the degree of pyroclastic welding. Surface exposures of lower yield bedrock aquifers occupy about 43 percent of the state.

Sensitivity

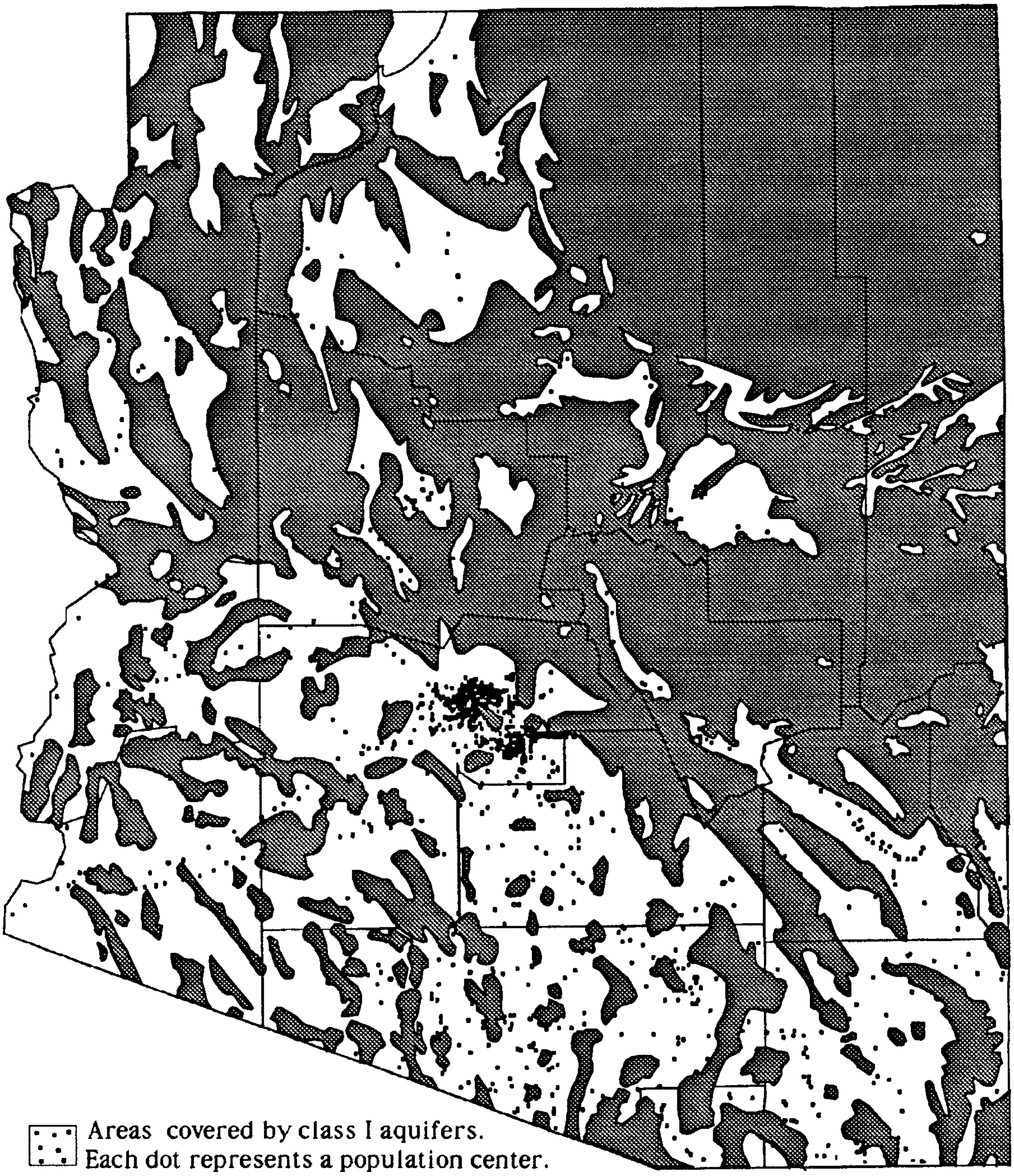
About 44 percent of Arizona is covered by Class I aquifers. On the other hand, the distribution of population centers and the population density indicate that the potential for the contamination of ground water from shallow injection wells is generally small. The most sensitive part of the state is in the vicinity of Phoenix.



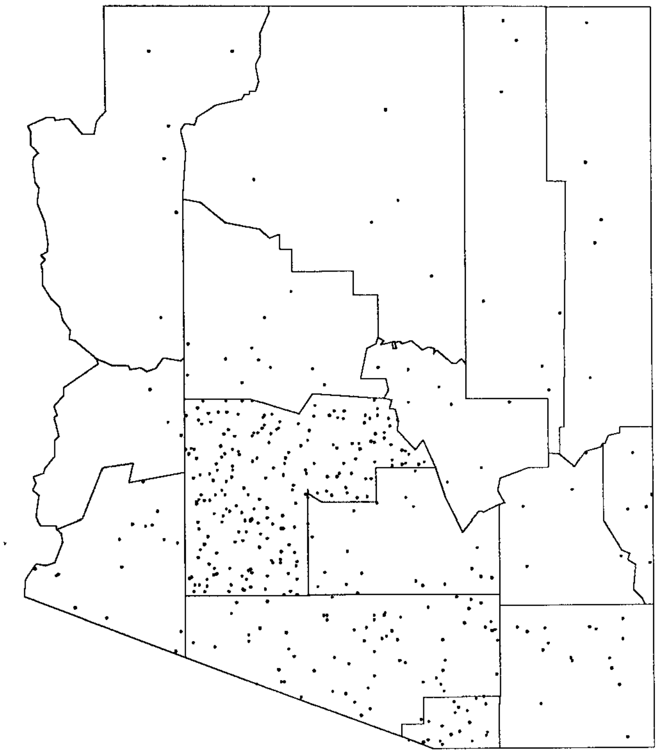
Aquifer Vulnerability Map of Arizona



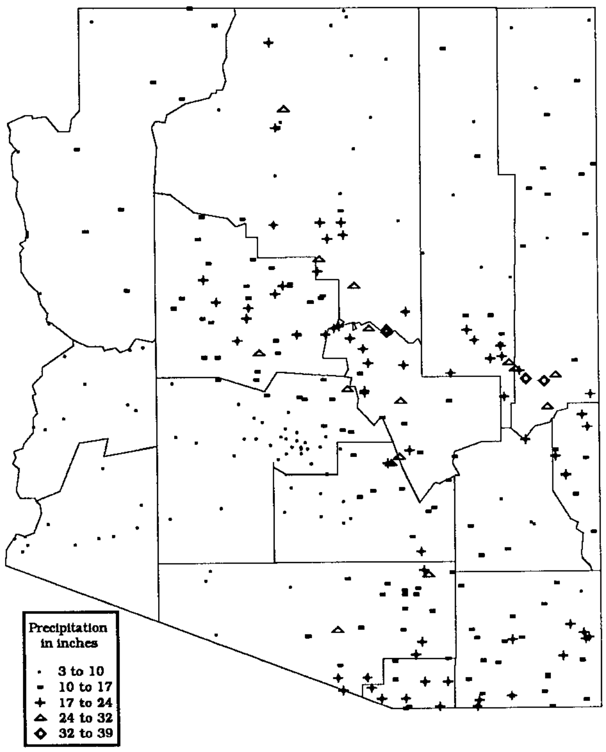
Potential Well Yields in Arizona



Aquifer Sensitivity Map of Arizona



Population Density of Arizona (Dot equals one person per square mile)



Average Annual Precipitation in Arizona

CALIFORNIA

General Setting

California, which contains approximately 158,700 square miles, lies in a physiographically diverse region. The broad and flat, northwest trending, Central Valley is bounded by the rugged mountains and valleys of the Coast Ranges, Klamath Mountains, Southern Cascade Range, Sierra Nevada, and Transverse and Peninsular Ranges subprovinces. Northeastern and southeastern California lie in the arid, block-faulted mountains, valleys, and plateaus of the Basin and Range, as well as the Southern California Desert. California's mountains are composed of a variety of folded and faulted, Precambrian to Cenozoic age sedimentary, igneous, and metamorphic rocks. Sedimentary and metasedimentary units include consolidated Precambrian to Mesozoic age marine shale, sandstone, conglomerate, limestone, and dolomite, and their metamorphic equivalents, as well as metavolcanic and granitic rocks. Cenozoic units include partially consolidated, marine and nonmarine, sandstone, shale, conglomerate, and siltstone, as well as igneous intrusive and extrusive rocks. Valley- and basin-fill deposits generally consist of considerable thicknesses of interbedded, unconsolidated, marine and nonmarine, sand, gravel, silt, and clay of Cenozoic age.

Most of California is drained by rivers that originate in the mountainous parts of the state and flow westward to the Pacific Ocean. Rivers in northeast and southeast California commonly terminate in closed basins. Annual precipitation is highly variable, ranging from less than 5 inches in the desert southeast to more than 80 inches along the northwest coast. The majority of California's population, approximately 28.3 million, is located in and around several large coastal cities and within the Central Valley. The remainder of the state is sparsely populated. Use of fresh and saline ground water amounts to about 14,800 and 284 mgd, respectively.

Unconsolidated Aquifers (Class Ia)

A variety of unconsolidated deposits occurs throughout the state, forming both vulnerable and productive aquifers. These unconfined to confined systems, which are present along modern streams and within basins and valleys, consist of unconsolidated, continental and marine origin sand, gravel, silt, and clay. Well yields for Central Valley and desert basin-fill unconsolidated aquifers commonly range from 50 to 1,500 gpm, and may exceed 4,000 gpm. Well yields for coastal and adjacent inland unconsolidated aquifers commonly range from 500 to 1,500 gpm, and may exceed 4,000 gpm. About 32 percent of the state is covered by Class Ia aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Fractured volcanic bedrock aquifers occur throughout northeastern California, and locally in the east-central part of the state. This system consists of faulted and jointed, Tertiary and Quaternary age andesite, rhyolite, and basalt flows, pyroclastic rocks, and associated sedimentary deposits. Ground-water movement is controlled by the density of joints and faults, as well as the occurrence of permeable rubble zones and clastic interbeds. Well yields commonly range from 100 to 1,000 gpm, and may exceed 4,000 gpm. Precambrian to Mesozoic age granitic and metamorphic rocks crop out across southern California. These units are strongly jointed, weathered, and contain springs. Ground-water movement is controlled by the density of joints, faults, and fractures, the presence of openings along schistocity, bedding, and sheeting planes, and the occurrence of permeable weathered material (Eckis, 1934; Wiese, 1950; Larsen and others, 1951). Similar hydrologic conditions may exist beyond those areas documented. Surface exposures of fractured volcanic and crystalline bedrock aquifers occupy about 17 percent of the state.

Semiconsolidated Aquifers (Class Ic)

Exposures of semiconsolidated, marine and nonmarine sediments occur along coastal and adjacent inland parts of California. These Tertiary age sediments consist of poorly- to well-indurated sand, silt, clay, and gravel. Calcite and hematite are common cementing agents. Volcanic material and minor limestone units occur within the section. Moderate to large well yields and spring discharges are associated with these sediments. Surface exposures of semiconsolidated aquifers occupy about 9 percent of the state.

Lower Yield Bedrock Aquifers (Class IIb)

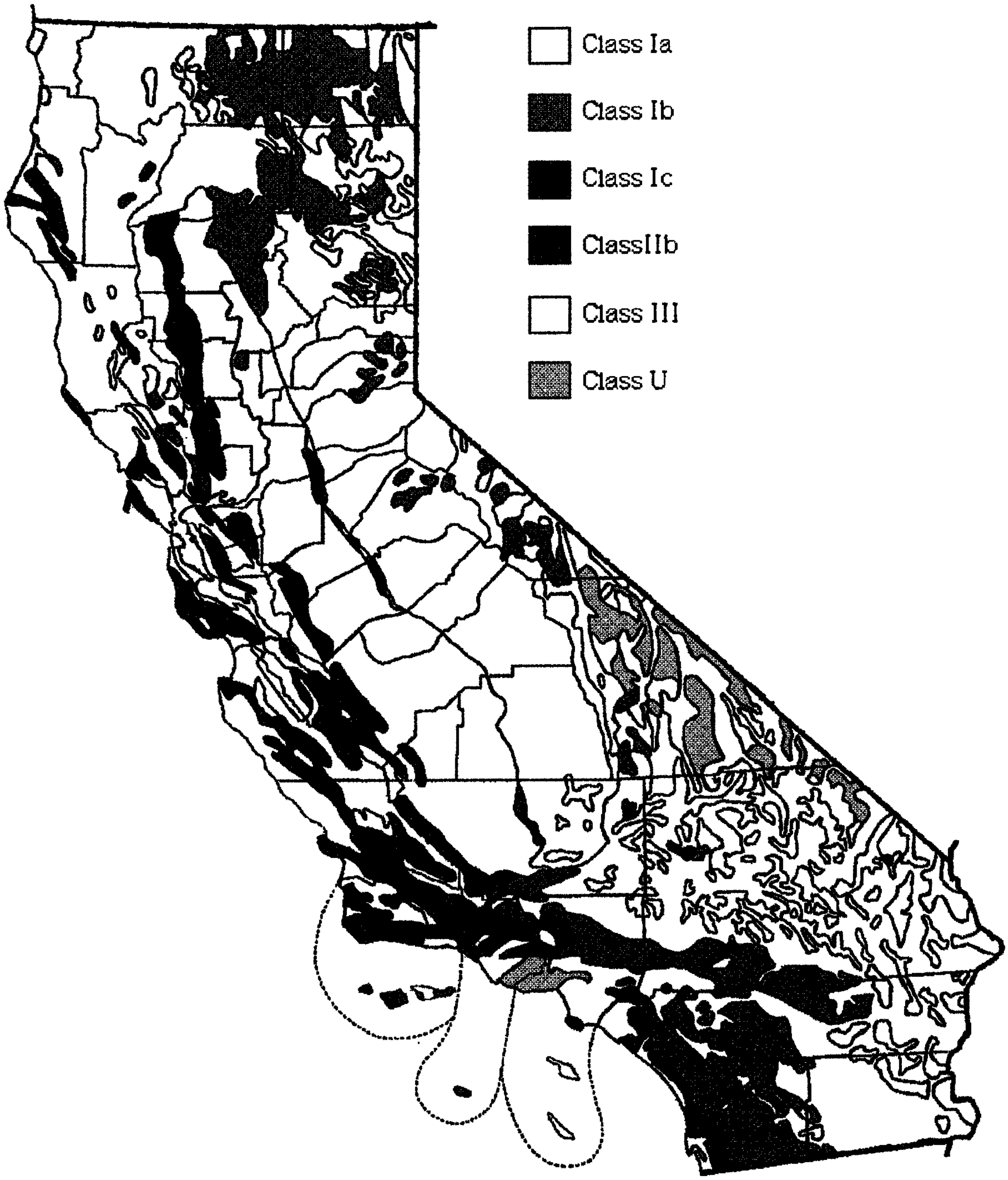
Lower yield Jurassic and Cretaceous age aquifers, composed of sandstone, shale, and conglomerate, interbedded with limestone and pyroclastic rocks, crop out within the coastal mountains of central and northern California. Low quantities of ground water are produced from wells and springs in these units. About 5.4 percent of California consists of Class IIb aquifers.

Undifferentiated Aquifers (Class U)

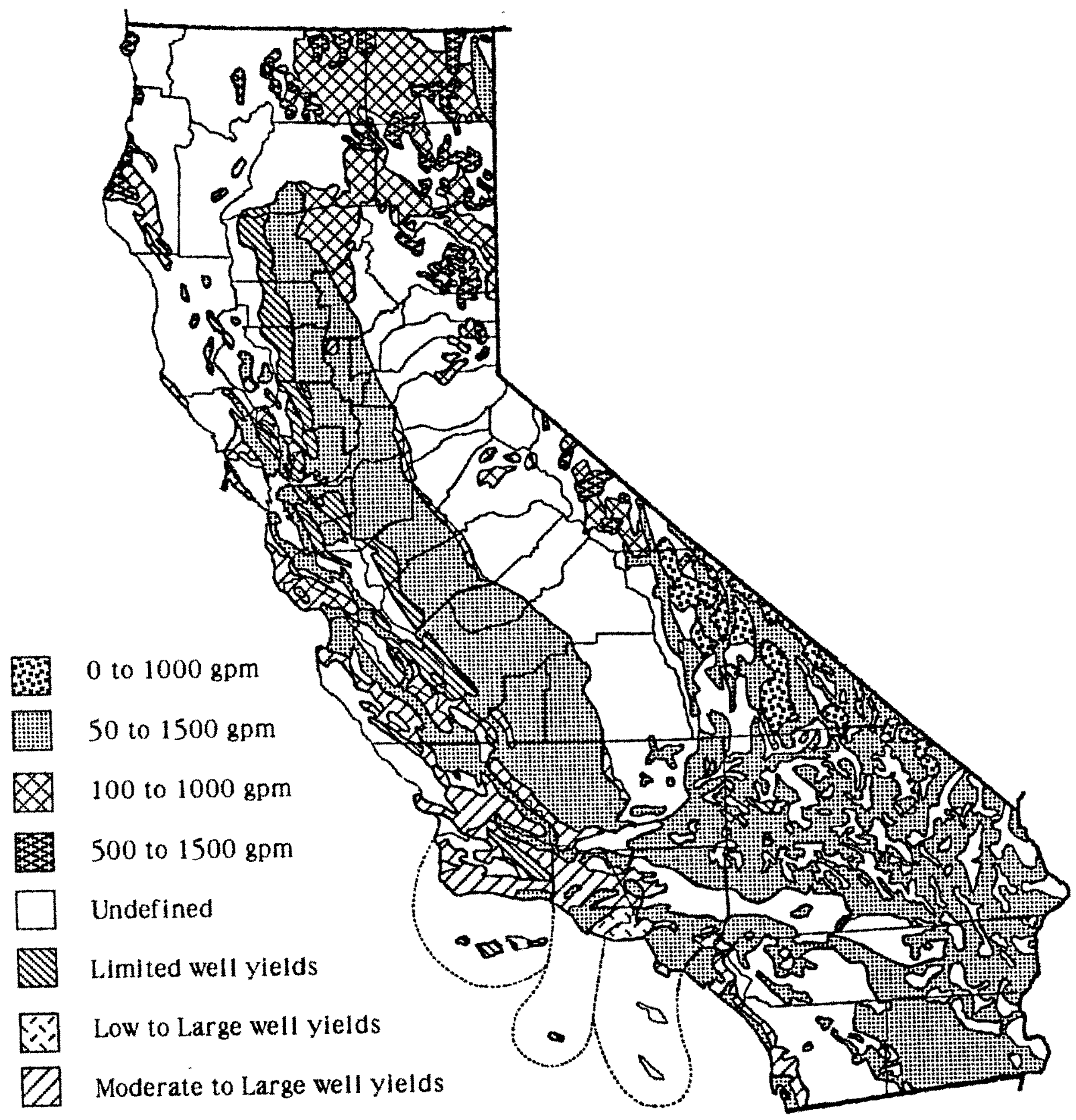
Several undivided and lithologically varied Precambrian and Paleozoic age formations, which crop out in the mountains of eastern California, consist of folded and faulted limestone, dolomite, sandstone, shale and metasedimentary rocks. The presence of karst features, numerous springs, and complexly faulted and fractured rock, provide the potential for ground-water movement in this region (Kunkel, 1962; Winograd and Thordarson, 1975). The lithologic, structural, and resultant hydrologic variability of these undivided formations have not been delineated. A wide range in aquifer permeability and vulnerability should be expected in these areas. In addition, undivided and lithologically varied Cretaceous and Tertiary age formations, which crop out along part of the southern California coast, consist of consolidated and semiconsolidated clastic sediments, as well as intrusive and extrusive igneous rocks. Surface exposures of undifferentiated aquifers occupy about 2 percent of the state.

Sensitivity

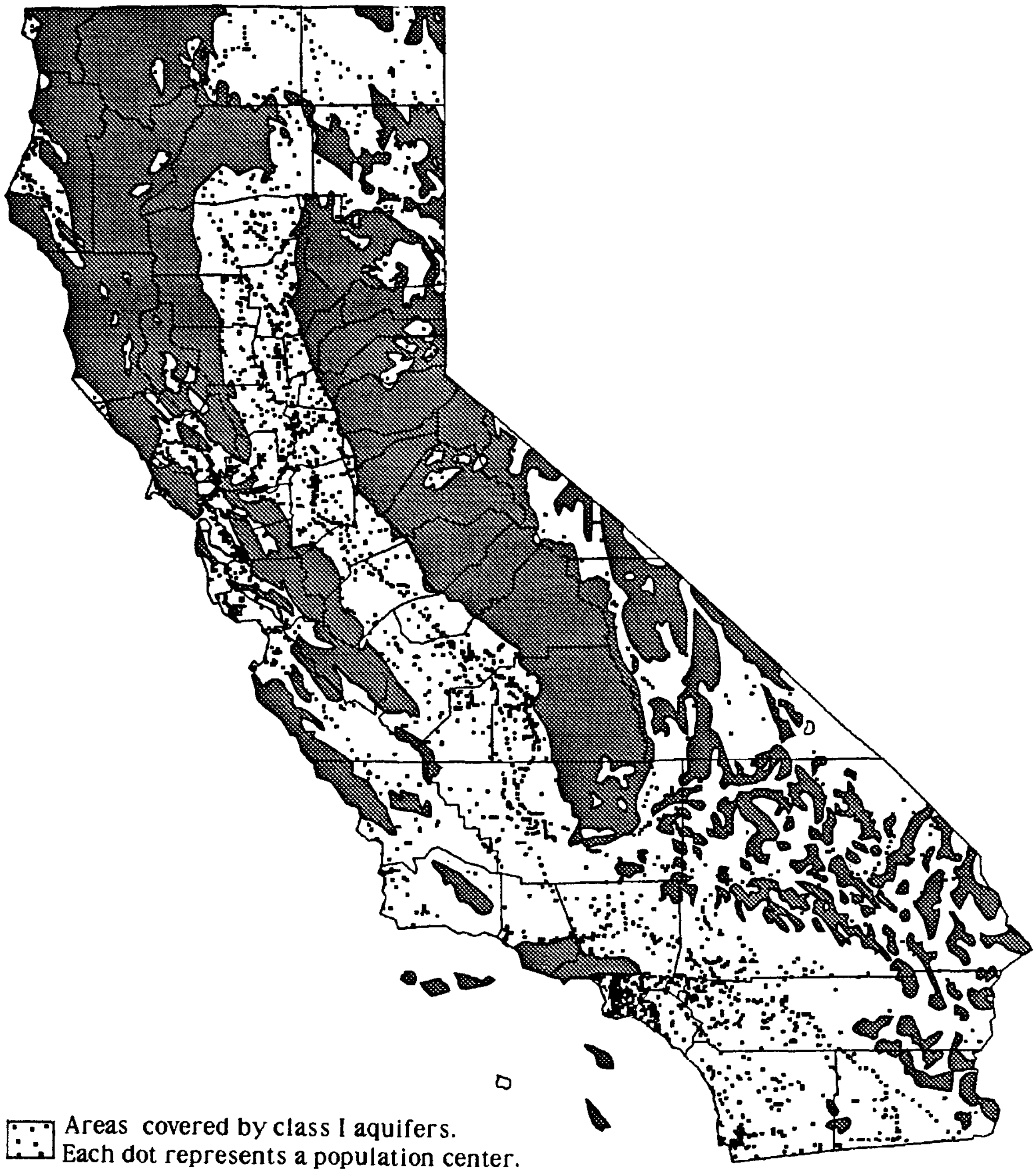
About 58 percent of California contains Class I aquifers. The potential for ground-water contamination from shallow injection wells is high in the densely populated, vulnerable areas in the vicinity of Los Angeles, San Francisco, and much of the Central Valley. Although vulnerable, wide areas between the major metropolitan areas and in the desert in the eastern part of the state are not particularly sensitive owing to the light distribution of population centers.



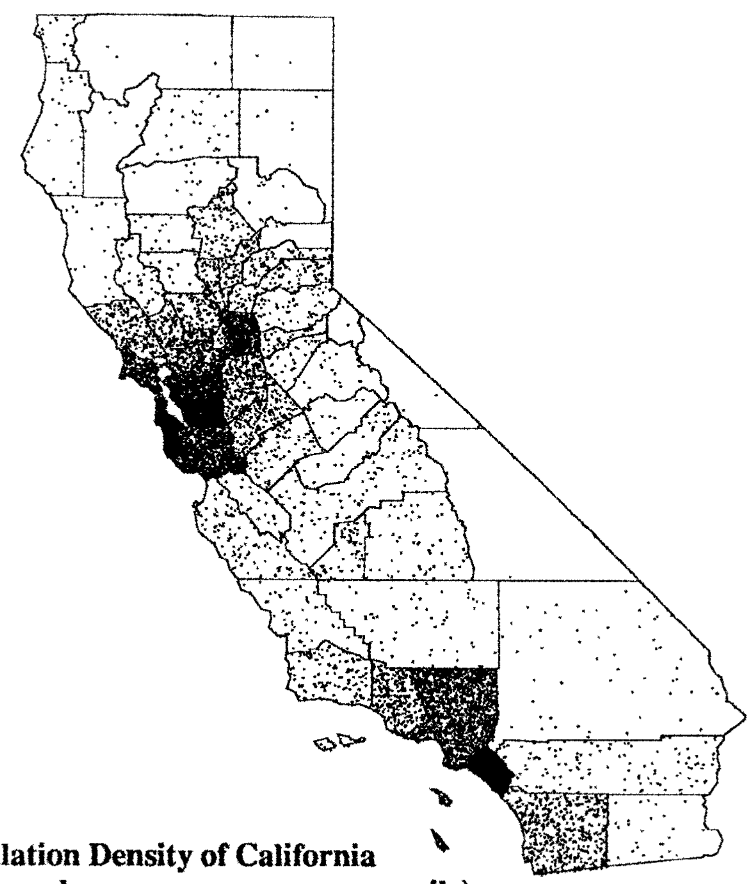
Aquifer Vulnerability Map of California



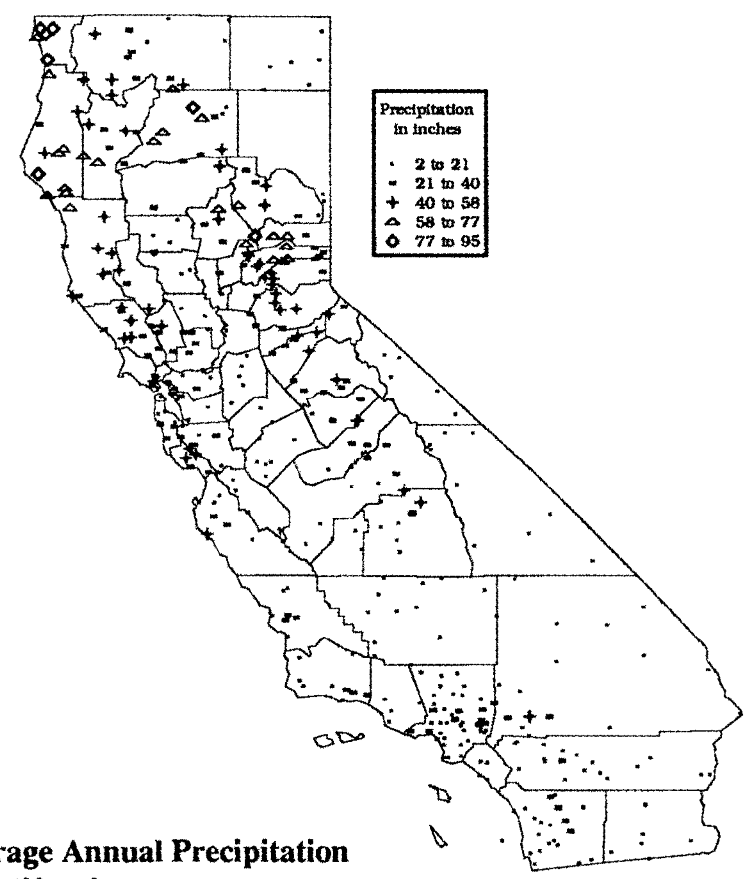
Potential Well Yields in California



Aquifer Sensitivity Map of California



Population Density of California
(Dot equals one person per square mile)



Average Annual Precipitation
in California

NEVADA

General Setting

Nevada contains approximately 110,561 square miles, and lies primarily in the structurally controlled mountain ranges and intermountain basins of the Basin and Range physiographic province. Small areas in northeastern and western Nevada lie within the Columbia Plateaus and Cascade-Sierra Mountains provinces. The mountains of eastern and southeastern Nevada consist largely of Paleozoic age limestone, dolomite, and shale. Mesozoic and Cenozoic age siliciclastic and igneous rocks become increasingly abundant in the mountains of central and western Nevada. Intermontane basins contain thick accumulations of Cenozoic age alluvial, lacustrine, and volcanic deposits.

Nevada receives water from the Truckee, Carson, and Walker rivers, which originate in the Sierra Nevada and end in closed basins within the state. The Humboldt River drains north-central Nevada and terminates in the Humboldt Sink, while the Colorado River drains southeastern Nevada. Annual precipitation ranges from 4 inches in low-altitude valleys to about 16 inches at higher elevations; locally precipitation exceeds 30 inches in the higher mountains. Nevada's average annual precipitation, 9 inches, is the lowest in the Nation. Ground-water recharge occurs primarily in the mountains and adjacent alluvial fans. The majority of Nevada's population, approximately 1,054,000, is located in Clark, Washoe, and Carson City counties. The remainder of the state is sparsely populated. About 905 and 2.8 million gallons of fresh and saline ground water, respectively, are used daily in Nevada.

Unconsolidated Aquifers (Class Ia)

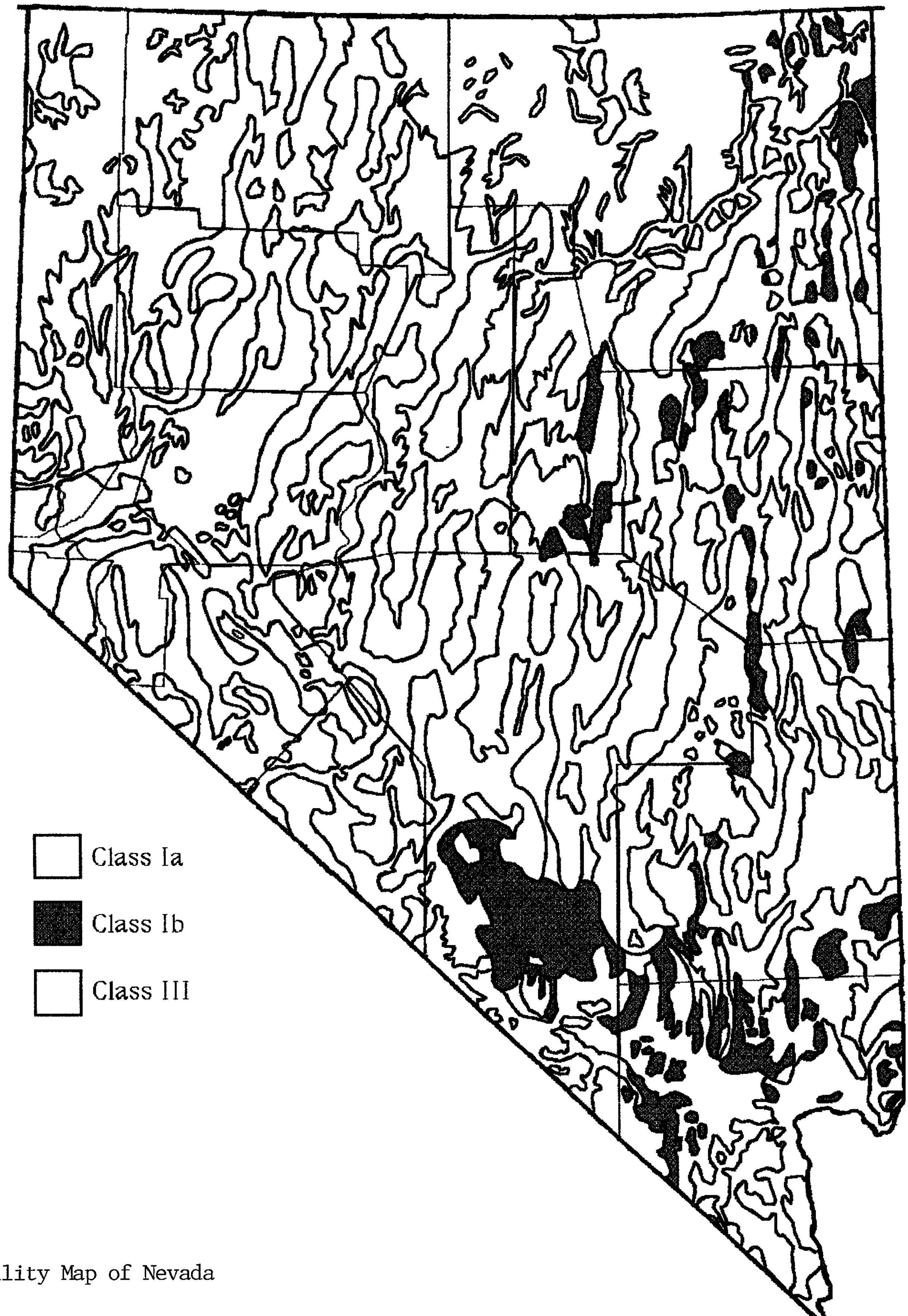
Basin fill, alluvial, colluvial, and lacustrine deposits form some of the most vulnerable aquifers in the state, and comprise Nevada's major ground-water resource. These unconfined to confined systems generally consist of permeable, unconsolidated gravel, sand, silt, and clay that commonly range from 2,000 to 5,000 feet in thickness, and may exceed 10,000 feet. The upper 1,000 feet are generally the most permeable (Bedinger and others, 1984). Well yields commonly range from 200 to 1,000 gpm, and may exceed 5,000 gpm. Evaporite deposits, limestone, and volcanic rocks are locally interbedded within the basin-fill deposits. About 51 percent of the state is covered by Class Ia deposits.

Soluble and Fractured Bedrock Aquifers (Class Ib)

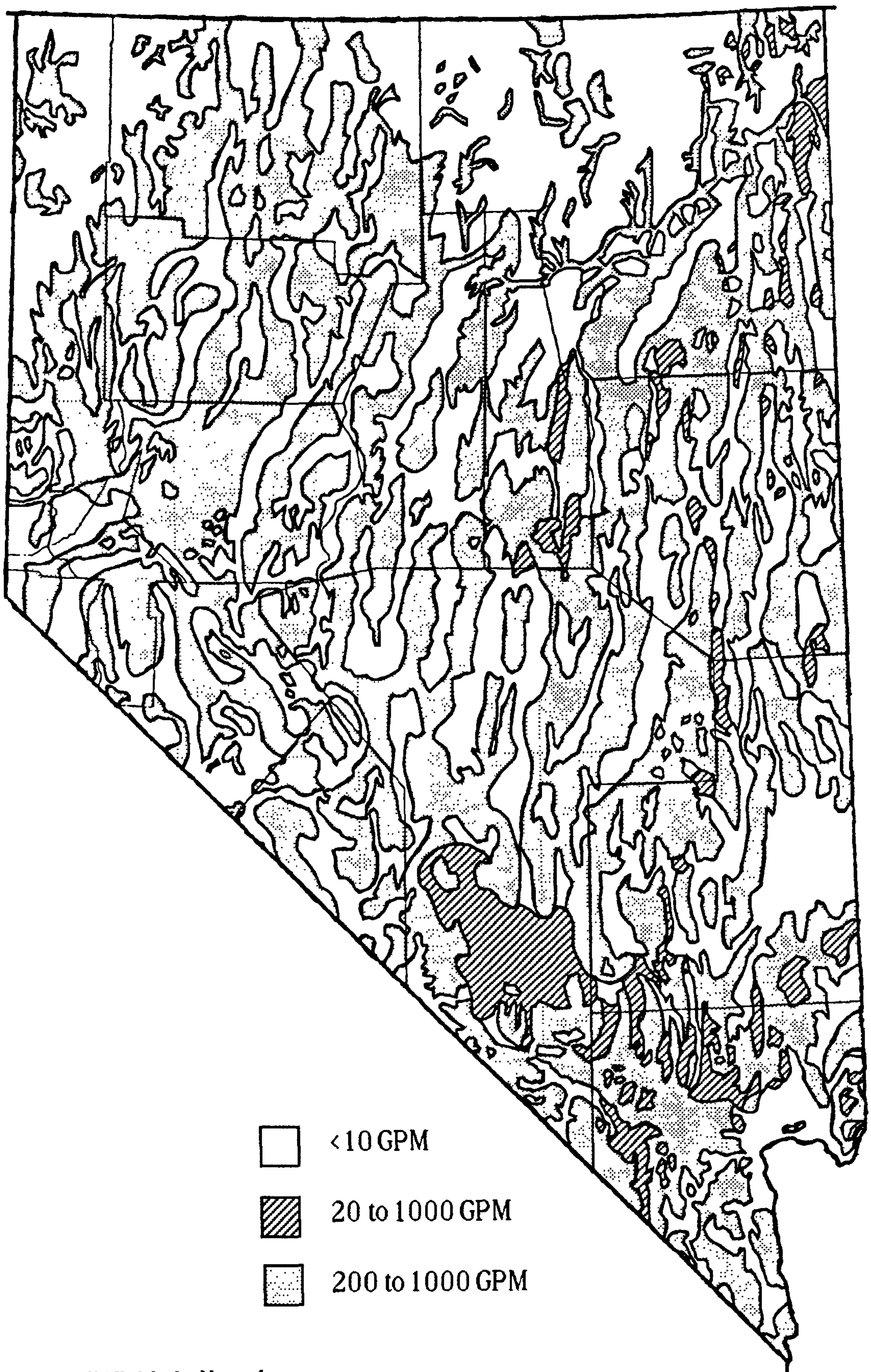
Solutional features and fractures are present in carbonate rocks in eastern and southeastern Nevada. Where present, solutional features and fractures contribute to the vertical and lateral permeability of the rock, creating highly productive and vulnerable aquifers. Interbasin ground-water flow is facilitated by secondary permeability. Well yields generally range from 50 to 1,000 gpm, but locally may exceed 3,400 gpm. Fractured volcanic bedrock aquifers occur in the south-central part of the state. These aquifers, unconfined in the outcrop area, consist of interbedded, nonwelded to densely welded ash-flow tuff, bedded ash-fall tuff, and rhyolite and basalt flows. Ground-water movement is controlled by the density of jointing and secondary fractures, the degree of welding, and the presence of rubble between flows. Well yields commonly range from 20 to 1,000 gpm, and may exceed 3,000 gpm. Class Ib aquifers occupy 7.4 percent of the state.

Sensitivity

Although 58 percent of Nevada is covered by Class I aquifers, the potential for ground-water contamination from shallow injection wells is low owing to Nevada's low population density. The potential for contamination is greater along major transportation routes and in the vicinity of large population centers.

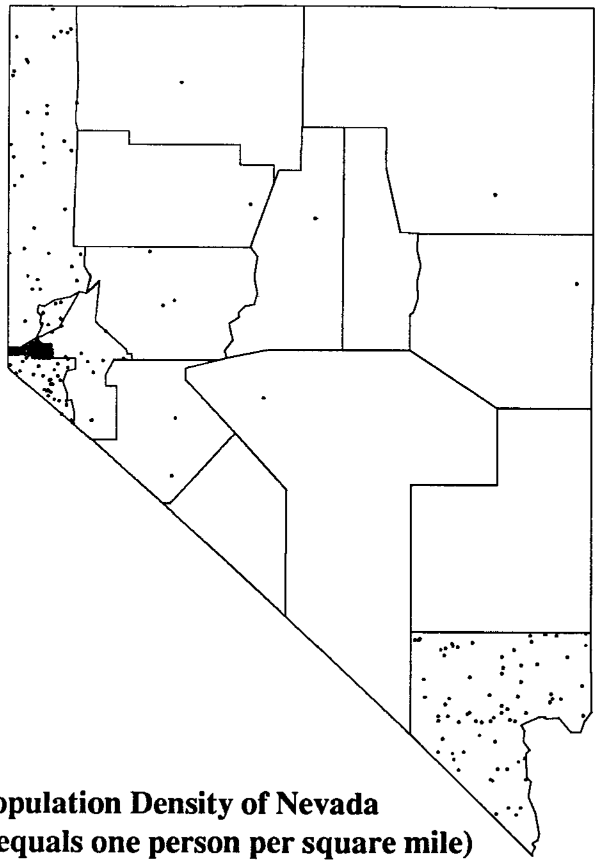


Aquifer Vulnerability Map of Nevada

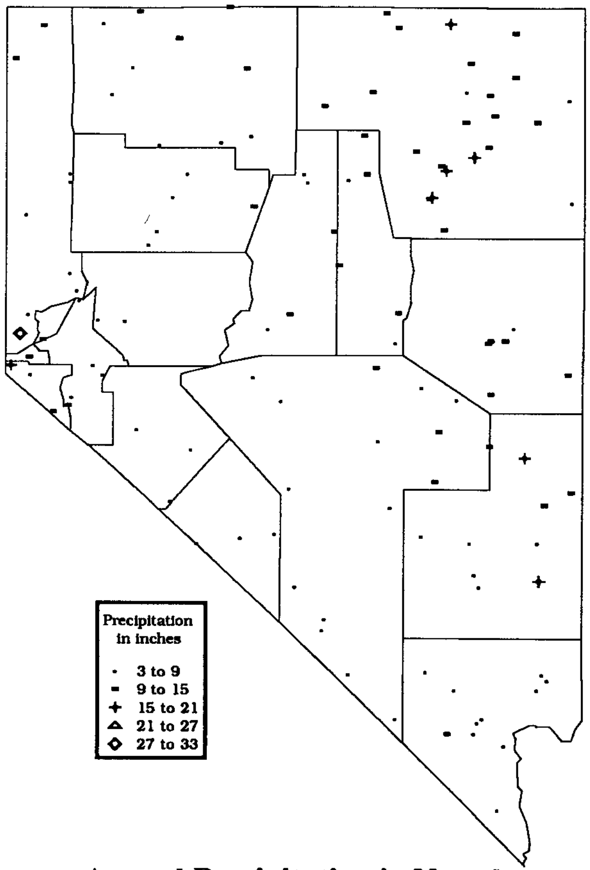


Potential Well Yields In Nevada

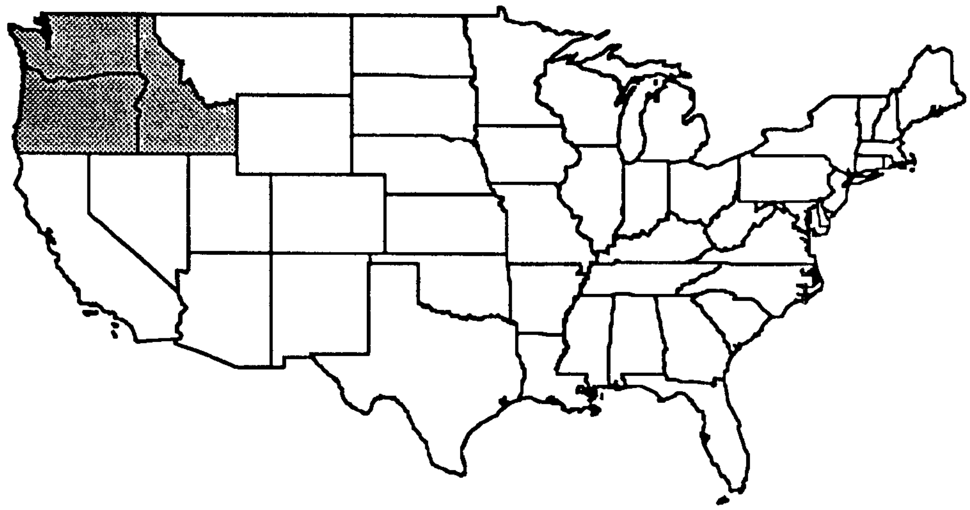
Aquifer Sensitivity Map of Nevada



Population Density of Nevada
(Dot equals one person per square mile)



Average Annual Precipitation in Nevada



REGION 10

Idaho
Oregon
Washington

IDAHO

General Setting

Idaho, which contains 83,564 square miles, lies among the mountains and plateaus of the Northern and Middle Rocky Mountains, Columbia Plateaus, and Basin and Range physiographic provinces. The mountains of northern and central Idaho are underlain by folded and faulted Precambrian age sedimentary and metamorphic rocks and Cretaceous age granitic intrusives. To the south, these units are intruded and overlain by Eocene age granites, lava flows, and pyroclastic material. The mountains of east-central and southeastern Idaho are composed of structurally complex, Paleozoic to Mesozoic age marine and nonmarine sediments and Late Tertiary and Quaternary age lava flows and pyroclastic material. Exposures of Mesozoic age volcaniclastics and metasediments occur locally in west-central Idaho. The remainder of the state is underlain by jointed and locally faulted basalt flows and associated pyroclastic and interbedded detrital material and by glacial and alluvial deposits of Tertiary and Quaternary age. Except for the southeastern corner of Idaho, the entire state is drained by the west- and north-flowing Snake River, and the west- and northwest-flowing Spokane, Pend, Oreille, and Kootenai rivers. The Bear River drains southeastern Idaho.

Annual precipitation varies with topography and ranges from about 10 to 30 inches in the Snake River Plain and surrounding highlands, and from 40 to more than 60 inches in the central mountains. The majority of Idaho's population, approximately a million, is located along the Snake, Boise, and Coeur d' Alene rivers. The remainder of the state is sparsely populated. Daily use of fresh ground water amounts to about 4800 million gallons.

Unconsolidated Aquifers (Class Ia)

Glacial outwash and alluvial deposits occur throughout the state, forming vulnerable and productive aquifers. These generally unconfined systems are present along modern streams and valleys, and consist of gravel, sand, silt, and clay. Well yields commonly range from 2 to 2,000 gpm, and may exceed 3,500 gpm. About 38 percent of the state is covered by permeable unconsolidated sediments.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Fractured volcanic bedrock aquifers occur throughout the Snake River Plain in southern Idaho, and locally along the state's western border. This system consists of jointed and locally faulted, Tertiary and Quaternary age basaltic and silicic flows, associated pyroclastics, and thin interbedded layers of gravel, sand, silt, and clay. Ground-water movement is controlled by the density of joints and faults, the presence of rubble between flows, and other voids and cavities produced by cooling and flow processes. Well yields commonly range from 300 to 3,300 gpm, and may exceed 7,000 gpm. Mississippian age limestone and dolomite of the Madison Group crop out in southeastern Idaho. Little data are available concerning these rocks in Idaho because they are found in rugged, sparsely populated areas. However, solutional features in the Madison Group have been documented in Idaho. Class Ib aquifers occupy about 31 percent of the state.

Variably Covered Aquifers (Class Ib-v)

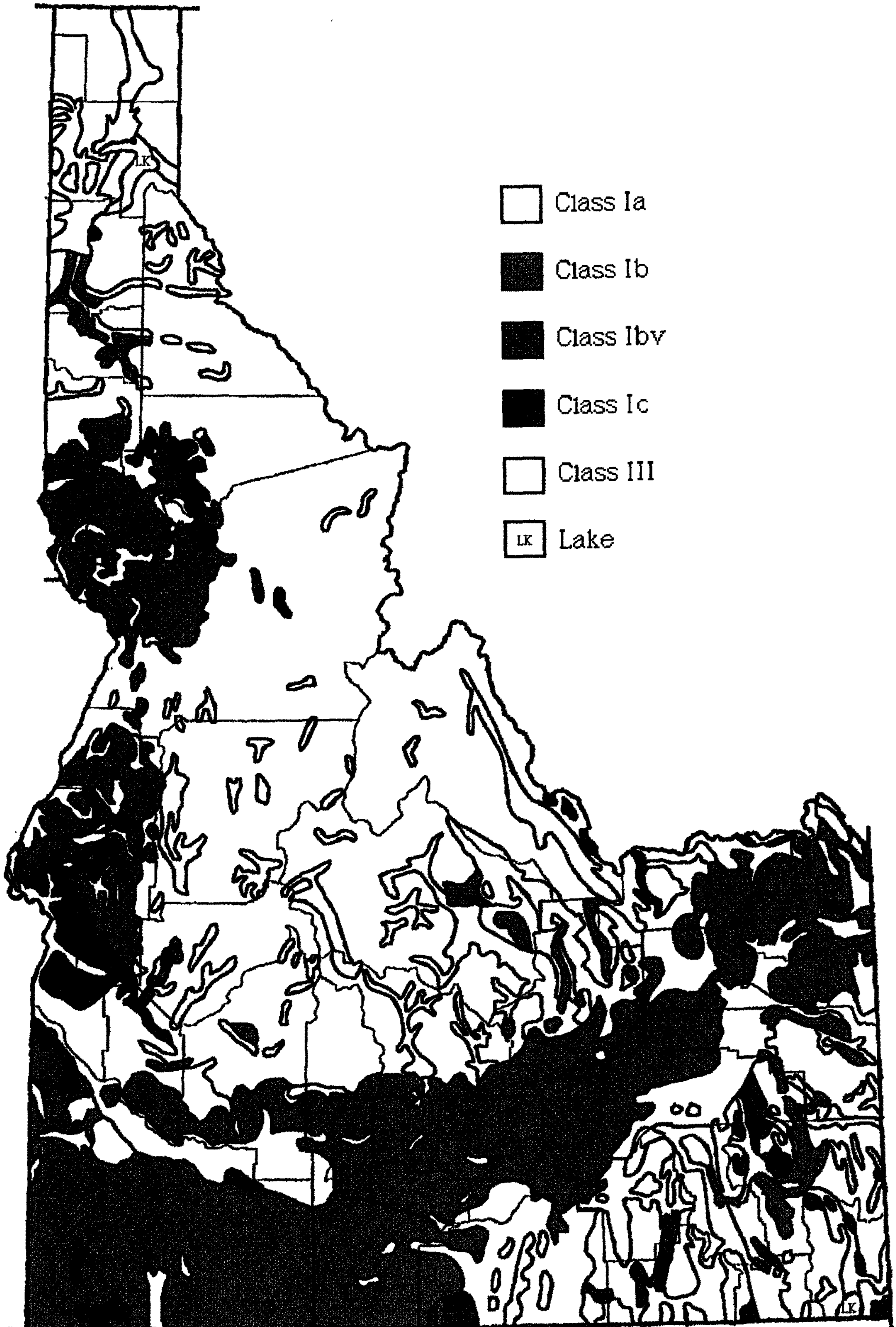
Fractured volcanic bedrock aquifers, overlain by an undetermined thickness of loess, occur along the northwestern border of Idaho. Well yields commonly range from 300 to 3,300 gpm, and may exceed 7,000 gpm. The vulnerability of this system is a function of the thickness of the overlying cover. About 1 percent of the state is underlain by Class Ib-v aquifers.

Semiconsolidated Aquifers (Class IIa)

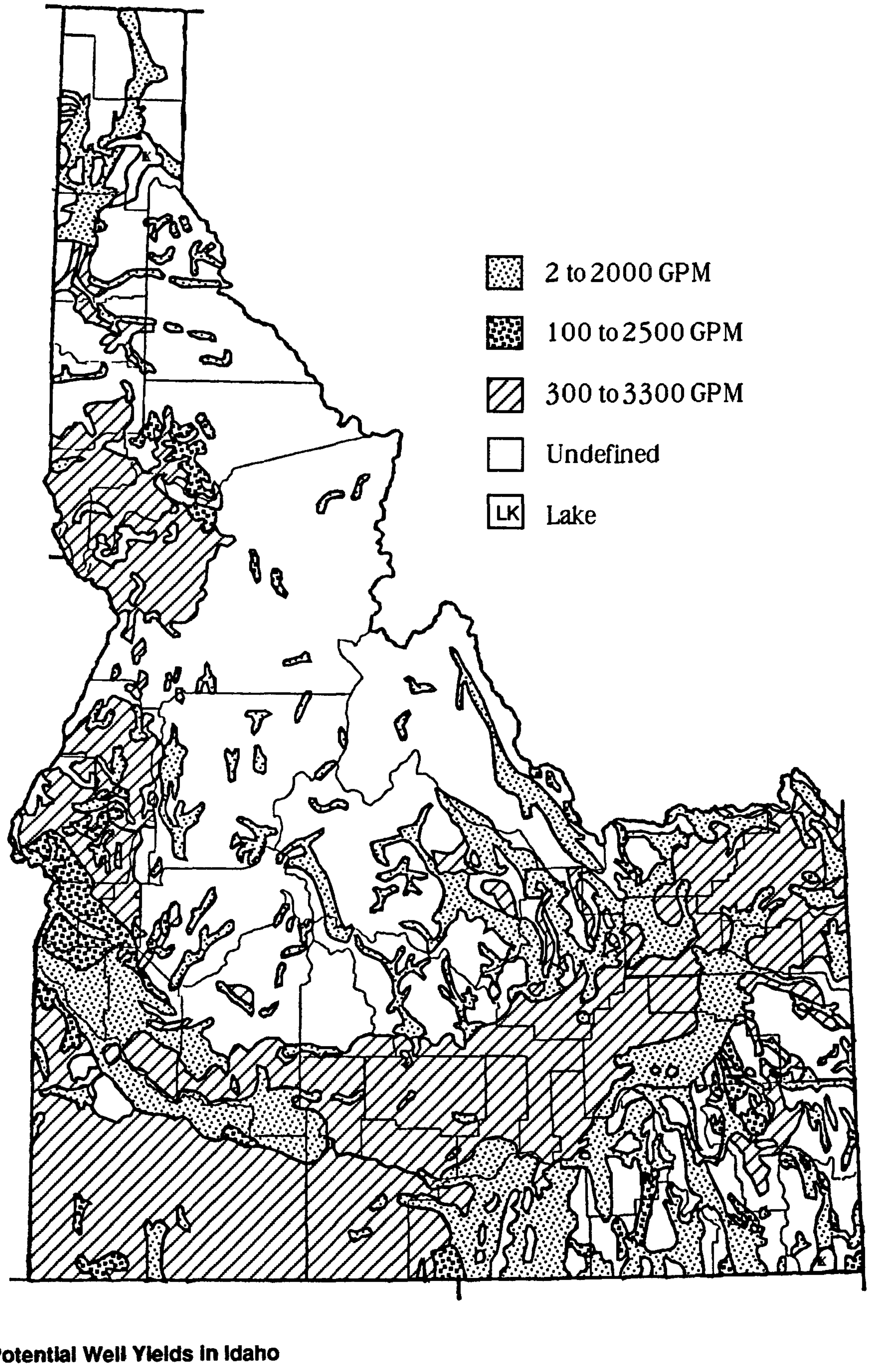
Exposures of semiconsolidated sedimentary and volcanic rocks occur locally throughout mountainous parts of Idaho. These Tertiary age deposits consist of poorly- to moderately-indurated gravel, sand, silt, and clay that is interbedded with basalt and pyroclastic material. Well yields commonly range from 100 to 2,500 gpm, and may exceed 3,000 gpm. Surface exposures of semiconsolidated aquifers occupy about 5.4 percent of the state.

Sensitivity

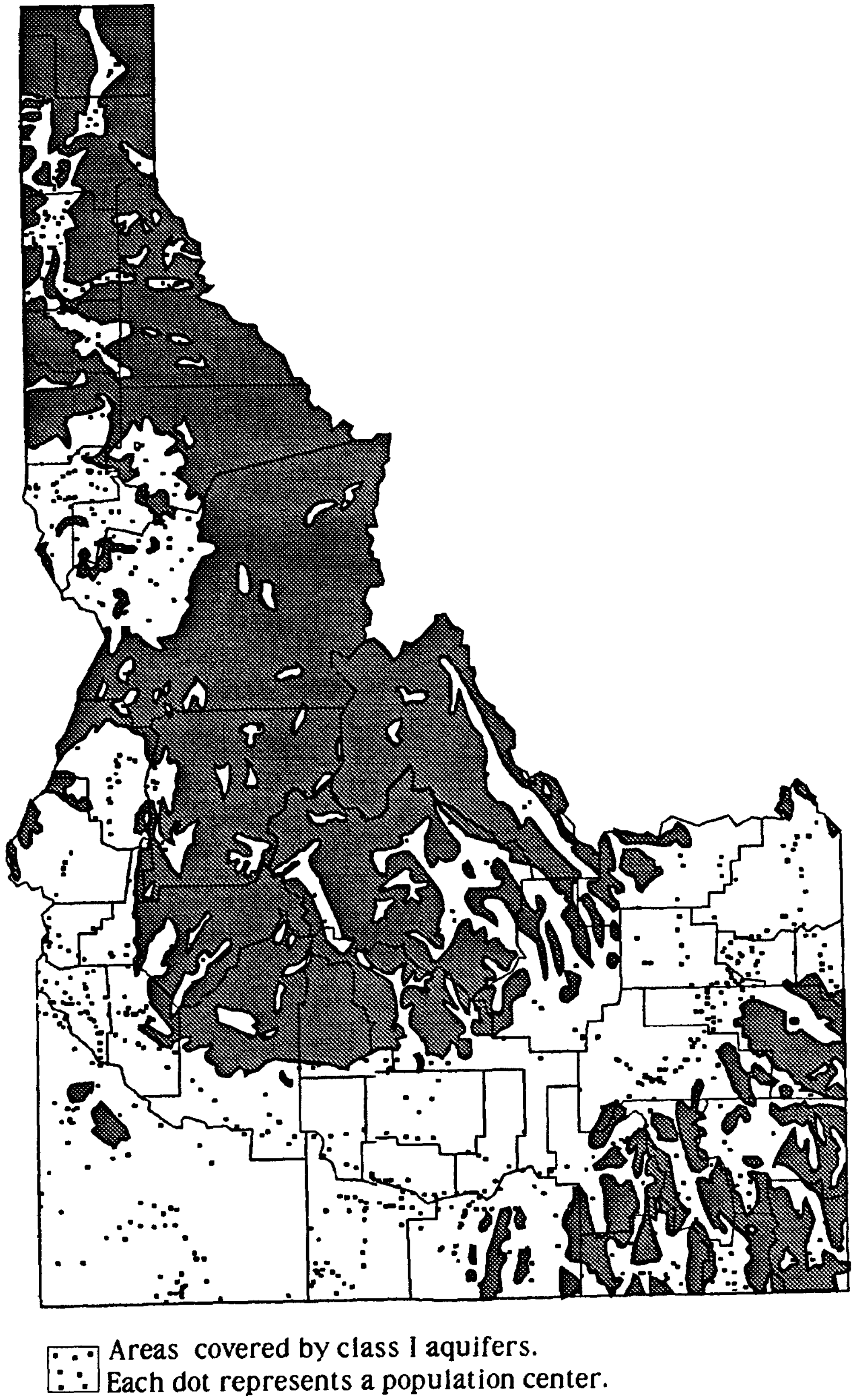
About 70 percent of Idaho is covered by Class I aquifers. The potential for ground-water contamination from shallow injection wells is relatively low due to Idaho's low population. The greatest sensitivity is along major transportation routes, which include the most dense concentration of population centers. An abundance of agricultural drainage wells occurs in the Snake River valley.



Aquifer Vulnerability Map of Idaho

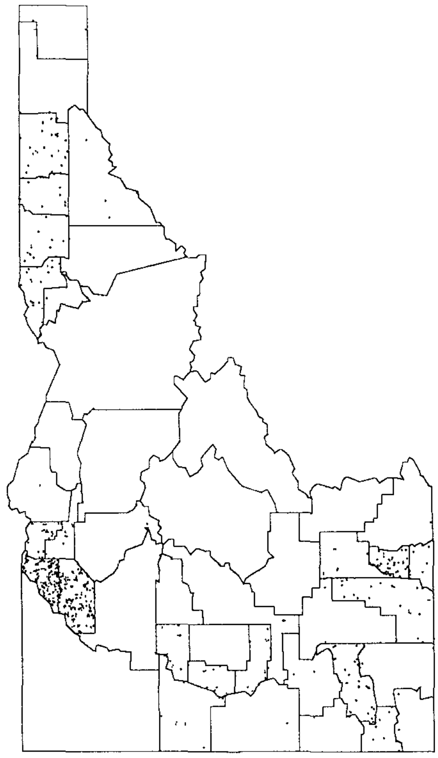


Potential Well Yields in Idaho

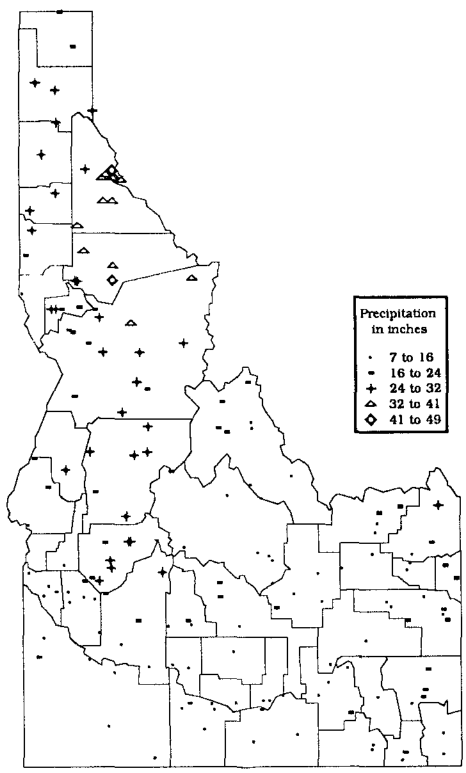


Areas covered by class I aquifers.
Each dot represents a population center.

Aquifer Sensitivity Map of Idaho



Population Density of Idaho
(Dot equals one person per square mile)



Average Annual Precipitation in Idaho

OREGON

General Setting

Oregon contains approximately 97,073 square miles, and is in a physiographically diverse region. The western third of the state lies in the structural valleys and rugged, extensively forested mountains of the Pacific Border and Cascade-Sierra physiographic provinces. South-central Oregon is in the block-faulted mountains and valleys of the Basin and Range province, while the remainder of the state lies in the arid plateaus, lava plains, and mountains of the Columbia Plateaus physiographic province. Oregon's coastal mountains are composed of gently folded, Early to Middle Cenozoic age marine sedimentary rocks and basalt and, to the south, Late Paleozoic to Mesozoic age metamorphic, sedimentary, and igneous rocks. To the east, semiconsolidated nonmarine terrace deposits of the Willamette Valley are bounded by altered Tertiary age volcanic rocks of the Western Cascade Range. Except for the Blue Mountains in northeastern Oregon, the remainder of the state is underlain by Quaternary and Tertiary age basalt and andesite flows, volcanic ash, and glacial and alluvial deposits. The Blue Mountains consist of Paleozoic to Mesozoic age metamorphic, igneous, sedimentary, and altered volcanic rocks.

Eastern Oregon is drained by the Snake River and its many tributaries. North-central and western Oregon are drained by the Columbia River and its north flowing tributaries, as well as by numerous shorter rivers that discharge directly into the Pacific Ocean. Annual precipitation varies with altitude and ranges from about 25 to 180 inches in western Oregon and from about 10 to 80 inches in the east. The majority of Oregon's population, approximately 2.7 million, is located along the Willamette Valley. The remainder of the state is sparsely populated. Daily use of fresh ground water amounts to about 660 million gallons.

Unconsolidated Aquifers (Class Ia)

A variety of unconsolidated deposits occusr throughout the state, forming vulnerable and productive aquifers. These generally unconfined systems are present along modern streams, on terraces and pediments above present flood plains, and within basins. Alluvial sediments and exposures of outwash and pediment deposits adjacent to the Columbia River consist of unconsolidated sand, gravel, silt, and pyroclastic debris. Outwash, terrace, and pediment deposits in southeastern Oregon consist of unconsolidated gravel, cobbles, and boulders, with clay, silt, and sand. Unconsolidated dacite ash-flow and ash-fall deposits floor parts of the Klamath Basin in southwestern Oregon. Dune sands contain ash and pumice. Well yields commonly range from 100 to 500 gpm, and may exceed 2,000 gpm. About 7.5 percent of the state is covered by Class Ia aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Fractured volcanic bedrock aquifers occur throughout the eastern three-fourths of the state, locally within the Willamette Valley, and in northwestern Oregon. These aquifers consists of faulted and jointed Miocene and Quaternary age basalt, andesite, and minor rhyolite flows, flow breccias, ash-flow tuffs, and interbeds of tuffaceous sand, gravel, silt, and clay. Some flows range from vesicular to scoriaceous. Ground-water movement is controlled by the density of joints and faults, and the occurrence of permeable clastic interbeds. Well yields commonly range from 50 to 500 gpm, and may exceed 3,000 gpm. Surface exposures of fractured volcanic bedrock aquifers occupy 44.5 percent of the state.

Variably Covered Aquifers (Class Ib-v)

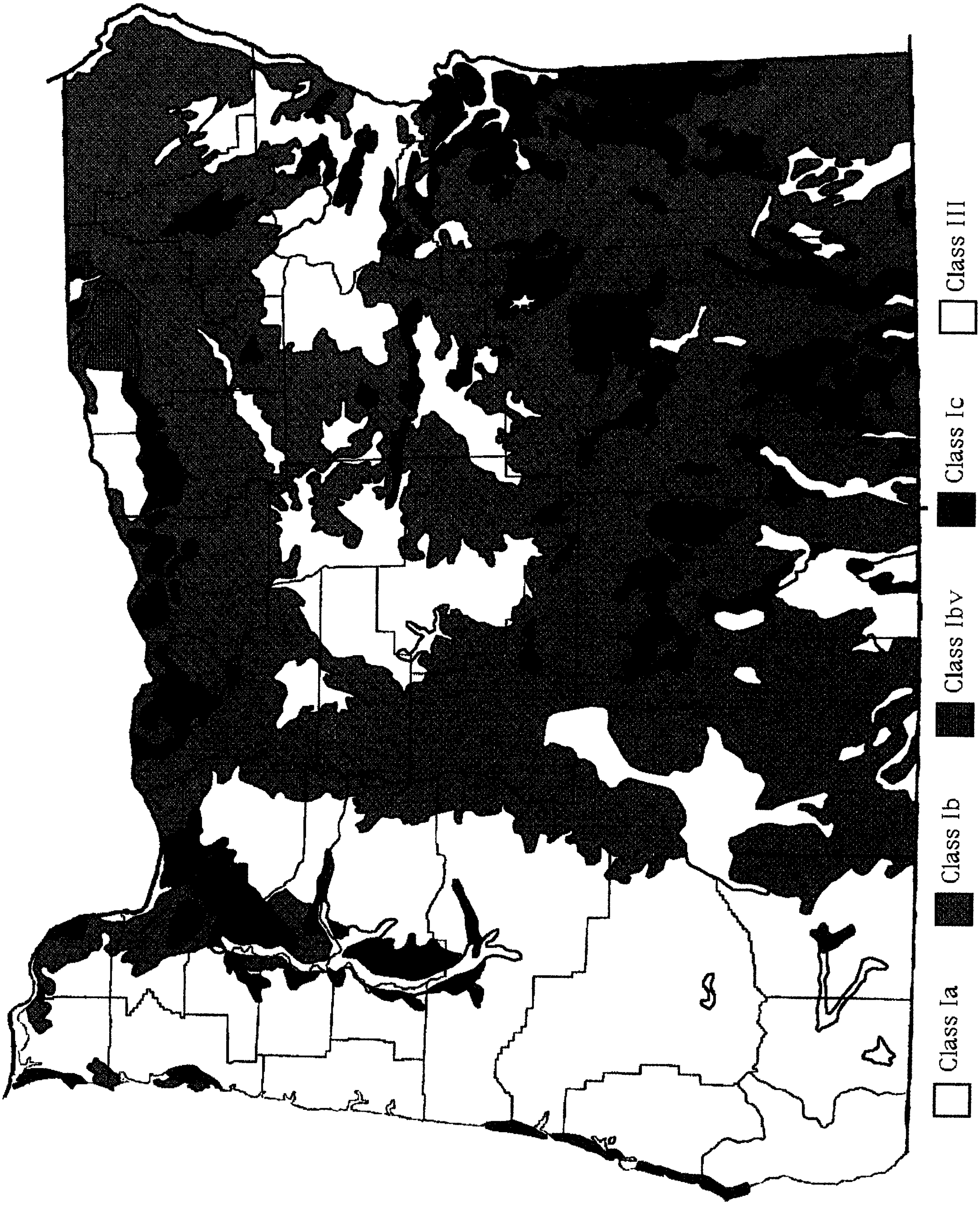
Fractured volcanic bedrock aquifers, overlain by an undetermined thickness of low permeability wind-blown clayey silt and fine sand, occur adjacent to the Columbia River in northeastern Oregon. The vulnerability of these aquifers is a function of the thickness and permeability of the overlying sediments. About .6 percent of the state is covered by Class Ib-v aquifers.

Semiconsolidated Aquifers (Class Ic)

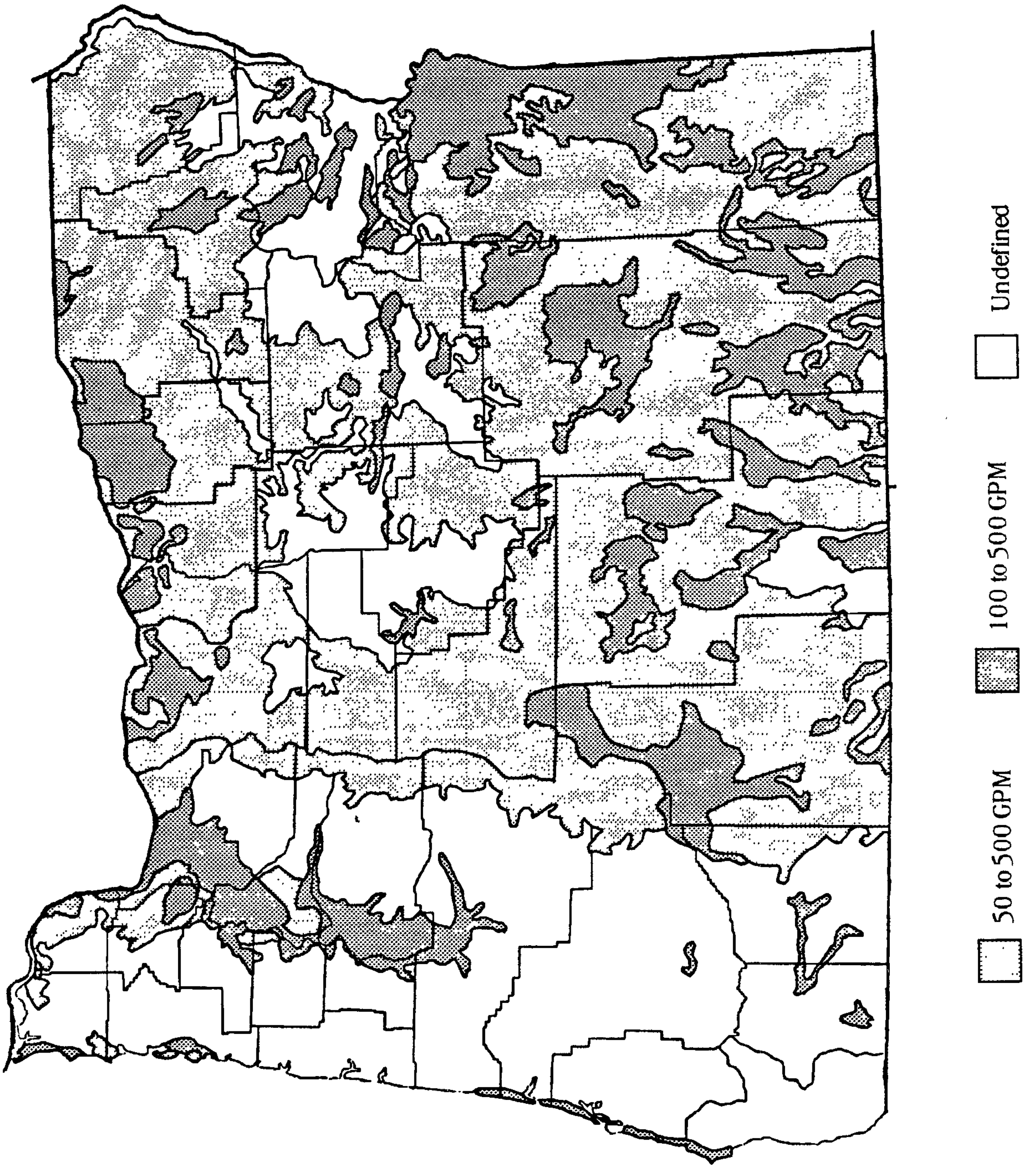
Exposures of semiconsolidated nonmarine and marine sediments occur along Oregon's coast, within the Willamette Valley, and throughout the eastern part of the state. These Quaternary to Tertiary age sediments consist of poorly- to moderately-indurated sand, silt, gravel, and clay. Nonmarine sediments east of the Cascade Range are tuffaceous and pumiceous, and locally grade into Miocene age basalt, andesite, and rhyolite flows. Lignite and diatomite beds occur within the section. Nonmarine sediments within the Willamette Valley contain peat beds and bouldery soils that, locally, are cemented with caliche. Marine sands are commonly silty and contain lenses of gravel, peat, and clay. Well yields generally range from 100 to 500 gpm, and may exceed 2,000 gpm. Surface exposures of semiconsolidated aquifers occupy about 14 percent of the state.

Sensitivity

About 66.5 percent of Oregon is covered by Class I aquifers. Aquifer sensitivity, however, is quite low except in the upper reaches of the Willamette Valley. Although the western two-thirds of the state contains a large expanse of Class I aquifers, vulnerability is low owing to the small population density. Most population centers lie along major highways.

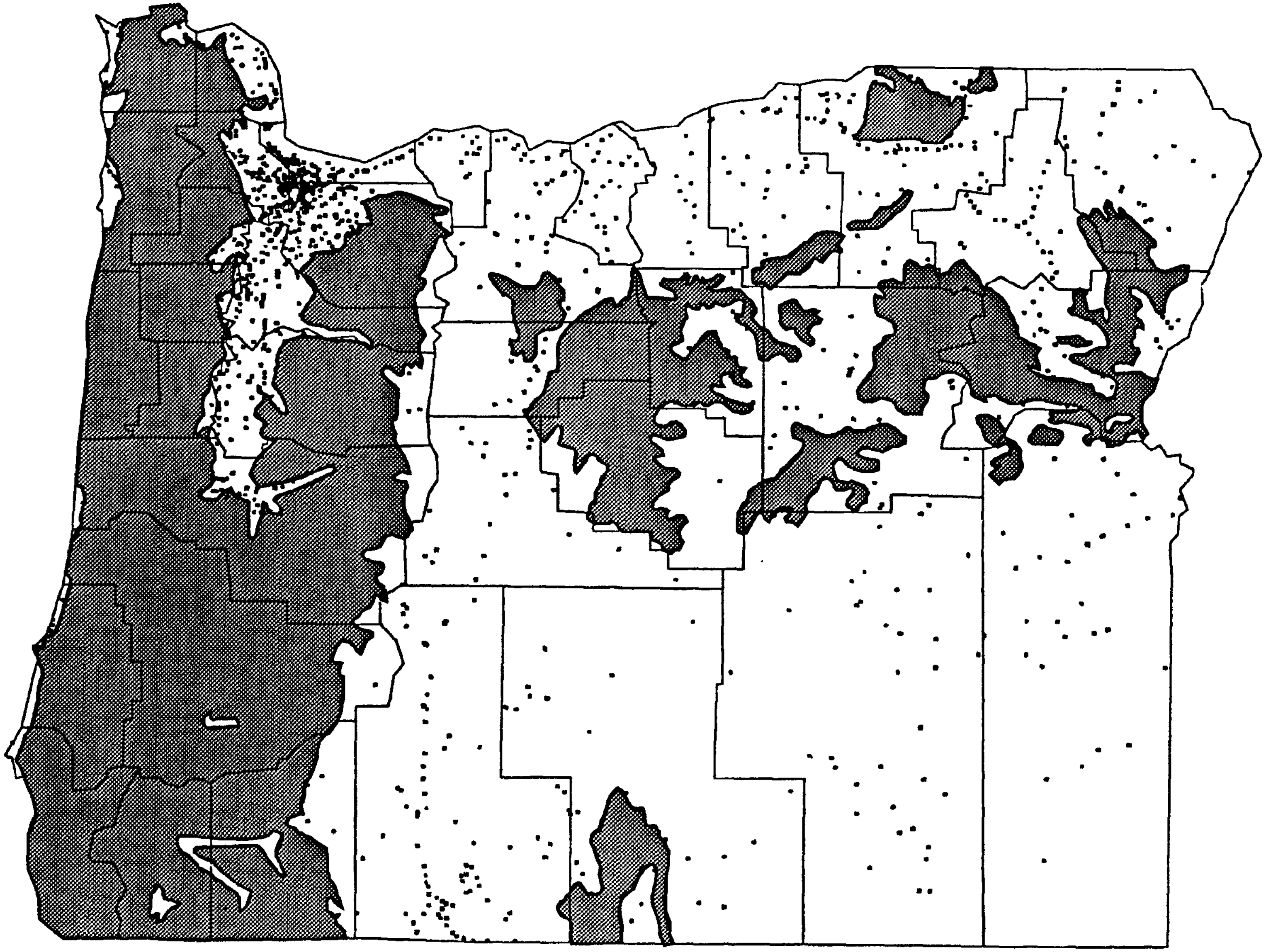


Aquifer Vulnerability Map of Oregon

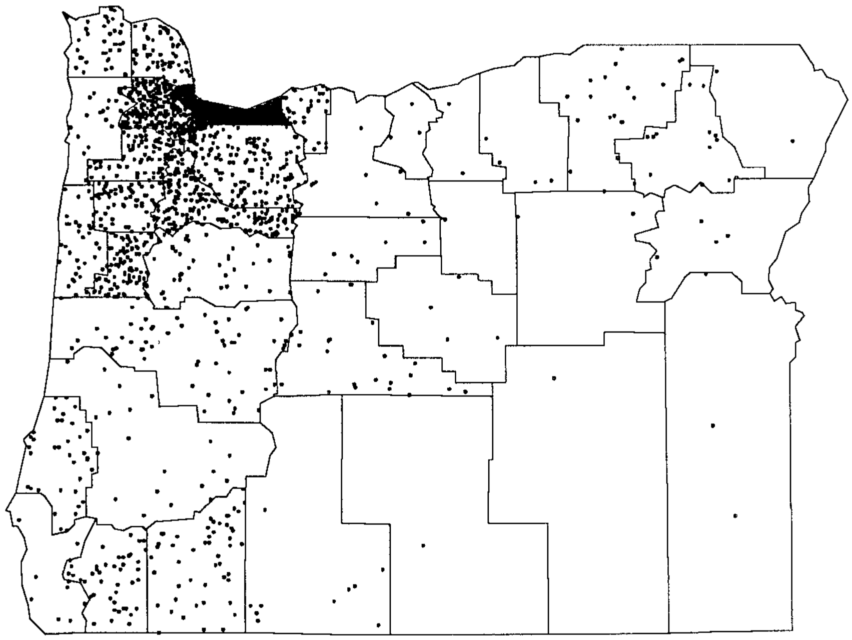


Potential Well Yields in Oregon

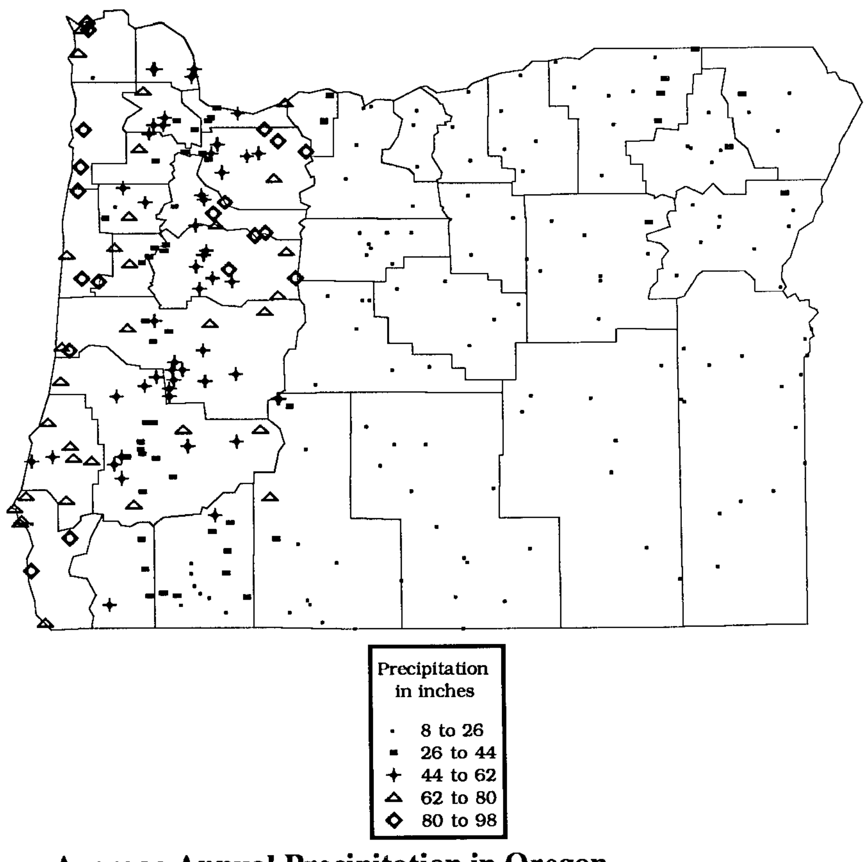
Aquifer Sensitivity Map of Oregon



Areas covered by class I aquifers.
Each dot represents a population center.



Population Density of Oregon (Dot equals one person per square mile)



Average Annual Precipitation in Oregon

WASHINGTON

General Setting

Washington contains approximately 68,140 square miles, and lies in a physiographically diverse region. The north trending Cascade-Sierra Mountains, which contains many rugged and glaciated peaks, roughly bisects the state. To the east lie the mountains and arid high plateaus of the Northern Rocky Mountains and Columbia Plateaus provinces. In the west, lies the Puget Trough and Olympic Mountains subdivisions of the Pacific Border province. The oldest exposed rocks in the state, which crop out in the Northern Rocky Mountains in northeastern Washington, consist of folded and faulted Precambrian age sedimentary and metamorphic rocks that are overlain by Paleozoic age marine sediments. The Cascade Range in north-central Washington is composed of structurally complex, pre-Jurassic age metamorphic rocks that are flanked by Paleozoic and Mesozoic age marine sediments. Exposures of Mesozoic and Early Tertiary age granitic rocks occur throughout the mountains in northeastern and north-central Washington. Cretaceous and Paleocene age continental deposits crop out in the northwestern and central parts of the Cascade Range, and nonmarine and marine sediments of similar age are exposed in the Olympic Mountains in northwestern Washington. The remainder of the state is underlain by Tertiary to Holocene age volcanic rocks, continental and marine sediments, and glacial and alluvial deposits.

Eastern Washington is drained by the south- and westward-flowing Columbia River and its three principal tributaries. Western Washington is drained by numerous shorter rivers, which discharge directly into Puget Sound and Pacific Ocean. Annual precipitation ranges from 8 inches in the east to more than 200 inches in the northwest. The majority of Washington's population, approximately 4.65 million, is located in the Puget Sound region and in several cities along major rivers. The remainder of the state is sparsely populated. About 1220 million gallons of fresh ground water are used daily in Washington.

Unconsolidated Aquifers (Class Ia)

Glacial, alluvial, and eolian deposits form vulnerable and productive aquifers. These generally unconfined systems are present along streams and throughout the glaciated and coastal parts of the state. Outwash deposits and locally permeable till units consist of unconsolidated sand, silt, gravel, and clay. Well yields commonly range from 1 to 1,000 gpm, and may exceed 10,000 gpm. Alluvial deposits consist of unconsolidated silt, sand, gravel, cobbles, and clay. Well yields range from 5 to 50 gpm, and may exceed 200 gpm. Eolian deposits consist of active dune and beach sands. About 16.7 percent of Washington is covered by unconsolidated aquifers.

Soluble and Fractured Bedrock Aquifers (Class Ib)

Fractured volcanic rock aquifers occur throughout southeastern and south-central Washington, and consist of dense, columnar to platy jointed, Miocene age basalt flows with interbeds of unconsolidated sand and gravel. Some flows range from vesicular to scoriaceous. Ground-water movement is controlled by the density of jointing, and the occurrence of permeable clastic interbeds. Well yields commonly range from 150 to 3,000 gpm, and may exceed 6,000 gpm. Surface exposures of fractured volcanic bedrock aquifers occupy 13.4 percent of the state.

Variably Covered Aquifers (Class Ib-v)

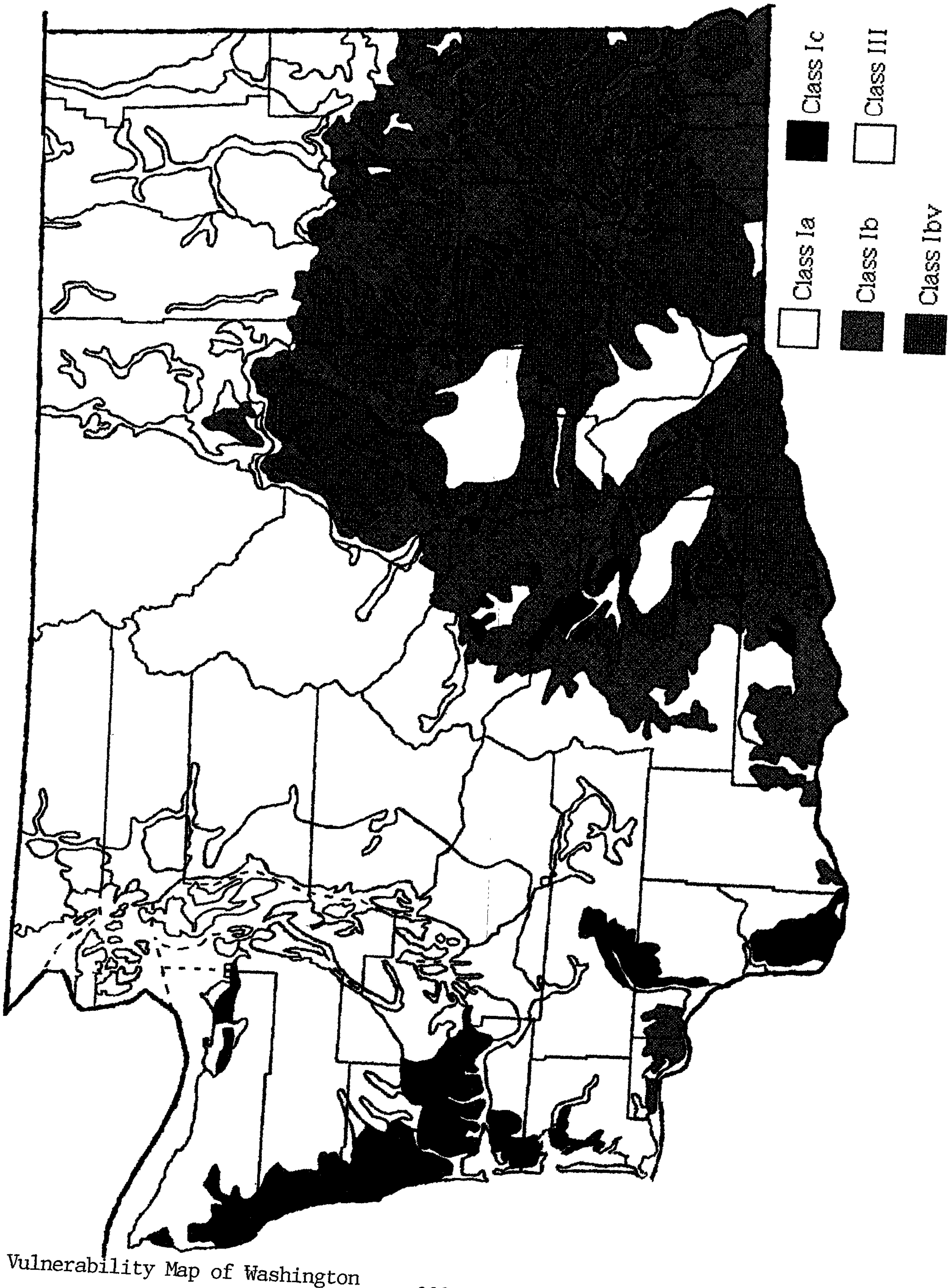
Fractured volcanic rock aquifers, overlain by an undetermined thickness of silt, occur throughout southeastern and south-central Washington. The vulnerability of these systems is a function of the thickness of the overlying low permeability sediments. Class Ib-v aquifers occupy about 19 percent of the state.

Semiconsolidated Aquifers (Class Ic)

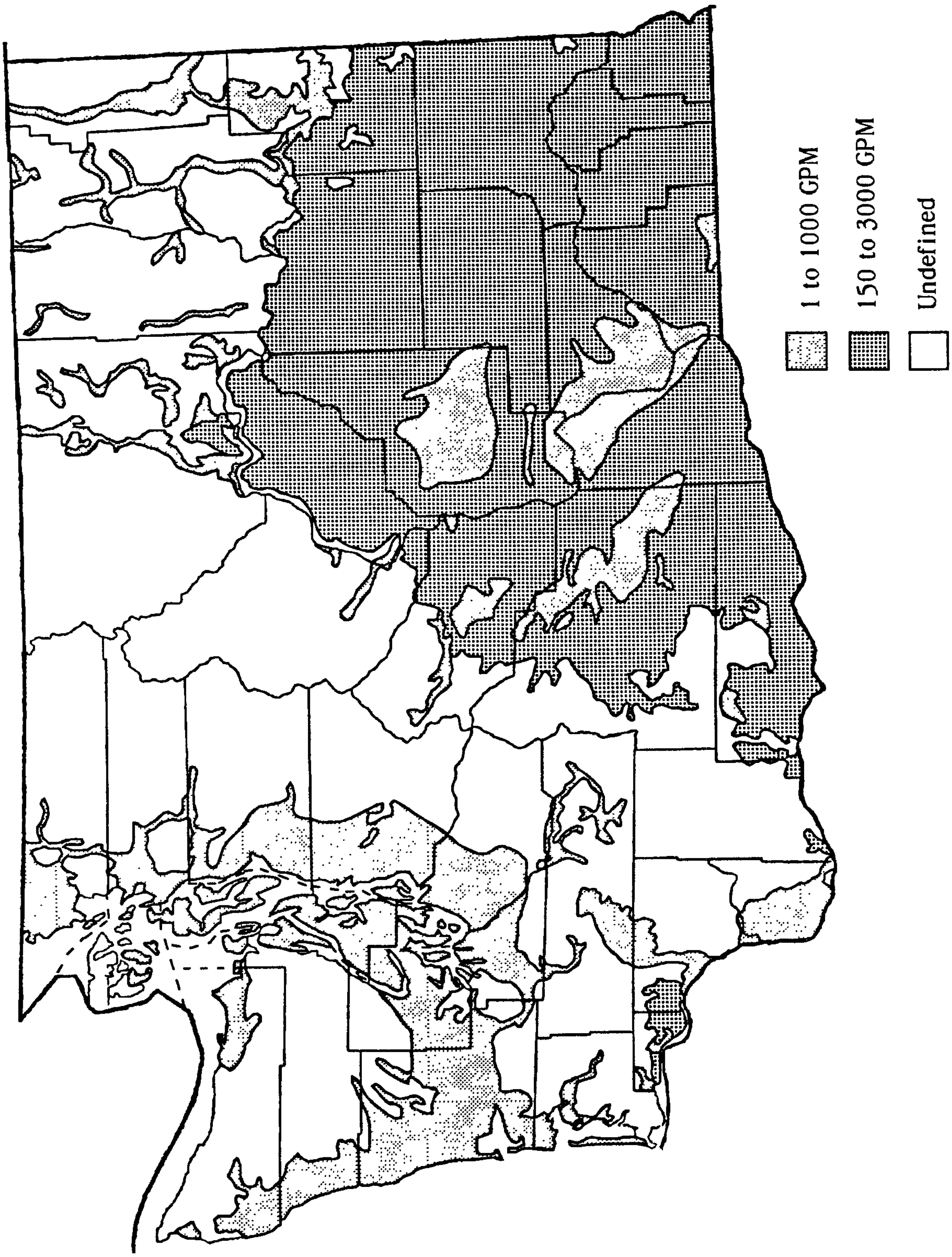
Exposures of semiconsolidated, nonmarine and marine sediments occur along the Washington coast, as well as in southwestern and south-central parts of the state. These Tertiary to Quaternary age sediments consist of poorly- to moderately-indurated sand, gravel, silt, and clay. Nonmarine sands commonly are tuffaceous and pumiceous, and locally calcareous; marine sands tend to be shaley. Basalt flows and diatomite beds occur locally within the section. Well yields commonly range from 10 to 1,000 gpm, and may exceed 4,500 gpm. Surface exposures of semiconsolidated aquifers occupy about 4.5 percent of the state.

Sensitivity

About 50 percent of Washington is covered by Class I aquifers.The potential for ground-water contamination from shallow injection wells is relatively high in areas of high population density and along major highways.

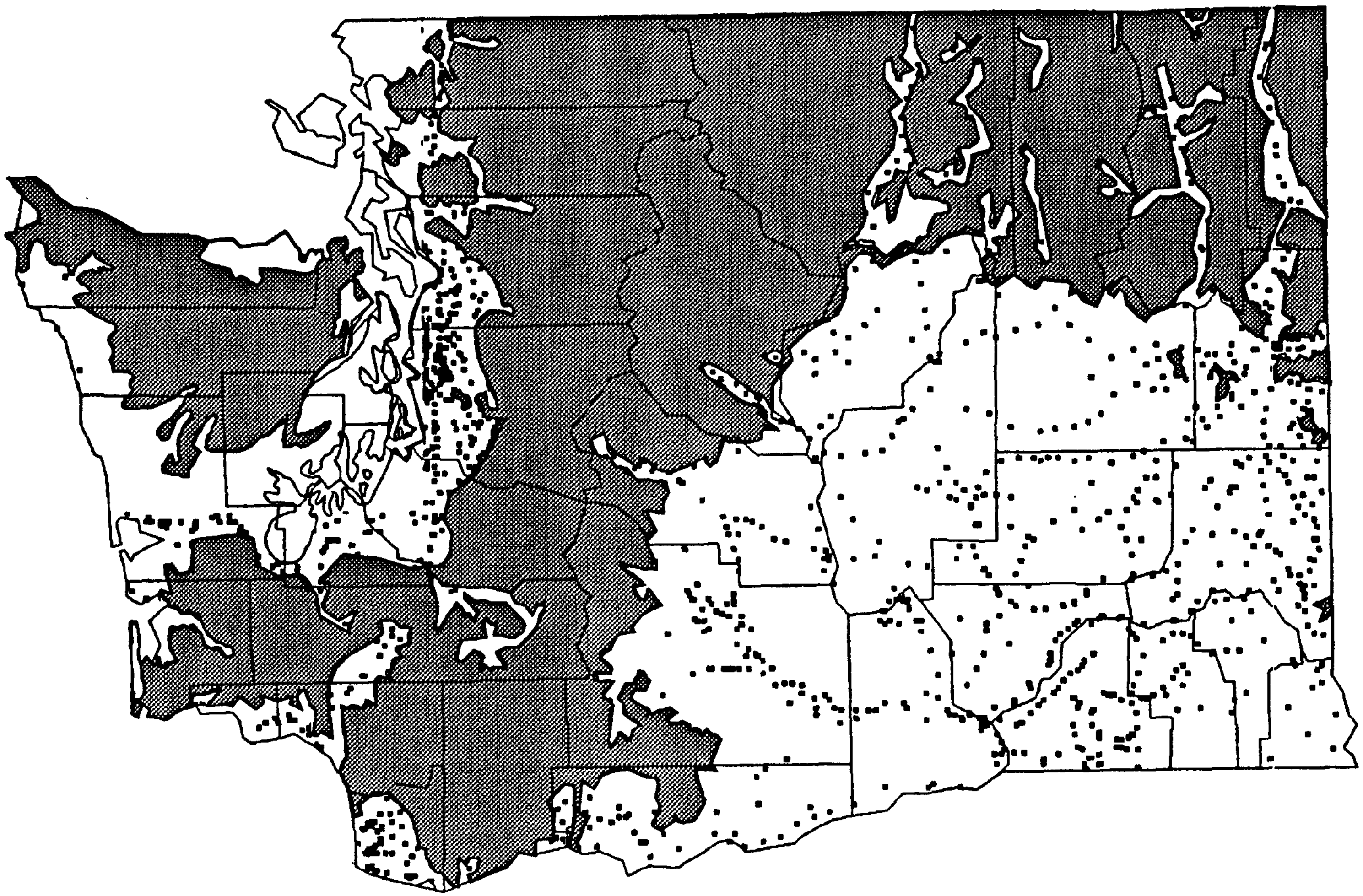


Aquifer Vulnerability Map of Washington

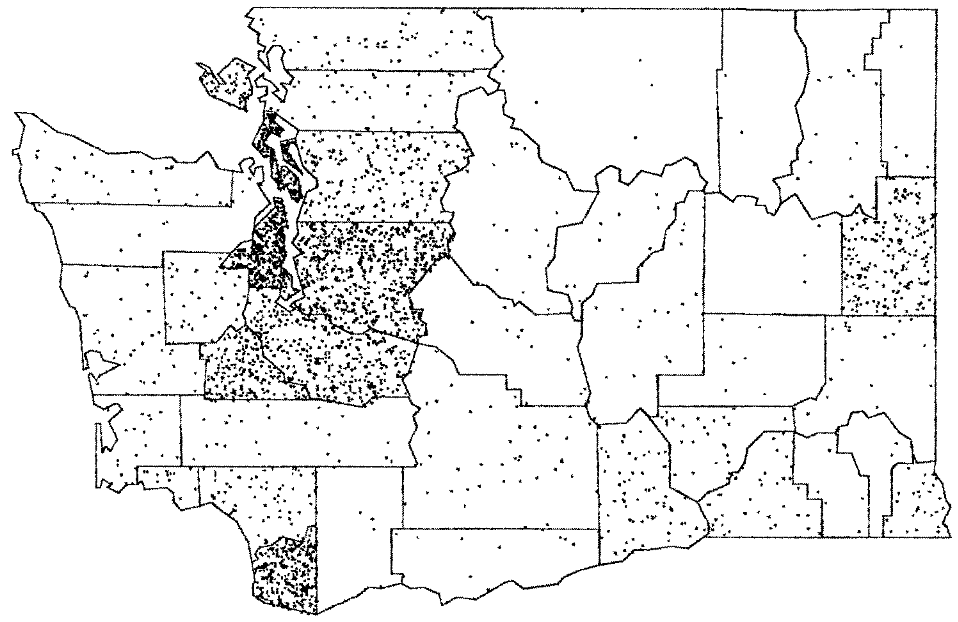


Potential Well Yields in Washington

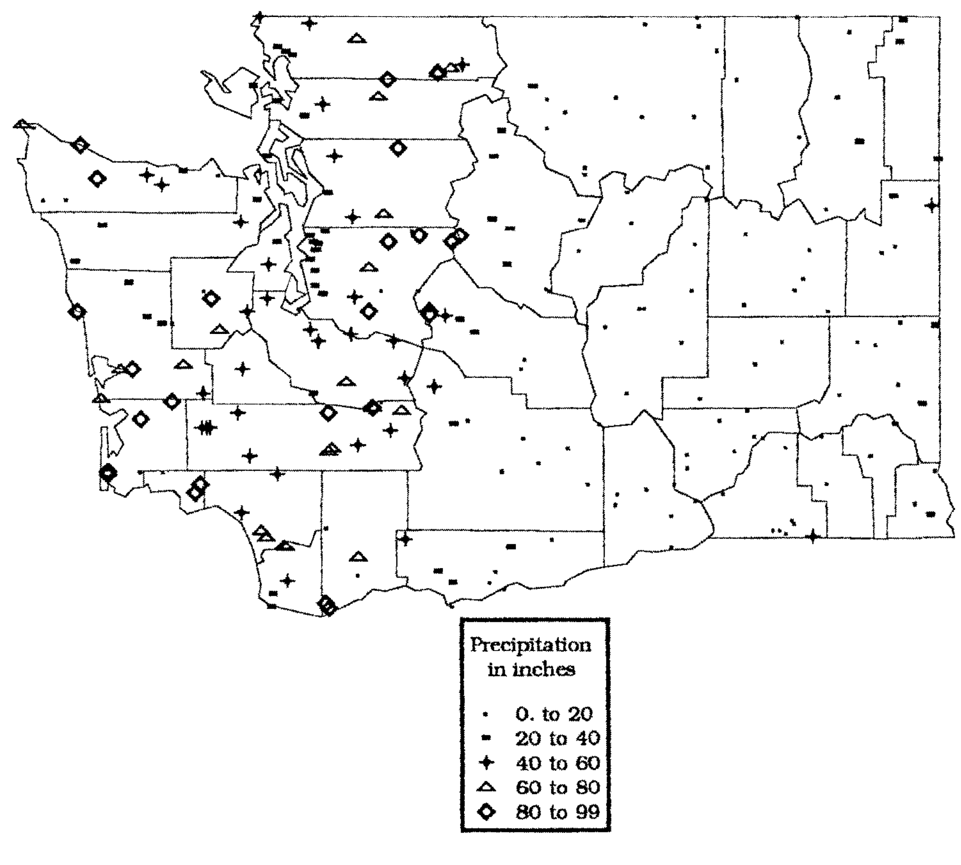
Aquifer Sensitivity Map of Washington



Areas covered by class I aquifers.
Each dot represents a population center.



Population Density of Washington (Dot equals one person per square mile)



Average Annual Precipitation in Washington

Section 3
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