GROUND-WATER QUALITY

The geochemistry of ground water may influence the utility of aquifer systems as sources of water. The types and concentrations of dissolved constituents in the water of an aquifer system determine whether the resource, without prior treatment, is suitable for drinking-water supplies, industrial purposes, irrigation, livestock watering, or other uses. Changes in the concentrations of certain constituents in the water of an aquifer system, whether because of natural or *anthropogenic* causes, may alter the suitability of the aquifer system as a source of water. Assessing ground-water quality and developing strategies to protect aquifers from contamination are necessary aspects of water-resource planning.

Sources of ground-water quality data

The quality of water from the aquifer systems defined in the **Aquifer Systems** section of the Ground-Water Hydrology chapter is described using selected inorganic chemical analyses from 372 wells (157 completed in unconsolidated deposits and 215 completed in bedrock) in the West Fork White River basin. Sources of ground-water quality data are domestic, commercial or livestock-watering wells sampled during a 1989 and 1990 cooperative effort between the Indiana Department of Natural Resources, Division of Water (DOW) and the Indiana Geological Survey (IGS). The locations of ground-water chemistry sites used in the analysis are displayed on plate 9, and selected water-quality data from individual wells are listed in appendices 1 and 2.

The intent of the water-quality analysis is to characterize the natural ground-water chemistry of the West Fork White River basin. Specific instances of ground-water contamination are not evaluated. In cases of contamination, chemical conditions are likely to be site-specific and may not represent typical ground-water quality in the basin. Therefore, available data from identified sites of ground-water contamination were not included in the data sets analyzed for this publication. Samples collected from softened or otherwise treated water were also excluded from the analysis because the chemistry of the water was altered from natural conditions.

Factors in the assessment of ground-water quality

Major dissolved constituents in the ground water of the West Fork White River basin include calcium, magnesium, sodium, chloride, sulfate, and bicarbonate. Less abundant constituents include potassium, iron, manganese, strontium, zinc, fluoride, and nitrate. Other chemical characteristics discussed in this report include pH, alkalinity, hardness, total dissolved solids (TDS), and radon.

Although the data from well-water samples in the West Fork White River basin are treated as if they represent the chemistry of ground water at a distinct point, they actually represent the average concentration of an unknown volume of water in an aquifer. The extent of aquifer representation depends on the depth of the well, hydraulic conductivity of the aquifer, thickness and areal extent of the aquifer, and rate of pumping. For example, the chemistry of water sampled from high-capacity wells may represent average ground-water quality for a large cone of influence (Sasman and others, 1981). Also, because much of the bedrock in the southern part of the basin does not produce much ground water, it is not uncommon for bedrock wells to be deep and to intersect several different bedrock units. Because the quality of water may vary substantially from different zones individual wells may show an unusual mixture of ground water types.

To further complicate analysis of the ground-water chemistry data in this basin, the bedrock in the southern third of the basin was formed in complex depositional environments resulting in complex horizontal and vertical relationships of various bedrock units. In addition, there is an extensive major unconformity (old erosion surface) of Mississippian/Pennsylvanian age. Erosion and subsequent deposition of bedrock material that occurred during this time period has resulted in younger or more recent bedrock overlapping onto bedrock of different ages and types.

The order in which ground water encounters strata of different mineralogical composition can exert an important control on the water chemistry (Freeze and Cherry, 1979). Considering that hydrogeologic systems in the basin contain numerous types of strata arranged in a wide variety of geometric configurations, it is not unreasonable to expect that in many areas the chemistry of ground water exhibits complex spatial patterns that are difficult to interpret, even when good stratigraphic and hydraulic head information is available.

The nature of the bedrock in the southern two-thirds of the West Fork White River basin makes the use of aquifer systems to describe ground-water quality somewhat problematic. The boundaries of the bedrock aquifer systems are defined by 2-dimensional mapping techniques. Although this type of mapping is useful, it should be remembered that more productive aquifer systems extend beneath less productive systems and are often used as a water supply within the boundaries of the latter.

In addition to the factors discussed above, the chemistry of original aquifer water may be altered to some degree by contact with plumbing, residence time in a pressure tank, method of sampling, and time elapsed between sampling and laboratory analysis. In spite of these limitations, results of sample analyses provide valuable information concerning ground-water quality characteristics of aquifer systems.

Analysis of data

Graphical and statistical techniques are used to analyze the available ground-water quality data from the West Fork White River basin. Graphical analyses are used to display the areal distribution of dissolved constituents throughout the basin, and to describe the general chemical character of the ground water of each aquifer system. Statistical analyses provide useful generalizations about the water quality of the

Factors affecting ground-water chemistry

The chemical composition of ground water varies because of many complex factors that change with depth and over geographic distances. Ground-water quality can be affected by the composition and solubility of rock materials in the soil or aquifer, water temperature, partial pressure of carbon dioxide, acid-base reactions, oxidation-reduction reactions, loss or gain of constituents as water percolates through clay layers, and mixing of ground water from adjacent strata. The extent of each effect will be determined in part by the residence time of the water within the different subsurface environments.

Rain and snow are the major sources of recharge to ground water. They contain small amounts of dissolved solids and gases such as carbon dioxide, sulfur dioxide, and oxygen. As precipitation infiltrates through the soil, biologically-derived carbon dioxide reacts with the water to form a weak solution of carbonic acid. The reaction of oxygen with reduced iron minerals such as pyrite is an additional source of acidity in ground water. The slightly acidic water dissolves soluble rock material, thereby increasing the concentrations of chemical constituents such as calcium, magnesium, chloride, iron, and manganese. As ground water moves slowly through an aquifer the composition of water continues to change, usually by the addition of dissolved constituents (Freeze and Cherry, 1979). A longer residence time will usually increase concentrations of dissolved solids. Because of short residence time, ground water in recharge areas often contains lower concentrations of dissolved constituents than water occurring deeper in the same aquifer or in shallow discharge areas.

Dissolved carbon dioxide, bicarbonate, and carbonate are the principal sources of alkalinity, or the capacity of solutes in water to neutralize acid. Carbonate contributors to alkalinity include atmospheric and biologically-produced carbon dioxide, carbonate minerals, and biologically-mediated sulfate reduction. Noncarbonate contributors to alkalinity include hydroxide, silicate, borate, and organic compounds. Alkalinity helps to buffer natural water so that the pH is not greatly altered by addition of acid. The pH of most natural ground waters in Indiana is neutral to slightly alkaline.

Calcium and magnesium are the major constituents responsible for hardness in water. Their presence is the result of dissolution of carbonate minerals such as calcite and dolomite.

The weathering of feldspar and clay is a source of sodium and potassium in ground water. Sodium and chloride are produced by the solution of halite (sodium chloride) which can occur as grains disseminated in unconsolidated and bedrock deposits. Chloride also occurs in bedrock cementing material, connate fluid inclusions, and as crystals deposited during or after deposition of sediment in sea water. High sodium and chloride levels can result from upward movement of brine from deeper bedrock in areas of high pumpage, from improper brine disposal from peteroleum wells, and from the use of road salt (Hem, 1985).

Cation exchange is often a modifying influence of ground-water chemistry. The most important cation exchange processes are those involving sodium-calcium, sodium-magnesium, potassium-calcium, and potassium-magnesium. Cation exchanges occurring in clay-rich semi-confining layers can cause magnesium and calcium reductions which result in natural softening.

Concentrations of sulfide, sulfate, iron, and manganese depend on geology and hydrology of the aquifer system, amount of dissolved oxygen, pH, minerals available for solution, amount of organic matter, and microbial activity.

Mineral sources of sulfate can include pyrite, gypsum, barite, and celestite. Sulfide is derived from reduction of sulfate when dissolve oxygen concentrations are low and anaerobic bacteria are present. Sulfate-reducing bacteria derive energy from oxidation of organic compounds and obtain oxygen from sulfate ions (Lehr and others, 1980).

Reducing conditions that produce hydrogen sulfide occur in deep wells completed in carbonate and shale bedrock. Oxygen-deficient conditions are more likely to occur in deep wells than in shallow wells because permeability of the carbonate bedrock decreases with depth, and solution features and joints become smaller and less abundant (Rosenshein and Hunn, 1968a; Bergeron, 1981; Basch and Funkhouser, 1985). Deeper portions of the bedrock are therefore not readily flushed by ground water with high dissolved oxygen. Hydrogen sulfide gas, a common reduced form of sulfide, has a distinctive rotten egg odor that can be detected in water containing only a few tenths of a milligram per liter of sulfide (Hem, 1985).

Oxidation-reduction reactions constitute an important influence on concentrations of both iron and manganese. High dissolved iron concentrations can occur in ground water when pyrite is exposed to oxygenated water or when ferric oxide or hydroxide minerals are in contact with reducing substances (Hem, 1985). Sources of manganese include manganese carbonate, dolomite, limestone, and weathering crusts of manganese oxide.

Sources of fluoride in bedrock aquifer systems include fluorite, apatite and fluorapatite. These minerals may occur as evaporites or detrital grains in sedimentary rocks, or as disseminated grains in unconsolidated deposits. Ground waters containing detectable concentrations of fluoride have been found in a variety of geological settings.

Natural concentrations of nitrate-nitrogen in ground water originate from the atmosphere and from living and decaying organisms. High nitrate levels can result from leaching of industrial and agricultural chemicals or decaying organic matter such as animal waste or sewage.

The chemistry of strontium is similar to that of calcium, but strontium is present in ground water in much lower concentrations. Natural sources of strontium in ground water include strontianite (strontium carbonate) and celestite (strontium sulfate). Naturally-occurring barium sources include barite (barium sulfate) and witherite (barium carbonate). Areas associated with deposits of coal, petroleum, natural gas, oil shale, black shale, and peat may also contain high levels of barium.

---

basin, such as the average concentration of a constituent and the expected variability.

Regional trends in ground-water chemistry can be analyzed by developing trilinear diagrams for the aquifer systems in the West Fork White River basin (appendix 3). Trilinear plotting techniques developed by Piper (1944) can be used to classify ground water on the basis of chemistry, and to compare chemical trends among different aquifer systems (appendix 3) (see sidebar titled **Chemical classification of ground water using trilinear diagrams**). To graphically represent variation in ground-water chemistry, box plots (appendix 4) are prepared for selected ground-water constituents. Box plots are useful for depicting descriptive statistics, showing the general variability in constituent concentrations occurring in an aquifer system, and making general chemical comparisons among aquifer systems.

Symmetry of a box plot across the *median* line (appendix 4) can provide insights into the degree of skewness of chemical concentrations or parameter values in a data set. A box plot that is almost symmetrical about the median line may indicate that the data originate from a nearly symmetrical distribution. In contrast, marked asymmetry across the median line may indicate a *skewed* distribution of the data.

The areal distribution of selected chemical constituents, mapped according to aquifer system, is included among figures 14 to 26. Several sampling and geologic factors complicate the development of chemical concentration maps for the West Fork White River basin. The sampling sites are not evenly distributed in the basin, but are clustered around towns and developed areas (plate 9). Data points are generally scarce in areas where surface-water sources are used for water supply. Furthermore, lateral and vertical variations in geology can also influence the chemistry of subsurface water. Therefore, the maps presented in the following discussion only represent approximate concentration ranges.

Where applicable, ground-water quality is assessed in the context of National Primary and Secondary Drinking-Water Standards (see sidebar titled **National Drinking-water Standards**). The secondary standard referred to in this report is the *secondary maximum contaminant level* (SMCL). The

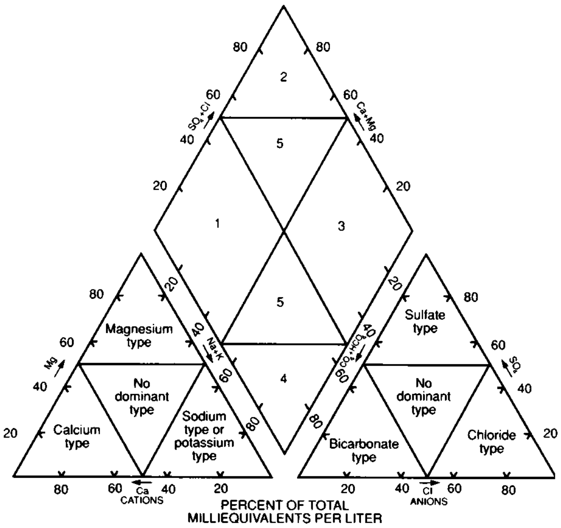
Chemical Classification of Ground waters Using Trilinear Diagrams

Trilinear plotting systems were used in the study of water chemistry and quality since as early as 1913 (Hem, 1985). The type of trilinear diagram used in this report, independently developed by Hill (1940) and Piper (1944), has been used extensively to delineate variability and trends in water quality. The technique of trilinear analysis has contributed extensively to the understanding of ground-water flow, and geochemistry (Dalton and Upchurch, 1978). On conventional trilinear diagrams sample values for three cations (calcium, magnesium and the alkali metals- sodium and potassium) and three anions (bicarbonate, chloride and sulfate) are plotted relative to one another. Since these ions are generally the most common constituents in unpolluted ground waters, the chemical character of most natural waters can be closely approximated by the relative concentration of these ions (Hem, 1985; Walton, 1970).

Before values can be plotted on the trilinear diagram the concentrations of the six ions of interest are converted into milliequivalents per liter (meq/L), a unit of concentration equal to the concentration in milligrams per liter divided by the equivalent weight (atomic weight divided by valence). Each cation value is then plotted, as a percentage of the total concentration (meq/L) of all cations under consideration, in the lower left triangle of the diagram. Likewise, individual anion values are plotted, as percentages of the total concentration of all anions under consideration, in the lower right triangle. Sample values are then projected into the central diamond-shaped field. Fundamental interpretations of the chemical nature of a water sample are based on the location of the sample ion values within the central field.

Distinct zones within aquifers having defined water chemistry properties are referred to as hydrochemical *facies* (Freeze and Cherry, 1979). Determining the nature and distribution of hydrochemical facies can provide insights into how ground-water quality changes within and between aquifers. Trilinear diagrams can be used to delineate hydrochemical facies, because they graphically demonstrate relationships between the most important dissolved constituents in a set of ground-water samples.

A simple but useful scheme for describing hydrochemical facies with trilinear diagrams is presented by Walton (1970) and is based on methods used by Piper (1944). This method is based on the "dominance" of certain cations and anions in solution. The dominant cation of a water sample is defined as the positively charged ion whose concentration exceeds 50 percent of the summed concentrations of major cations in solution. Likewise, the concentration of the dominant anion exceeds 50 percent of the total anion concentration in the water sample. If no single cation or anion in a water sample meets this criterion, the water has no dominant ion in solution. In most natural waters, the dominant cation is calcium, magnesium or alkali metals (sodium and potassium), and the dominant anion is chloride, bicarbonate or sulfate (accompanying figure). Distinct hydrochemical facies are defined by specific combinations of dominant cations and anions. These combinations will plot in certain areas of the central, diamond-shaped part of the trilinear diagram. Walton (1970) described a simple but useful classification scheme that divides the central part of the diagram into five subdivisions. In the first four of these subdivisions, the concentration of a specific cation-anion combination exceeds 50 percent of the total milliequivalents per liter (meq/L). Five basic hydrochemical facies can be defined with these criteria:



1. Primary Hardness; Combined concentrations of calcium, magnesium and bicarbonate exceed 50 percent of the total dissolved constituent load in meq/L. Such waters are generally considered hard and are often found in limestone aquifers or unconsolidated deposits containing abundant carbonate minerals.
2. Secondary Hardness; Combined concentrations of sulfate, chloride, magnesium and calcium exceed 50 percent of total meq/L.
3. Primary Salinity; Combined concentrations of alkali metals, sulfate and chloride are greater then 50 percent of the total meq/L. Very concentrated waters of this hydrochemical facies are considered brackish or (in extreme cases) saline.
4. Primary Alkalinity; Combined sodium, potassium and bicarbonate concentrations exceed 50 percent of the total meq/L. These waters generally have low hardness in proportion to their dissolved solids concentration (Walton, 1970).
5. No specific cation-anion pair exceeds 50 percent of the total dissolved constituent load. Such waters could result from multiple mineral dissolution or mixing of two chemically distinct ground-water bodies.

Additional information on trilinear diagrams and a more detailed discussion of the geochemical classification of ground waters is presented in Freeze and Cherry (1979) and Fetter (1988).

SMCLs are recommended, non-enforceable standards established to protect aesthetic properties such as taste, odor, or color of drinking water. Some chemical constituents (including fluoride and nitrate) are also considered in terms of the *maximum contaminant level* (MCL). The MCL is the concentration at which a constituent may represent a threat to human health. Maximum *contaminant* levels are legally-enforceable primary drinking-water standards that should not be exceeded in treated drinking water distributed for public supply. General water-quality criteria for irrigation and livestock and standards for public supply are given in appendix 5.

Because of data constraints, ground-water quality can only be described for selected aquifer systems as defined in the **Aquifer Systems** section of this report (plate 5). Unconsolidated aquifer systems analyzed include the Tipton Till Plain, Tipton Till Plain subsystem, Dissected Till and Residuum, White River and Tributaries Outwash, White River and Tributaries Outwash subsystem, Buried Valley, and Lacustrine and Backwater Deposits aquifer systems. Bedrock aquifer systems analyzed include the Silurian and Devonian Carbonates, Devonian and Mississippian/New Albany Shale, Mississippian/Borden Group, Mississippian/Blue River and Sanders Group, Mississippian/Buffalo Wallow, Stephensport, and West Baden Group, Pennsylvanian/Raccoon Creek Group, Pennsylvanian/Carbondale Group, and Pennsylvanian/McLeansboro Group Aquifer systems. The bedrock Ordovician/Maquoketa Group Aquifer system is not included in the analysis as none of the wells sampled were completed in that aquifer (Data on ground-water chemistry of wells completed in Ordovician bedrock are available in the DOW Whitewater River Basin report). Because the number of samples from the White River and Tributaries Outwash, Dissected Till and Residuum, Lacustrine and Backwater Deposits, and Devonian and Mississippian/New Albany Shale Aquifer systems is 7 or less, the sampling results may not accordingly reflect chemical conditions in these aquifers.

NATIONAL DRINKING-WATER STANDARDS

National Drinking Water Regulations and Health Advisories (U. S. Environmental Protection Agency, 1993) list concentration limits of specified inorganic and organic chemicals in order to control amounts of contaminants in drinking water. Primary regulations list maximum contaminant levels (MCLs) for inorganic constituents considered toxic to humans above certain concentrations. These standards are health-related and legally enforceable. Secondary maximum contaminant levels (SMCLs) cover constituents that may adversely affect the aesthetic quality of drinking water. The SMCLs are intended to be guidelines rather than enforceable standards. Although these regulations apply only to drinking water at the tap for public supply, they may be used to assess water quality for privately-owned wells. The table below lists selected inorganic constituents of drinking water covered by the regulations, the significance of each constituent, and their respective MCL or SMCL. Fluoride and nitrate are the only constituents listed which are covered by the primary regulations.

Constituent	Secondary Maximum Contaminant Level (SMCL) (ppm)	Maximum Contaminant Level (MCL) (ppm)	Remarks
Total Dissolved (TDS)	500	*	Levels above SMCL can give water a disagreeable taste. Levels above 1000 Solids mg/L may cause corrosion of well screens, pumps, and casings.
Iron	0.3	*	More than 0.3 ppm can cause staining of clothes and plumbing fixtures, encrustation of well screens, and plugging of pipes. Excessive quantities can stimulate growth of iron bacteria.
Manganese	0.05	*	Amounts greater than 0.05 ppm can stain laundry and plumbing fixtures, and may form a dark brown or black precipitate that can clog filters.
Chloride	250	*	Large amounts in conjunction with high sodium concentrations can impart a salty taste to water. Amounts above 1000 ppm may be physiologically unsafe. High concentrations also increase the corrosiveness of water.
Fluoride	2.0	4.0	Concentration of approximately 1.0 ppm help prevent tooth decay. Amounts above recommended limits increase the severity and occurrence of mottling (discoloration of the teeth). Amounts above 4 ppm can cause adverse skeletal effects (bone sclerosis).
Nitrate**	*	10	Concentrations above 20 ppm impart a bitter taste to drinking water. Concentrations greater than 10 ppm may have a toxic effect (methemoglobinemia) on young infants.
Sulfate	250	*	Large amounts of sulfate in combination with other ions (especially sodium and magnesium) can impart odors and a bitter taste to water. Amounts above 600 ppm can have a laxative effect. Sulfate in combination with calcium in water forms hard scale in steam boilers.
Sodium	NL	NL	Sodium salts may cause foaming in steam boilers. High concentrations may render water unfit for irrigation. High levels of sodium in water have been associated with cardiovascular problems. A sodium level of less than 20 ppm has been recommended for high risk groups (people who have high blood pressure, people genetically predisposed to high blood pressure, and pregnant women).
Calcium	NL	NL	Calcium and magnesium combine with bicarbonate, carbonate, sulfate and silica to form heat-retarding, pipe-clogging scales in steam boilers. For further information on calcium and magnesium, see hardness.
Magnesium	NL	NL	
Hardness	NL	NL	Principally caused by concentration of calcium and magnesium. Hard water consumes excessive amounts of soap and detergents and forms an insoluble scum or scale.
pH	-	-	USEPA recommends pH range between 6.5 and 8.5 for drinking water.

NL No Limit Recommended.
* No MCL or SMCL established by USEPA.
** Nitrate concentrations expressed as equivalent amounts of elemental nitrogen (N).(Adapted from U.S. Environmental Protection Agency, 1993)
Note: 1 part per million (ppm) = 1 mg/L.

Also, although the two-dimensional mapping used to delineate the bedrock aquifer systems is useful, it should be remembered that, especially for deeper wells, a significant portion of the water produced could come from aquifer systems underlying the one mapped at the bedrock surface.

Trilinear-diagram analyses

Ground-water samples from aquifer systems in the West Fork White River basin are classified using the trilinear plotting strategy described in the sidebar titled **Chemical classification of ground water using trilinear diagrams**. Trilinear diagrams developed with the available ground-water chemistry data are presented in appendix 3.

Trilinear analysis indicates that most of the available ground-water samples from the unconsolidated aquifers (92 percent) are chemically dominated by alkaline-earth metals (calcium and magnesium) and bicarbonate. Sodium concentrations exceed 40 percent of the sum of major *cations* in only 8 samples, but variations in sodium levels are observed among samples. The combined chloride and sulfate concentration exceeds 50 percent of the sum of major *anions* in only 2 percent of the samples.

In contrast, approximately 70 percent of the ground-water samples from the bedrock aquifers are chemically dominated by alkaline-earth metals (calcium and magnesium) and bicarbonate. Two-thirds (approximately 22 percent) of the remainder are chemically dominated by sodium and bicarbonate. The combined chloride and sulfate concentration exceeds 50 percent of the sum of major anions in fewer than 4 percent of the samples.

Trilinear analysis suggests that the ground water from all but one of the unconsolidated aquifer systems belong to a distinct hydrochemical facies (appendix 3). Most samples from these aquifer systems are chemically dominated by calcium, magnesium, and bicarbonate (Ca-Mg-HCO_3). The one exception is the Lacustrine and Backwater Deposits Aquifer system in which only 2 of the 4 samples belong to this facies. Also, samples from a total of 6 wells in the White River and Tributaries Outwash Aquifer system, White River and Tributaries Outwash Aquifer subsystem, and the Lacustrine and Backwater Deposits system have sodium as the dominant cation with little calcium or magnesium.

In contrast to the ground-water samples from the unconsolidated aquifers, samples from some of the bedrock aquifers appear to originate from more than one hydrochemical facies. Although most of the samples in 6 of the 8 bedrock aquifer systems belong to the calcium-magnesium-bicarbonate facies, a large portion of the samples from the Pennsylvanian aquifer systems belong to the sodium bicarbonate facies. A few samples from the Pennsylvanian aquifer systems belong to the sodium-chloride facies. A small portion, 5 of the 215 ground-water samples from the bedrock aquifer systems, is chemically dominated by calcium, magnesium, and sulfate (Ca-Mg-SO_4) ions. Three of these are within an approximate 4-mile radius of each other in northeastern Greene and southeastern Owen counties.

Differences in hydrochemical facies within and between aquifer systems may indicate differences in the processes influencing ground-water quality. Variations in the mineral content of aquifer systems are probably a significant control on the geochemistry of ground water. For example, the calcium-magnesium-bicarbonate waters in some wells probably result from the dissolution of carbonate minerals. Calcium-magnesium-sulfate dominated ground water in the West Fork White River basin probably result from the dissolution of gypsum, pyrite, or other sulfur-containing minerals. Sodium bicarbonate dominated ground water may be due to cation exchange processes with surrounding clays and clay minerals. Ground-water flow from areas of recharge to areas of discharge and the subsequent mixing of chemically-distinct ground water may also influence the geochemical classification of ground water in the West Fork White River basin.

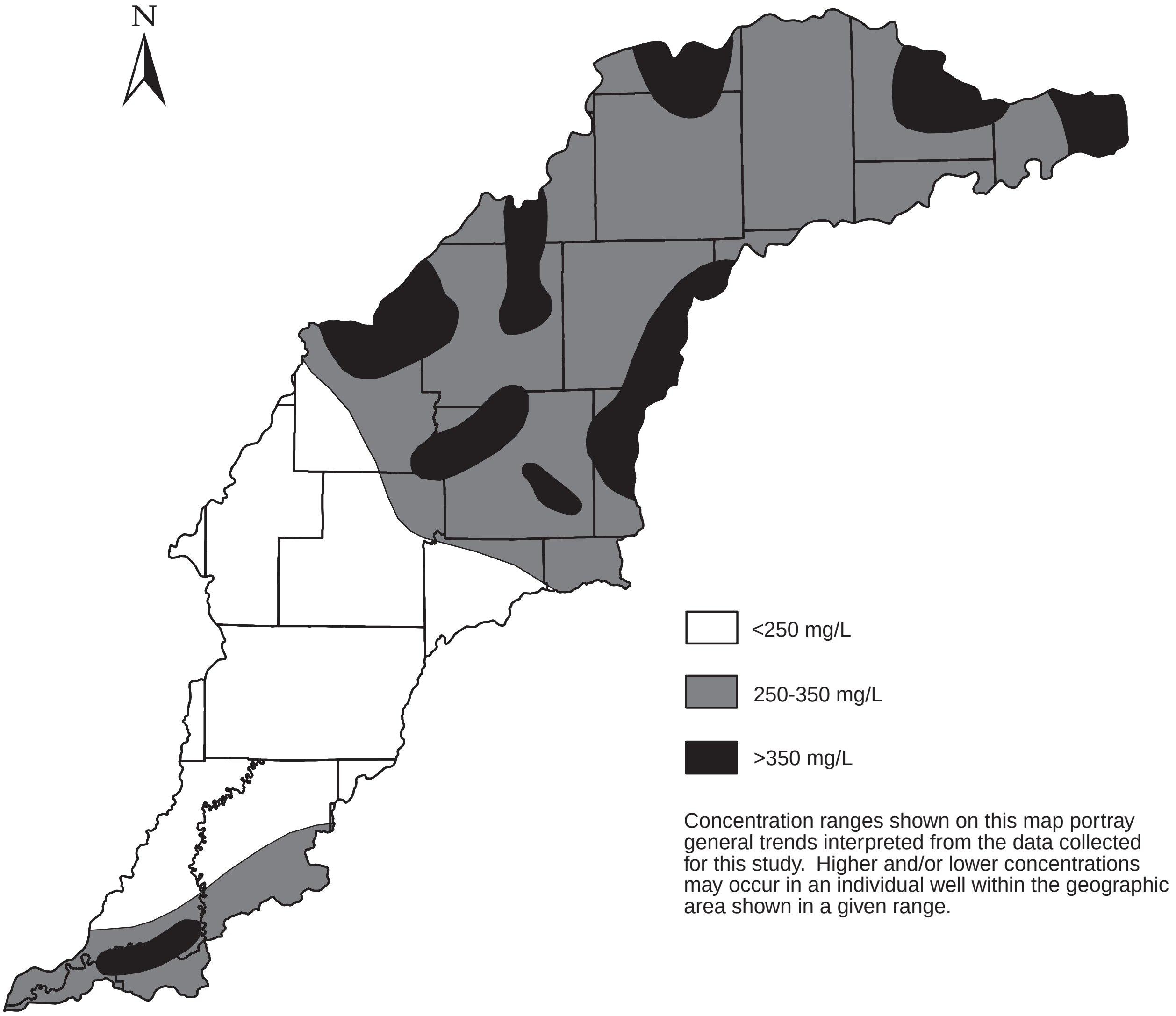
Assessment of ground-water quality

Alkalinity and pH

The alkalinity of a solution may be defined as the capacity of its solutes to react with and neutralize acid. The alkalinity in most natural waters is primarily due to the presence of dissolved carbon species, particularly bicarbonate and carbonate. Other constituents that may contribute minor amounts of alkalinity to water include silicate, hydroxide, borates, and certain organic compounds (Hem, 1985). In this report, alkalinity is expressed as an equivalent concentration of dissolved calcite ($CaCO_3$). At present, no suggested limits have been established for alkalinity levels in drinking water. However, some alkalinity may be desirable in ground water because the carbonate ions moderate or prevent changes in pH.

Median alkalinity levels vary among samples from different aquifer systems in the West Fork White River basin. In the unconsolidated aquifer systems, alkalinity levels tend to be higher in the northern part of the basin (figure 14a). In general, lower alkalinity levels are observed in the White River and Tributaries Outwash Aquifer system relative to the other unconsolidated aquifer systems (figure 14a and appendix 4). Median alkalinity values for the bedrock aquifer systems exhibit somewhat more variability than the unconsolidated ones (figure 14b and appendix 4). Of these, the Pennsylvanian systems show the greatest variability. Both the lowest and highest median alkalinity levels of all the aquifer systems occur in the bedrock aquifers. The lowest alkalinity levels are observed in the Mississippian/Buffalo Wallow, Stephensport, and West Baden Group Aquifer system, and the highest occur in the Pennsylvanian/Carbondale Group Aquifer system.

The pH, or hydrogen ion activity, is expressed on a logarithmic scale and represents the negative base-10 log of the hydrogen ion concentration. Waters are considered acidic when the pH is less than 7.0 and basic when the pH exceeds 7.0. Water with a pH value equal to 7.0 is termed neutral and is not considered either acidic or basic. The pH of most



Concentration ranges shown on this map portray general trends interpreted from the data collected for this study. Higher and/or lower concentrations may occur in an individual well within the geographic area shown in a given range.

Figure 14a. Generalized areal distribution for Alkalinity - Unconsolidated aquifers

ground water generally ranges between 5.0 and 8.0 (Davis and DeWiest, 1970).

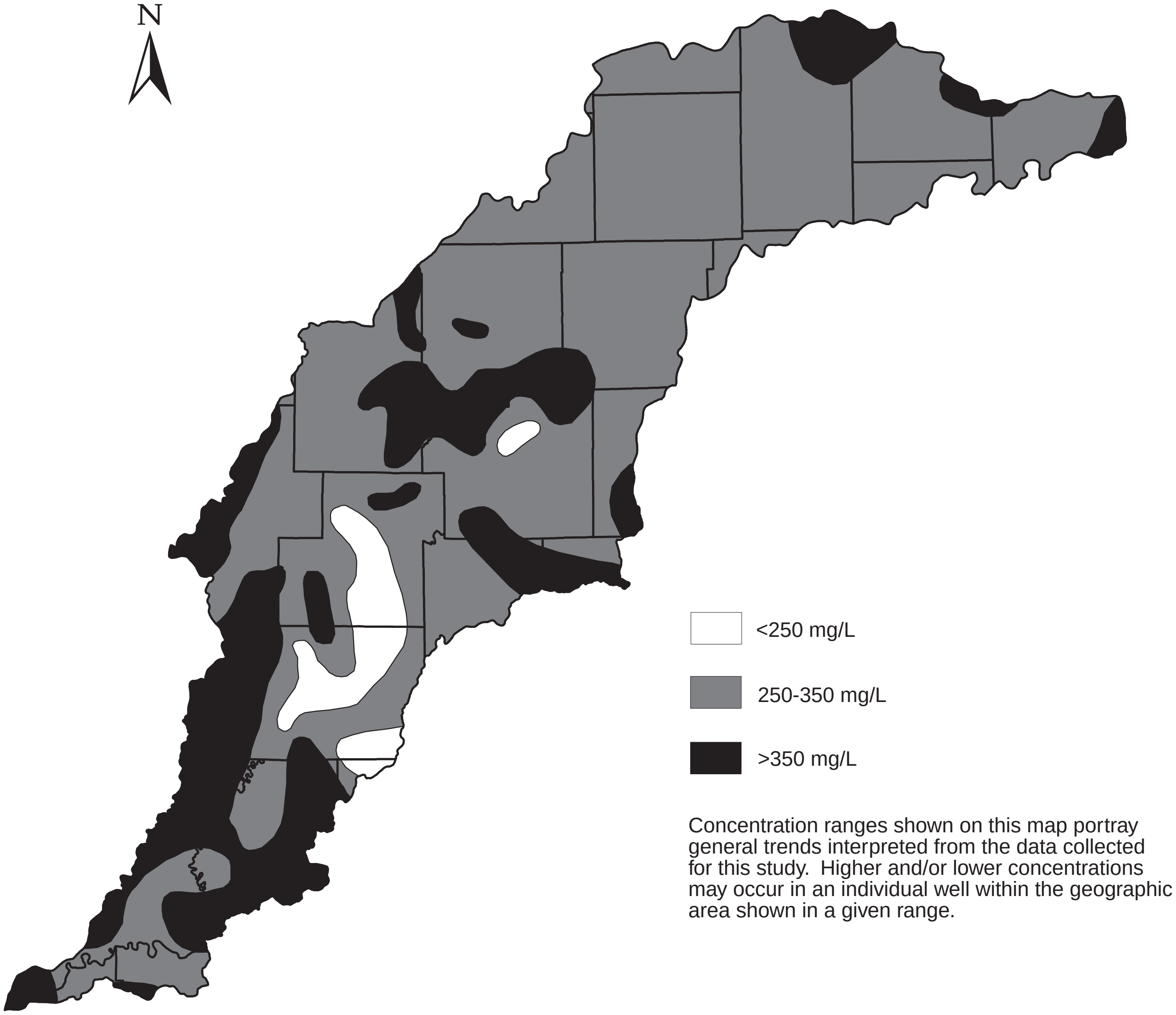
The types of dissolved constituents in ground water can influence pH levels. Dissolved carbon dioxide (CO_2), which forms carbonic acid in water, is an important control on the pH of natural waters (Hem, 1985). The pH of ground water can also be lowered by organic acids from decaying vegetation, or by dissolution of sulfide minerals (Davis and DeWiest, 1970). The United States Environmental Protection Agency (USEPA) recommends a pH range between 6.5 and 8.5 in waters used for public supply. Ninety-two percent of the ground-water samples in this study are within this range.

Of the 30 wells (23 bedrock and 7 unconsolidated) having a pH outside the 6.5 and 8.5 range, twenty-two occur in the southwest part of the basin in areas underlain by Pennsylvanian bedrock (figure 15a and b). The Raccoon Creek Group, which is Pennsylvanian in age, has the highest median pH of all aquifer systems studied; it also exhibits the greatest variability (appendix 4). The Carbondale Group, which is also Pennsylvanian in age, has the lowest median pH of all aquifer systems studied; it also exhibits great variability.

Two areas, one in Clay County, the other near the Daviess/Martin county line, display the greatest variability in pH values including high and low values from wells in close proximity to each other. The depth of wells and type of bedrock sampled appear to play an important role in the variability. The complex lithology of the Pennsylvanian bedrock and the presence of a major unconformity that creates a variable sequence of layers can explain the variability in ground-water chemistry. Human influence, especially previous mining nearby, may also play a role on a local level.

Hardness, calcium and magnesium

"Hardness" is a term relating to the concentrations of certain metallic ions in water, particularly magnesium and calcium, and is usually expressed as an equivalent concentration of dissolved calcite ($CaCO_3$). In hard water, the metallic ions of concern may react with soap to produce an insoluble residue. These metallic ions may also react with negatively-charged ions to produce a solid precipitate when hard water is



Concentration ranges shown on this map portray general trends interpreted from the data collected for this study. Higher and/or lower concentrations may occur in an individual well within the geographic area shown in a given range.

Figure 14b. Generalized areal distribution for Alkalinity - Bedrock aquifers

heated (Freeze and Cherry, 1979). Hard waters can thus consume excessive quantities of soap, and cause damaging scale in water heaters, boilers, pipes, and turbines. Many of the problems associated with hard water, however, can be mitigated by using water-softening equipment.

Durfor and Becker (1964) developed the following classification for water hardness that is useful for discussion purposes: soft water, 0 to 60 mg/L (as $CaCO_3$); moderately hard water, 61 to 120 mg/L; hard water, 121 to 180 mg/L; and very hard water, over 180 mg/L. A hardness level of about 100 mg/L or less is generally not a problem in waters used for ordinary domestic purposes (Hem, 1985). Lower hardness levels, however, may be required for waters used for other purposes. For example, Freeze and Cherry (1979) suggest that waters with hardness levels above 60-80 mg/L may cause excessive scale formation in boilers.

Ground water in the West Fork White River basin can be generally characterized as hard to very hard in the Durfor and Becker hardness classification system. The measured hardness level is below 180 mg/L (as $CaCO_3$) in fewer than 20 percent of the ground-water samples. Generally, the unconsolidated aquifer systems in the basin have higher hardness values than the bedrock aquifer systems (appendix 4). The Tipton Till Plain Aquifer system has the highest median hardness value of all the aquifer systems at 350 mg/L (appendix 4). Only two aquifer systems have median hardness values below 180 mg/L: The Pennsylvanian/Raccoon Creek Group, and Carbondale Group. Median hardness levels exceed 260 mg/L in samples from all other aquifer systems under consideration (appendix 4). Wells having hardness levels below 60 mg/L occur primarily in the Pennsylvanian bedrock aquifers in the southwest part of the basin.

Figure 16a and b display the spatial distribution of ground-water hardness levels for the unconsolidated and bedrock aquifers in the West Fork White River basin. In general, ground-water hardness levels are higher in the northeast portion of the West Fork White River basin relative to the southwest portion of the basin. The unconsolidated Tipton Till Plain Aquifer system and subsystem and the bedrock Silurian and Devonian Carbonates Aquifer system, all of which have high median hardness levels, cover a substantial part of the northeast portion of the basin.

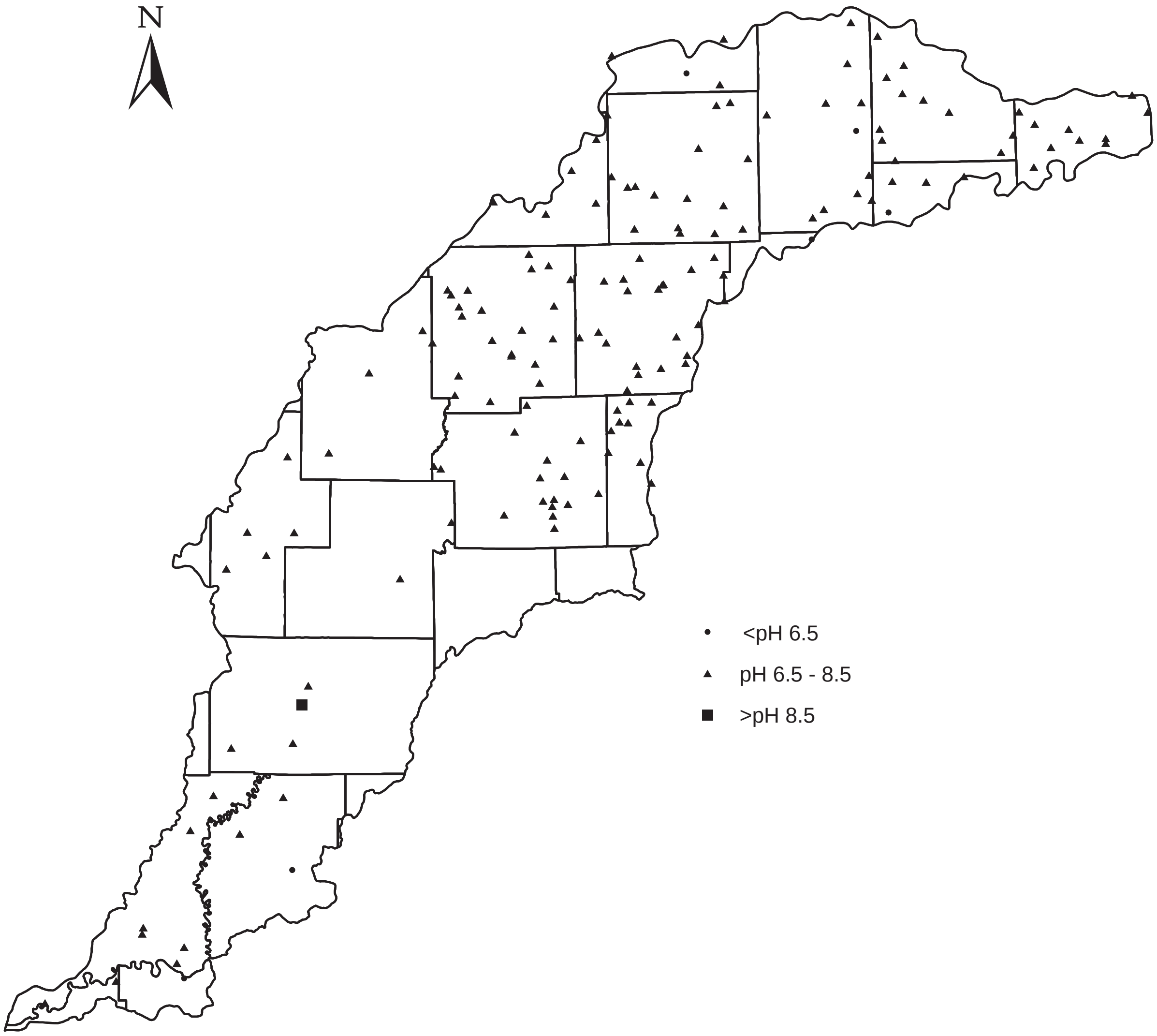


Figure 15a. Distribution of pH values for sampled wells - Unconsolidated aquifers

Box plots of calcium and magnesium concentrations in ground water are presented in appendix 4. Because calcium and magnesium are the major constituents responsible for hardness in water, the highest levels of these ions generally occur in ground water with high hardness levels. As expected, the unconsolidated Tipton Till Plain Aquifer system and subsystem and the bedrock Silurian and Devonian Carbonates Aquifer system have high median calcium and magnesium levels relative to most of the other aquifer systems. At the time of this publication, no enforceable or suggested standards have been established for calcium or magnesium.

Chloride, sodium and potassium

Chloride in ground water may originate from various sources including: the dissolution of halite and related minerals, marine water entrapped in sediments, and anthropogenic sources. Although chloride is often an important dissolved constituent in ground water, only three of the samples from the aquifer systems in the West Fork White River basin are classified as chloride dominated (appendix 3). Median chloride levels are less than 15 mg/L in all of the aquifer systems under consideration except the New Albany Shale (appendix 4). The highest median levels of all aquifer systems (approximately 40 mg/L) are in the Devonian and Mississippian New Albany Shale (appendix 4). The highest median values for unconsolidated aquifers occur in the White River and Tributaries Outwash subsystem and White River and Tributaries Outwash. Chloride concentrations at or above 250 mg/L, the SMCL for this ion, are detected in only six samples, all from bedrock aquifers.

Anthropogenic processes can locally affect chloride concentrations in ground water. Some anthropogenic factors commonly cited as influences on chloride levels in water include road salting during the winter, improper disposal of oil-field brines, contamination from sewage, and contamination from various types of industrial wastes (Hem, 1985, 1993). Five of the six wells with chloride levels at or above the SMCL occur in the southwestern part of the basin in the Pennsylvanian/Raccoon Creek Group Aquifer system. These wells have characteristics similar to the "soda water" wells

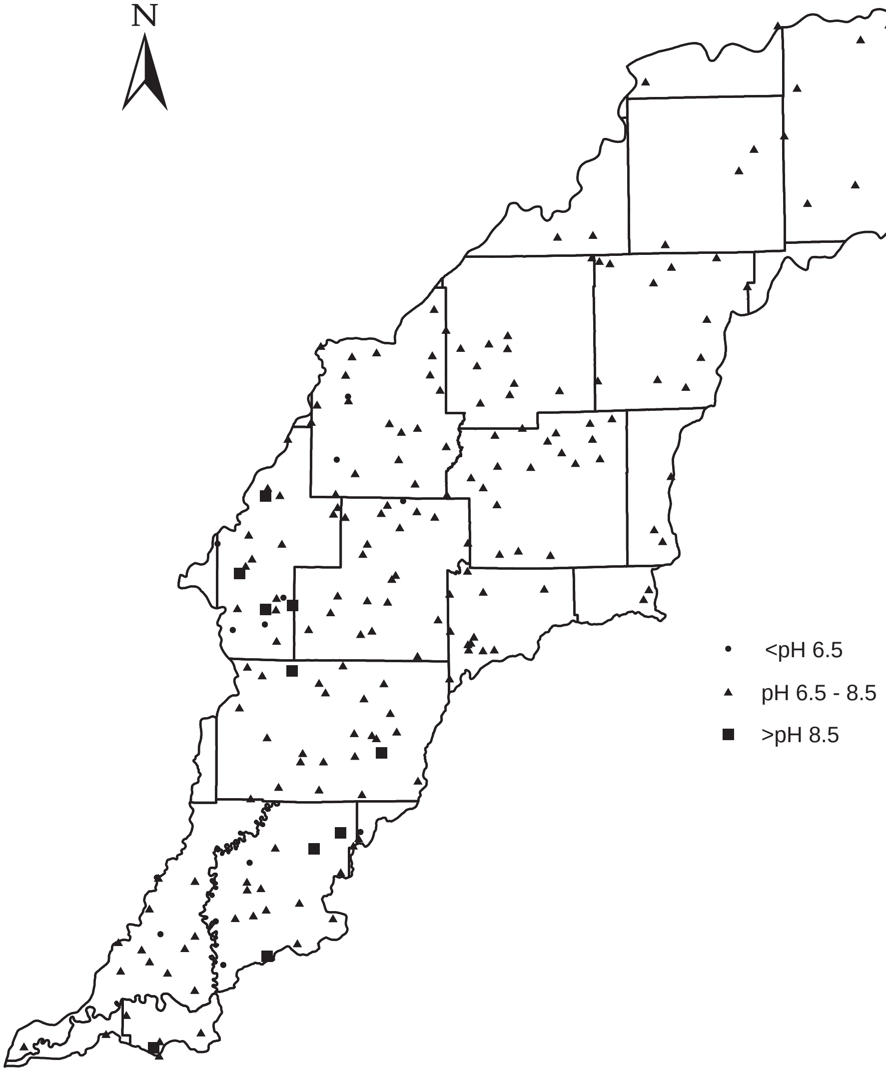


Figure 15b. Distribution of pH values for sampled wells - Bedrock aquifers

referenced in USGS WRI Report 97-4260 p. 35: bedrock wells greater than 100 feet deep in coal seams or sandstone aquifers that produce soft, sodium-chloride type water, with high TDS levels.

The dissolution of table salt or halite (NaCl) is sometimes cited as a source of both sodium and chloride in ground water. A qualitative technique to determine if halite dissolution is an influence on ground-water chemistry is to plot sodium concentrations relative to chloride concentrations. Because sodium and chloride ions enter solution in equal quantity during the dissolution of halite, an approximately linear relationship may be observed between these ions (Hem, 1985). If the concentrations are plotted in milliequivalents per liter, this linear relationship should be described by a line with a slope equal to one.

No clearly-defined linear relationship between concentrations of chloride and sodium is apparent in the ground-water samples under consideration (figure 17). This suggests that the concentrations of sodium and chloride in ground water of the West Fork White River basin are heavily influenced by factors other than to the dissolution of halite. Figure 17 and the box plots in appendix 4 indicate that sodium concentrations exceed chloride concentrations in many (70 percent) of the samples under consideration, suggesting that additional sources of sodium may be present. For example, calcium and magnesium in solution can be replaced by sodium on the surface of certain clays by *ion exchange*. Another possible source of sodium in ground water is the dissolution of silicate minerals in glacial deposits.

The highest sodium levels are found generally in the Pennsylvanian bedrock aquifer systems (figure 18), especially in the Carbondale and Raccoon Creek Groups. Trilinear analysis suggests that approximately 22 percent of bedrock samples are sodium and bicarbonate dominated.

Box plots of potassium concentrations in ground-water samples from the aquifer systems under consideration are displayed in appendix 4. In many natural waters, the concentration of potassium is commonly less than one-tenth the concentration of sodium (Davis and DeWiest, 1970). Almost 85 percent of the samples used for this report have potassium

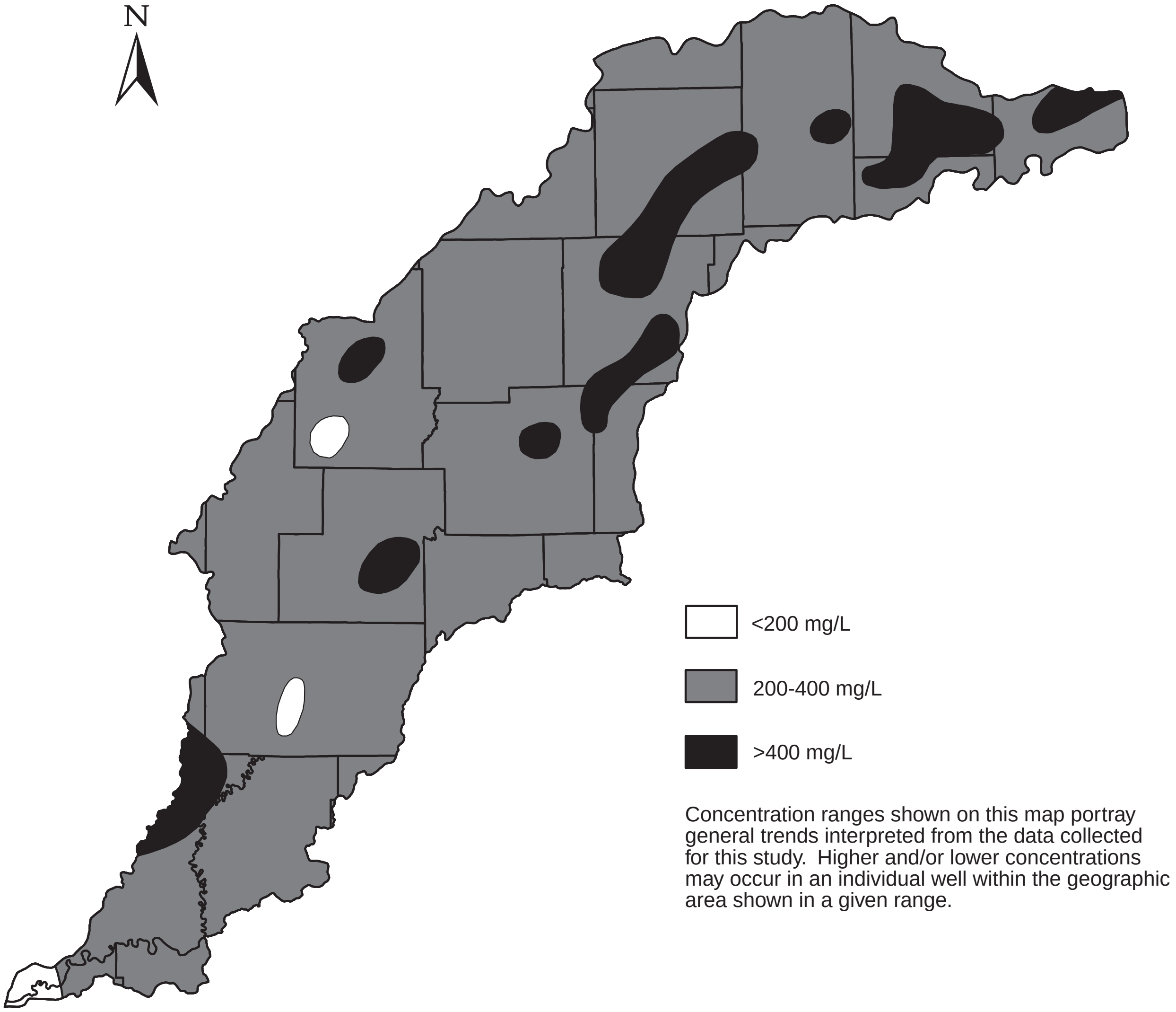


Figure 16a. Generalized areal distribution for Hardness - Unconsolidated aquifers

concentrations that are less than one-tenth the concentration of sodium.

Sulfate and sulfide

Sulfate (SO_4), an anion formed by oxidation of the element sulfur, is commonly observed in ground water. The established secondary maximum contaminant level (SMCL) for sulfate is 250 mg/L. Median sulfate levels for the samples from all aquifer systems in the West Fork White River are well below the SMCL. However, there are 8 ground-water samples that have sulfate concentrations above the SMCL, and another 16 samples have sulfate concentrations above 100 mg/L. The eight samples having sulfate values above the SMCL are all bedrock wells located in the southern part of Owen and Clay Counties and the northern part of Greene County. The other 16 are also located primarily in the southwest part of the basin with about half from unconsolidated aquifer systems. In general, sulfate levels are higher in the bedrock aquifer systems in the basin than in the unconsolidated systems. But, median sulfate concentrations vary considerably in both bedrock and unconsolidated aquifer systems.

Concentration ranges of sulfate in the unconsolidated aquifer systems are shown in figures 19a and b. Of the unconsolidated aquifer systems, the White River and Tributaries Outwash Aquifer system has the highest median levels. The aquifer system having the overall highest median levels is the Mississippian/Buffalo Wallow, Stephensport, and West Baden Group bedrock aquifer system; however, it must be remembered that the boundaries of each bedrock aquifer system are based on the boundaries of the subcrop of each major bedrock system. Therefore, wells located within this bedrock aquifer system may actually extend through the upper system into the underlying aquifer system (Blue River Group).

Various geochemical processes, sources, and time may influence the concentration of sulfate in ground water. One important source is the dissolution or weathering of sulfur-containing minerals. Two possible mineral sources of sulfate have been identified in the aquifers of the West Fork White River basin.

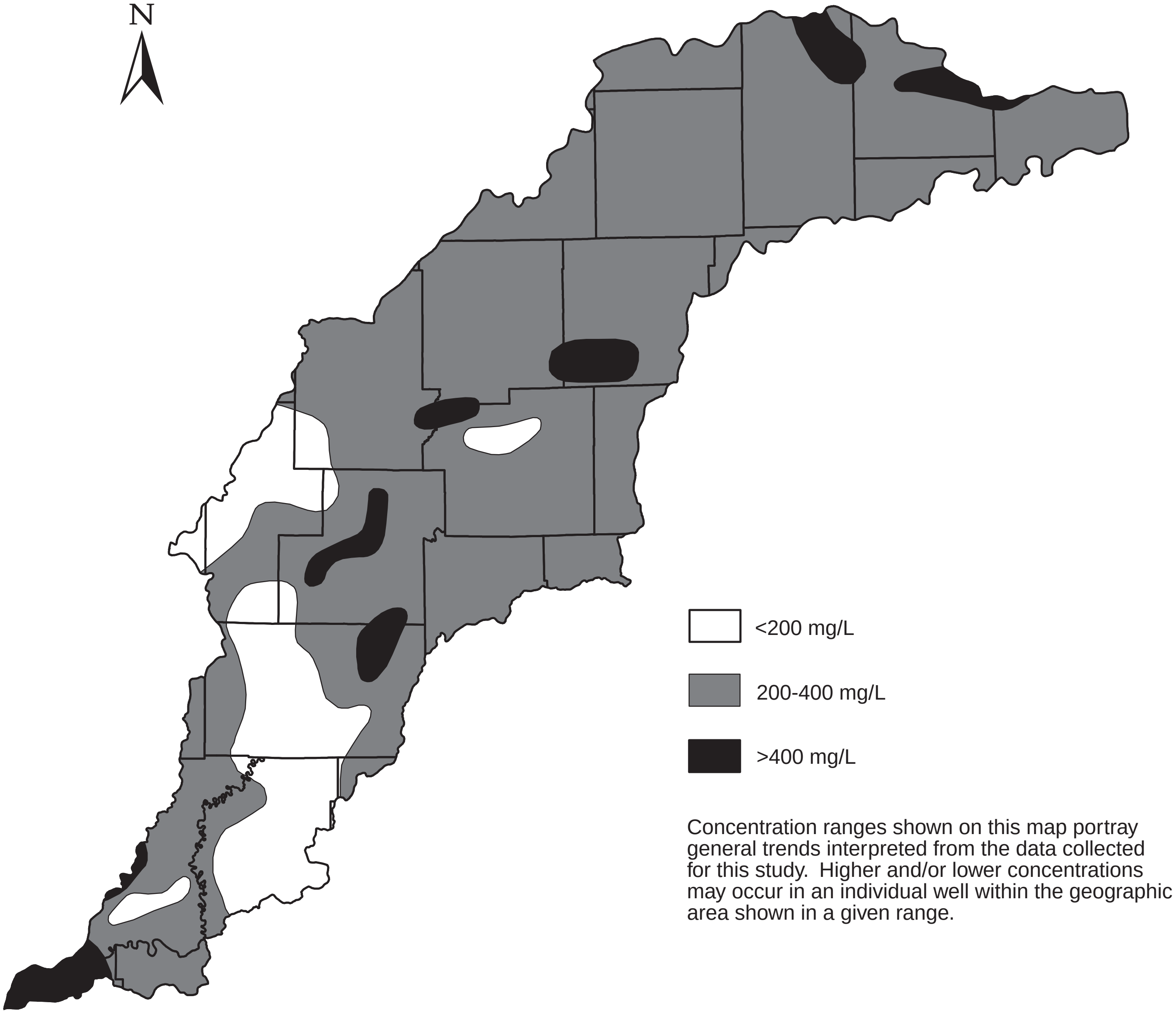


Figure 16b. Generalized areal distribution for Hardness - Bedrock aquifers

The first includes *evaporite* minerals, such as gypsum and anhydrite ($CaSO_4$). Gypsum and anhydrite are the two calcium sulphate minerals occurring in nature. Evaporite minerals are known to occur in both Mississippian and Devonian bedrock, and to a lesser extent, in Pennsylvanian and Silurian bedrock. Fragments of evaporite-bearing rocks may also have been incorporated into some unconsolidated units during glacial advances. There are rather extensive gypsum deposits in the lower part of the St. Louis limestone. The St. Louis evaporite unit accumulated in small basins within larger basins (intrasilled basins). Three major intrasilled basins exist in southwestern Indiana and are aligned in a northwest-southeast direction that corresponds to the trend of the rock formations. The maximum accumulation of the evaporites corresponds to the geographic locations of the intrasilled basins. One of these intrasilled basins lies within the West Fork White River basin in northern Greene County, southwestern Owen County, and southern Clay County.

The second possible mineral source of sulfate is pyrite (FeS_2), a mineral present in Silurian dolomite as highly localized nodules. Pyrite is also a common mineral in carbonaceous or black shales and Pennsylvanian coal beds. The oxidation of pyrite releases iron and sulfate into solution.

The high-sulfate ground-water samples taken from western Monroe, northeastern Greene, and southeastern Owen counties appear to be a result of dissolution of gypsum deposits related to the St. Louis limestone deposits. The high-sulfate ground-water samples taken from western Owen and Clay counties may be related to past coal-mining operations nearby. However, it is not apparent what the sources of other high-sulfate samples in the basin are.

Under *reducing*, low-oxygen conditions, sulfide (S^{-2}) may be the dominant species of sulfur in ground water. Some of the most important influences on the levels of sulfide in ground water are the metabolic processes of certain types of anaerobic bacteria. These bacteria use sulfate reduction in

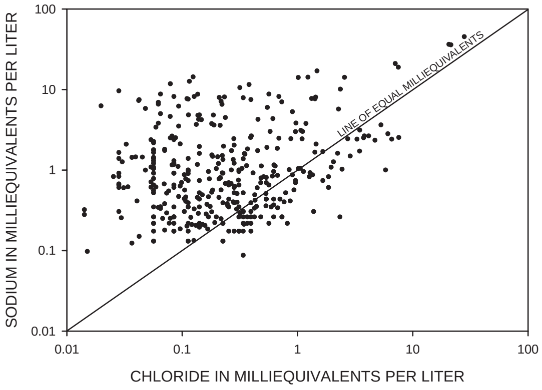


Figure 17. Sodium vs. Chloride in ground-water samples from the West Fork White River Basin

their metabolism of organic matter, which produces sulfide ions as a by-product (Freeze and Cherry, 1979; Hem, 1985).

A sulfide compound that is commonly considered undesirable in ground water is hydrogen sulfide (H_2S) gas. In sufficient quantities, hydrogen sulfide gas can give water an unpleasant odor, similar to that of rotten eggs. At present, there is no established SMCL for hydrogen sulfide in drinking water. Hem (1985) notes that most people can detect a few tenths of a milligram per liter of hydrogen sulfide in solution, and Freeze and Cherry (1979) state that concentrations greater than about 1 mg/L may render water unfit for drinking. Hydrogen sulfide is also corrosive to metals and, if oxidation to sulfuric acid occurs, concrete pipes. Possible results of hydrogen sulfide-induced corrosion include damage to plumbing, and the introduction of metals into water supplies (GeoTrans Inc., 1983)

Available data on the occurrence of hydrogen sulfide in the ground waters of the West Fork White River basin are qualitative. Well drillers may note the occurrence of "sulfur water" or "sulfur odor" on well records. This observation usually indicates the presence of noticeable levels of hydrogen sulfide gas in the well water. The occurrence of hydrogen sulfide is recorded on a few well records of those sampled in this study from Marion, Clay, and Putnam counties. Most of the recorded instances of detectable hydrogen sulfide levels examined for this report occur in wells completed in the Mississippian and Pennsylvanian bedrock aquifer systems.

Iron and Manganese

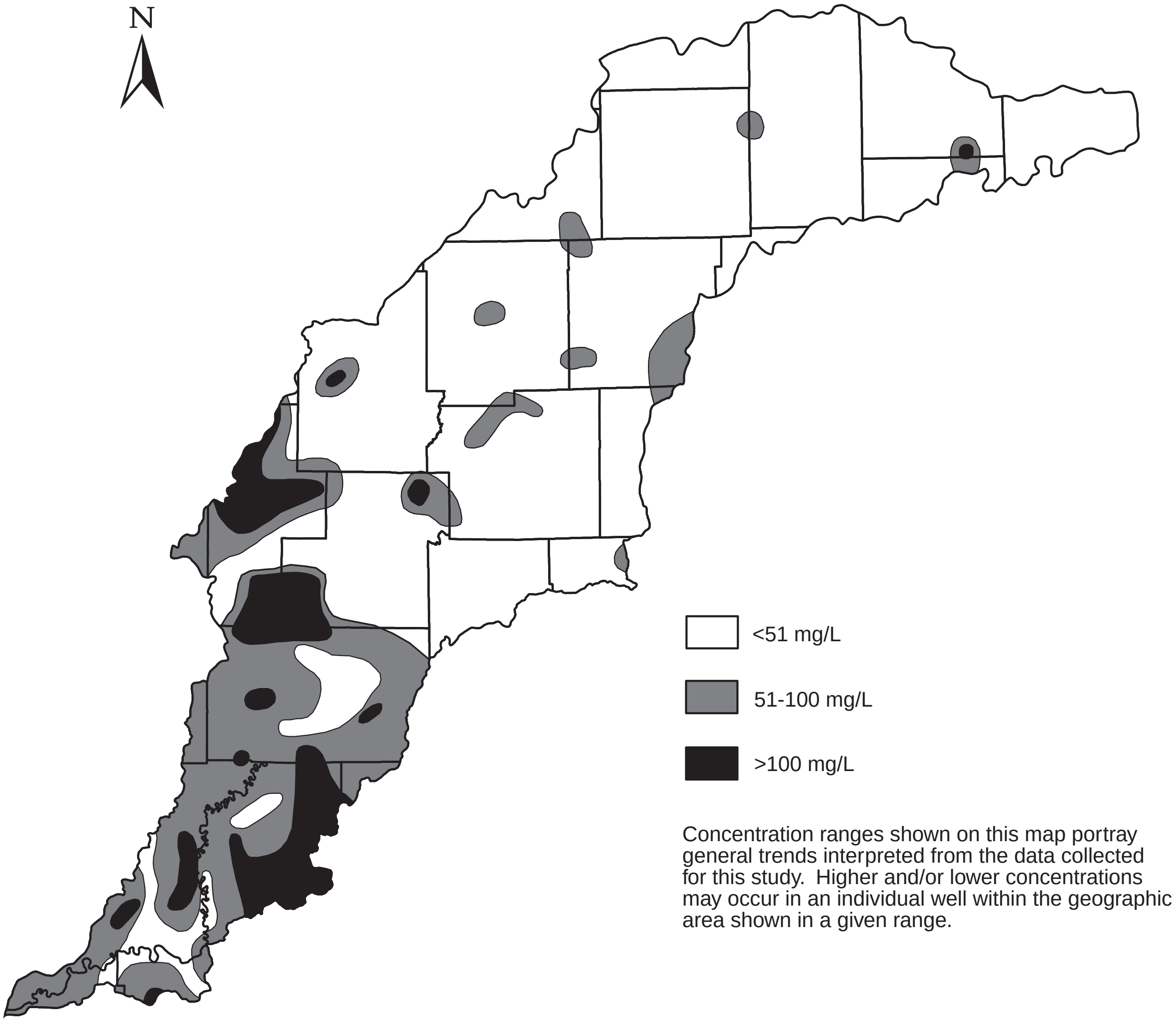
Because iron is the second most abundant metallic element in the Earth's outer crust (Hem, 1985), iron in ground water may originate from a variety of mineral sources; and several sources of iron may be present in a single aquifer system. Oxidation-reduction potentials, organic matter content, and the metabolic activity of bacteria can influence the concentration of iron in ground water. Because iron-bearing rocks were eroded, transported and deposited by glaciers, including igneous and metamorphic rocks from as far north as Canada, they have been incorporated into and are abundant in many unconsolidated deposits. Pyrite (FeS_2) oxidation may also contribute iron to unconsolidated aquifer systems. Iron is also present in organic wastes and in plant debris in soils. The presence of high iron concentrations in ground water with low sulfate levels may reflect siderite ($FeCO_3$) dissolution or the reduction of sulfate created by pyrite oxidation (Hem, 1985). Low concentrations in some of the bedrock systems may be explained by precipitation of iron minerals from activity of reducing bacteria (Hem, 1985) or by the loss of iron from cation-exchange processes occurring in confining clay, till or shale overlying the bedrock.

Iron levels equal to or below the SMCL are observed in less than 40 percent of all samples analyzed for this constituent. Iron concentrations commonly exceed the SMCL of 0.3 mg/L in water samples from both the unconsolidated and the bedrock aquifer systems (appendix 4). The SMCL for iron is less commonly exceeded in bedrock aquifer systems than in unconsolidated deposits. Forty-eight percent of the bedrock aquifer systems samples exceed the SMCL but 80 percent of the unconsolidated aquifer systems samples exceed the SMCL. Calculated median iron concentrations range between approximately 0.1mg/L and 1.2 mg/L in samples from the bedrock aquifer systems, and 0.75 mg/L and 2.4 mg/L in samples from the unconsolidated aquifer systems. Concentration ranges of iron in ground water of the unconsolidated and bedrock aquifer systems are mapped in figures 20a and b.

Water samples with iron levels above the SMCL are observed in all samples from wells completed in the unconsolidated Buried Valley aquifer system and 92 percent of the wells completed in the Tipton Till Plain Aquifer system. Water samples in bedrock aquifer system that have the highest percentage of ground-water samples with iron levels above the SMCL originate from wells completed in the Silurian and Devonian Carbonates.

In the West Fork White River basin the oxidation of pyrite fragments in glacial till deposits may produce the high iron concentrations in the Tipton Till Plain; the occurrence of high sulfate concentrations in many of the samples containing high iron concentrations is one indication that pyrite may be a source of dissolved iron. High iron concentrations are known to occur locally in the Silurian and Devonian carbonates; for example, the Liston Creek and upper Mississinewa formations in the northern part of the basin are known to contain pyrite and glauconite (another mineral that contains iron). In the southern part of the basin, the minerals pyrite and siderite are present in clay, shale, and coal units. Ferruginous shales and sandstones in some Pennsylvanian formations are also a source of other iron minerals.

Although the geochemistry of manganese is similar to that of iron, the manganese concentration in unpolluted waters is typically less than half the iron concentration (Davis and DeWiest, 1970). Manganese has a low SMCL (0.05 mg/L) relative to many other common constituents in ground water because even small quantities of manganese can cause objectionable taste and the deposition of black oxides. Because the *detection limit* for manganese in the DOW-IGS samples is twice the value of the SMCL, the number of times the SMCL



Concentration ranges shown on this map portray general trends interpreted from the data collected for this study. Higher and/or lower concentrations may occur in an individual well within the geographic area shown in a given range.

Figure 18. Generalized areal distribution for Sodium - Bedrock aquifers

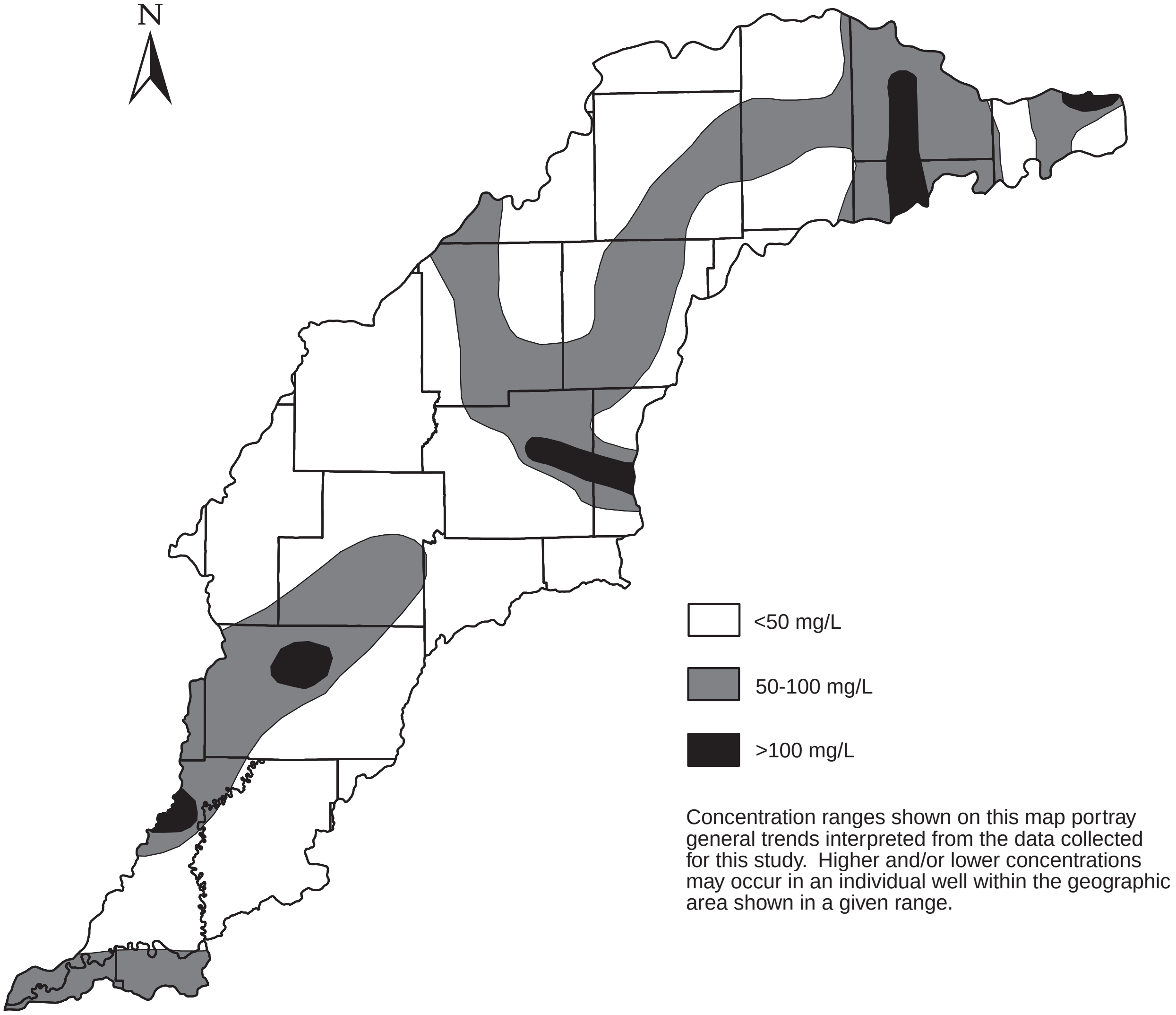
is exceeded in this data set cannot be quantified. However, ground-water samples with manganese concentrations equal to or above the detection limit are observed in all of the aquifer systems in the West Fork White River basin (appendix 1).

Manganese in West Fork White River basin ground water originates from the weathering of rock fragments in the unconsolidated deposits and oxidation/dissolution of the underlying bedrock. Limestones and dolomites may be a minor source of manganese, because small amounts of manganese commonly substitute for calcium in the mineral structure of carbonate rocks (Hem, 1985). Manganese oxides have been found in siderite and limonite concretions in Mississippian rocks of the Borden Group and in concretions in the Mansfield iron ores of the Raccoon Creek Group. Manganese oxides have also been found in Indiana kaolin (halloysite) deposits, some of which occur at the contact of the Pennsylvanian Mansfield Formation with underlying Mississippian formations (Erd and Greenberg, 1960). Oxides of manganese can also accumulate in bog environments or as coatings on stream sediments (Hem, 1985). Therefore, it is possible that high manganese levels may occur in ground water from wetland environments or buried stream channels.

Fluoride

Many compounds of fluoride can be characterized as only slightly soluble in water. Concentrations of fluoride in most natural waters generally range between 0.1 mg/L and 10 mg/L (Davis and DeWiest, 1970). Hem (1985) noted that fluoride levels generally do not exceed 1 mg/L in most natural waters with TDS levels below 1000 mg/L. The beneficial and potentially detrimental health effects of fluoride in drinking water are outlined in the sidebar titled **National Drinking-Water Standards**.

Box plots of fluoride concentrations in ground-water samples from the aquifer systems under consideration are displayed in appendix 4. Seven of the well samples analyzed for fluoride contain levels at or above the 4.0 mg/L MCL. All of these occur in the Pennsylvanian/Raccoon Creek Group Aquifer system. Concentrations equal to or above the SMCL



Concentration ranges shown on this map portray general trends interpreted from the data collected for this study. Higher and/or lower concentrations may occur in an individual well within the geographic area shown in a given range.

Figure 19a. Generalized areal distribution for Sulfate - Unconsolidated aquifers

for fluoride (2.0 mg/L) are detected in 33 samples and occur in all of the bedrock aquifer systems, but occur in only three samples from the unconsolidated aquifer systems (appendix 4 and figures 21a and b).

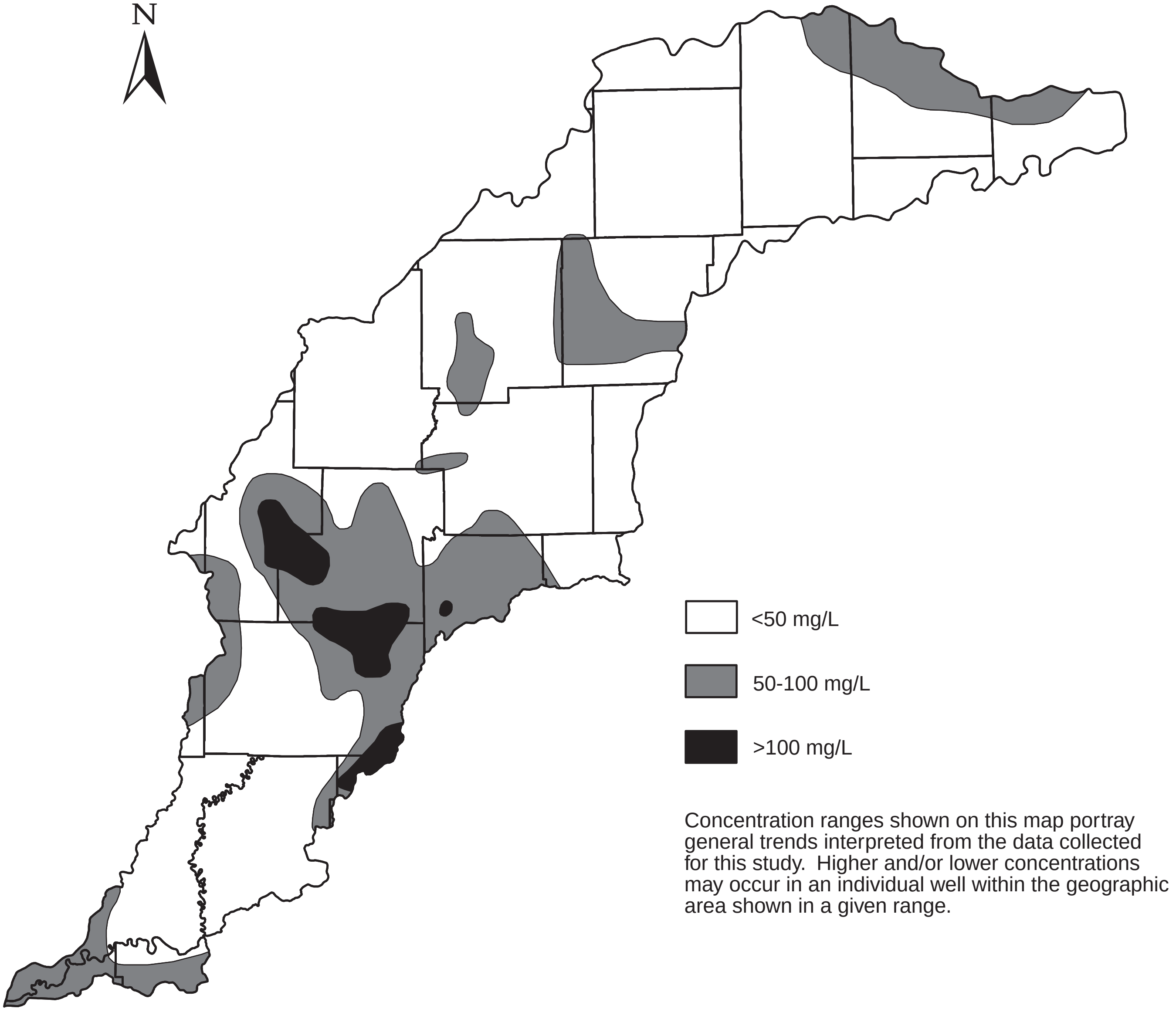
Fluoride-containing minerals such as fluorite, apatite and fluorapatite commonly occur in clastic sediments (Hem, 1985). The weathering of these minerals may thus contribute fluoride to ground water in sand and gravel units. The mineral fluorite may also occur in limestones or dolomites. Fluoride may also substitute for hydroxide (OH^-) in some minerals because the charge and ionic radius of these two ions are similar (Manahan, 1975; Hem, 1985).

Nitrate

Nitrate (NO_3^-) is the most frequently detected drinking-water contaminant in the state (Indiana Department of Environmental Management, [1995]) as well as the most common form of nitrogen in ground water (Freeze and Cherry, 1979). Madison and Brunett (1984) developed concentration criteria to qualitatively determine if nitrate levels (as an equivalent amount of nitrogen) in ground water may be influenced by anthropogenic sources. Using these criteria, nitrate levels of less than 0.2 mg/L are considered to represent natural or background levels. Concentrations ranging from 0.21 to 3.0 mg/L are considered transitional, and may or may not represent human influences. Concentrations between 3.1 and 10 mg/L may represent elevated concentrations due to human activities.

High concentrations of nitrate are undesirable in drinking waters because of possible health effects. In particular, excessive nitrate levels can cause *methemoglobinemia* primarily in infants. The maximum contaminant level, MCL, for nitrate (measured as N) is 10 mg/L.

Ranges of nitrate levels (measured as N) in ground-water samples from the West Fork White River basin are plotted in figures 22a and b. Because most samples were below the DOW-IGS detection limit, the occurrence of "background" levels as defined by Madison and Brunett (1984) cannot be quantified. However, figures 22a and b indicate that most of the samples contain nitrate concentrations below the level



Concentration ranges shown on this map portray general trends interpreted from the data collected for this study. Higher and/or lower concentrations may occur in an individual well within the geographic area shown in a given range.

Figure 19b. Generalized areal distribution for Sulfate - Bedrock aquifers

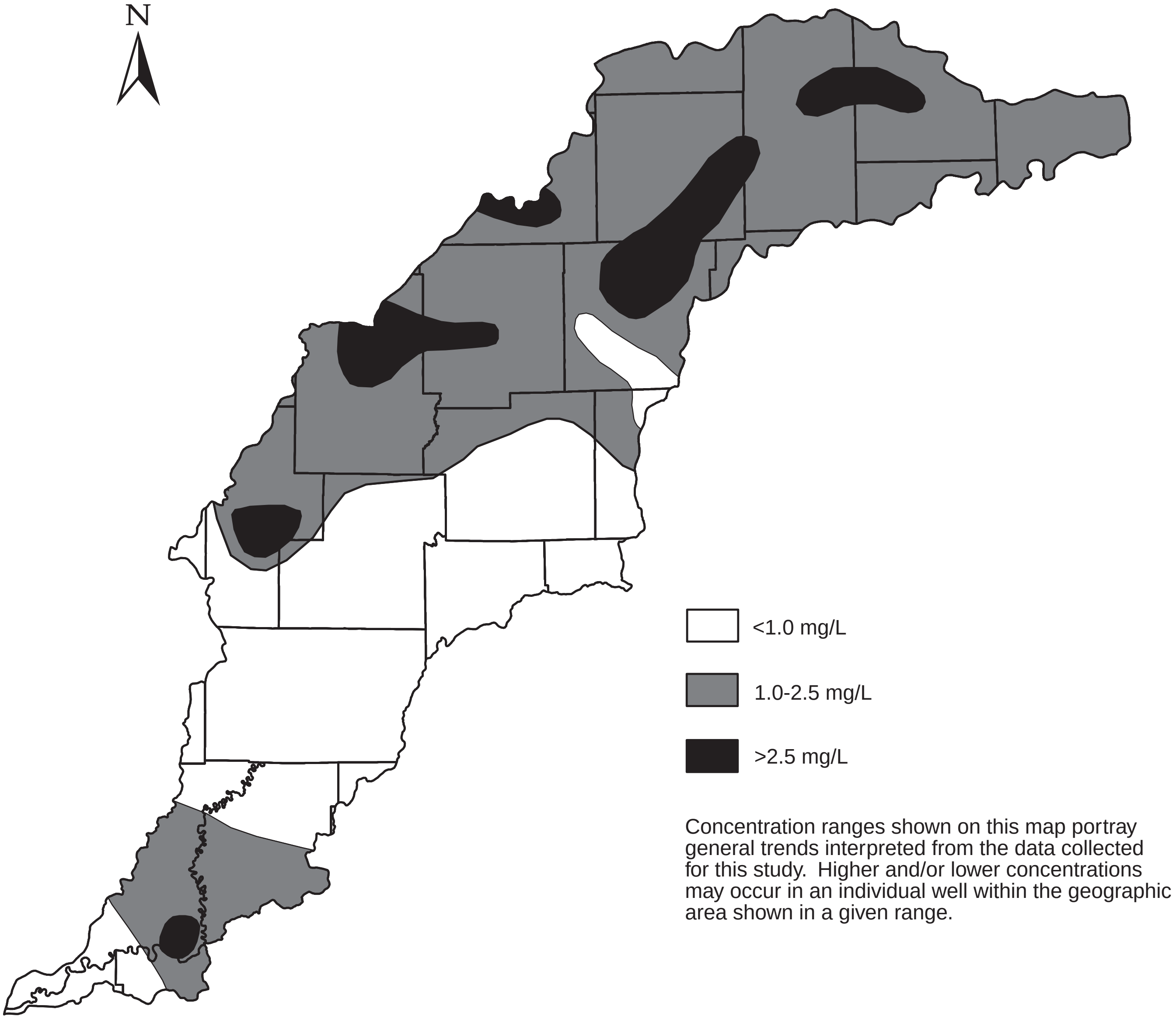
interpreted by Madison and Brunett (1984) to indicate possible human influences.

Only six samples with nitrate levels exceeding the MCL were recovered from wells in the basin (figures 22a and b). Four of these were from the White River and Tributaries Outwash Aquifer system in Knox and Daviess Counties. Nitrate levels from other sampled wells that are nearby, however, are below the detection limit. Overall, the distribution of nitrate concentrations in ground water of the West Fork White River basin appears to indicate that levels generally do not exceed 1.0 mg/L, as almost 90 percent of the samples are below that level. High concentrations of nitrate, which may suggest human influences, appear to occur in isolated wells or limited areas.

Two other studies also provide perspective on nitrate in ground water in the West Fork White River basin, one conducted by the Indiana Farm Bureau and another by the U.S. Geological Survey. A brief discussion of these studies and their findings follow.

In 1987, the Indiana Farm Bureau, in cooperation with various county and local agencies, began the Indiana Private Well Testing Program. The purpose of this program is to assess ground-water quality in rural areas, and to develop a statewide database containing chemical analysis of well samples. By the end of 1993 samples from over 9000 wells, distributed over 68 counties, had been collected and analyzed as a part of the program (Wallrabenstein and others, 1994). Most of the ground-water samples collected during this study were analyzed for inorganic nitrogen and some specific pesticides. The results of the pesticide sampling are presented in the section entitled **Pesticides in West Fork White River basin ground waters**.

The techniques used to analyze the samples collected for the Farm Bureau study actually measured the combined concentrations of nitrate and nitrite (nitrate+nitrite). However, the researchers noted that nitrite concentrations were general-



Concentration ranges shown on this map portray general trends interpreted from the data collected for this study. Higher and/or lower concentrations may occur in an individual well within the geographic area shown in a given range.

Figure 20a. Generalized areal distribution for Iron - Unconsolidated aquifers

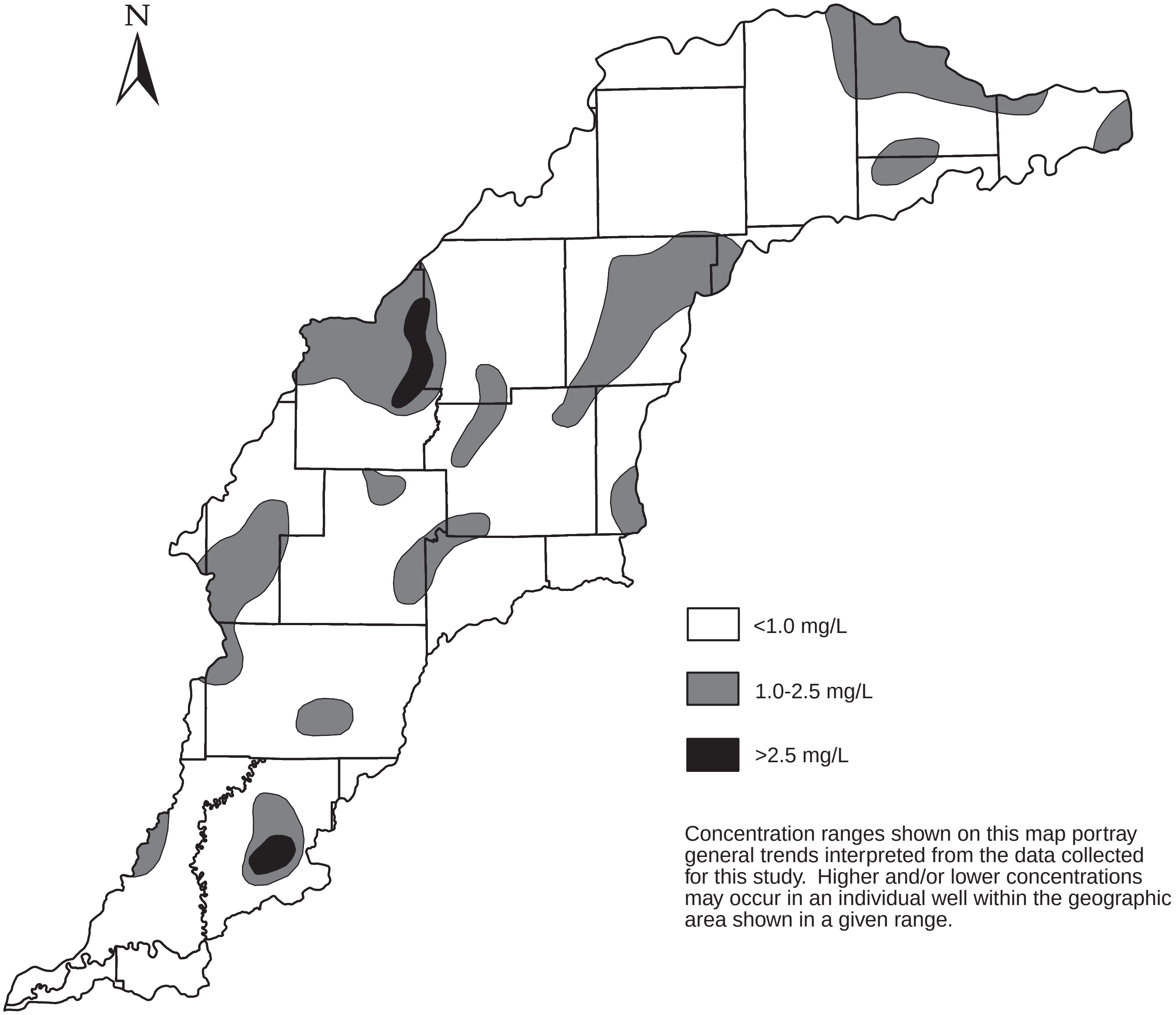
ly low. Thus the nitrate+nitrite concentrations were approximately equal to the concentrations of nitrate in the sample (Wallrabenstein and others, 1994). The MCL for nitrate+nitrite (as equivalent elemental nitrogen) is 10 mg/L.

Greene, Pike, and Randolph are the only counties of the 29 counties (table 1) that lie partially or wholly within the West Fork White River basin that did not participate in the Farm Bureau study. For this discussion, however, only the statistics for the counties that have more than 50 percent of their area encompassed within the basin were closely examined: Clay, Daviess, Delaware, Hamilton, Hendricks, Knox, Madison, Marion, Morgan, Owen, and Putnam. Statistics for Boone, Johnson, Monroe, and Tipton counties were also briefly examined because these counties have more than 35 percent of their area in the basin. Data on the owners and exact locations of the wells sampled for the Farm Bureau study were not provided in the report. Although the exact locations of the samples cannot be determined, the data do provide a general sense for nitrate conditions in the basin.

Approximately 80 percent of all samples in the counties of the basin had nitrate+nitrite concentrations below the reporting limit of 0.3 mg/L. Nitrate+nitrite concentrations above the MCL were observed in approximately 3 percent of the wells sampled.

Although most of the samples had concentrations below reporting limits, samples from each county contained nitrate+nitrite levels over the reporting limit (0.3 mg/L). The largest number of samples having nitrate+nitrite concentrations above the reporting limit were in Hendricks, Putnam, Johnson, Morgan, and Daviess Counties. The smallest number of samples and smallest percentage of samples having nitrate+nitrite concentrations above the reporting limit were reported for Tipton, Boone, and Madison Counties.

However, sheer numbers do not necessarily represent the complete picture of the nitrate situation in a county. Differences in sample size in the counties tend to distort the



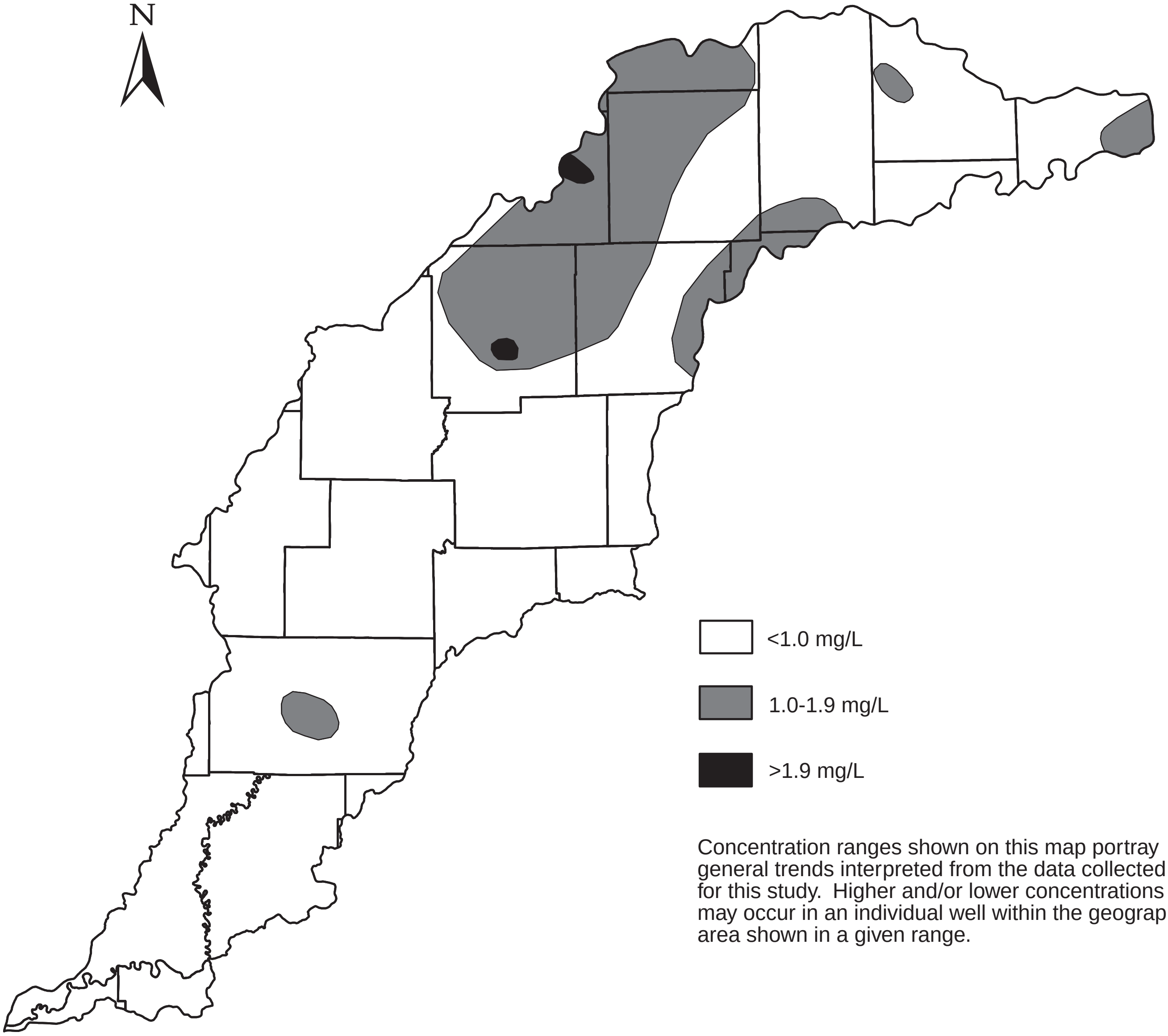
Concentration ranges shown on this map portray general trends interpreted from the data collected for this study. Higher and/or lower concentrations may occur in an individual well within the geographic area shown in a given range.

Figure 20b. Generalized areal distribution for Iron - Bedrock aquifers

magnitude of the nitrate issue in a county. For example, although Hendricks County reported 94 samples above reporting limits, the large sample size of 873 make the percentage of samples having reportable levels at less than 11 percent. Whereas, the small sample size of 31 for Knox County produce approximately 71 percent result for samples having reportable values. In spite of the small sample size there are obviously nitrate issues in Knox County, because approximately 50 percent of the samples taken in the county had reported values greater than 3.0 mg/L, including 29 percent with nitrate values greater than the MCL.

A variety of anthropogenic activities can contribute nitrate to ground waters, and may increase nitrate concentrations above the MCL. Because nitrate is an important plant nutrient, nitrate fertilizers are often added to cultivated soils. Under certain conditions, however, these fertilizers may enter the ground water through normal infiltration or through a poorly-constructed water well. Nitrate is commonly present in domestic wastewater, and high levels of this constituent are often associated with septic systems. Animal manure can also be a source of nitrate in ground-water systems, and high nitrate levels are sometimes detected in ground waters down-gradient from barnyards or feedlots. Because many sources of nitrate are associated with agriculture, rural areas may be especially susceptible to nitrate pollution of ground water. To help farmers and other rural-area residents assess and minimize the risk of ground-water contamination by nitrate and other agricultural chemicals, the American Farm Bureau Federation has developed a water quality self-help checklist specifically for agricultural operations (American Farm Bureau Federation, 1987).

In 1991, the U.S. Geological Survey (USGS) began the National Water-Quality Assessment (NAWQA) Program. The long-term goals of the NAWQA Program are to describe the status and trends in the quality of the Nation's surface and ground water and to provide a sound scientific understanding



Concentration ranges shown on this map portray general trends interpreted from the data collected for this study. Higher and/or lower concentrations may occur in an individual well within the geographic area shown in a given range.

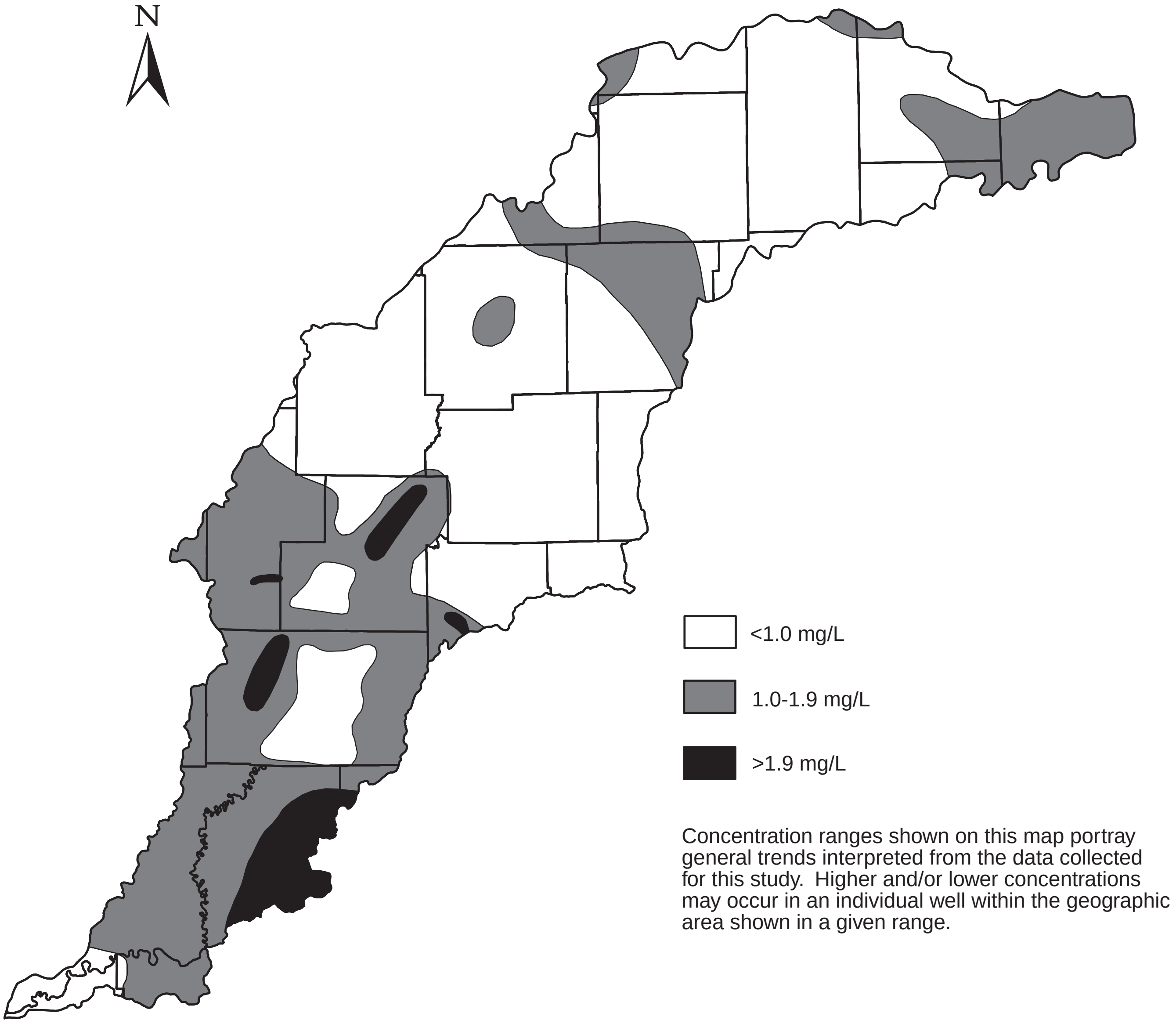
Figure 21a. Generalized areal distribution for Fluoride - Unconsolidated aquifers

of the primary natural and human factors affecting the quality of these resources (Hirsch and others, 1988).

The White River Basin in Indiana was among the first 20 river basins to be studied as part of the NAWQA program. A component of the White River Basin study is to determine the occurrence of nitrate in the shallow ground water of the basin. Moore and Fenelon (1996) describe nitrate data collected from 103 monitoring wells from June 1994 through August 1995. The study included both the West Fork and the East Fork White River Water Management basins of Indiana.

Findings of the study:

- Nitrate concentrations in water samples from the 94 shallow wells in the White River Basin ranged from less than 0.05 mg/L to a high of 21 mg/L.
- Water from 6 of the 94 shallow wells (6.4 percent) contained nitrate concentrations higher than 10 mg/L. Nitrate was not detected, at a detection limit of 0.05 mg/L, in 43 percent of the shallow wells.
- In contrast to the wells with no detectable nitrate, samples from 29 percent of the shallow wells had nitrate concentrations higher than 3.0 mg/L.
- The paired wells in the fluvial deposits show stratification of nitrate concentration with depth. The largest percentage of shallow wells with a nitrate concentration between 3.1 and 10 mg/L (42 percent) and the largest percentage of shallow wells with a nitrate concentration higher than 10 mg/L (17 percent) were in fluvial deposits underlying agricultural land.
- Nitrate concentrations in samples from three-fourths of the shallow wells in fluvial deposits underlying urban land were above the detection limit; however, the nitrate concentration did not exceed 10 mg/L in any of the samples.
- Water samples from more than one third of the wells in the glacial lowland had nitrate concentrations higher than 3.0 mg/L.



Concentration ranges shown on this map portray general trends interpreted from the data collected for this study. Higher and/or lower concentrations may occur in an individual well within the geographic area shown in a given range.

Figure 21b. Generalized areal distribution for Fluoride - Bedrock aquifers

• Nitrate concentrations were below the detection limit in samples from approximately 65 percent of the wells in the till plain and 41 percent of the wells in the glacial lowland.

Strontium

Ground water in the West Fork White River basin may be characterized as containing "relatively high" concentrations of strontium compared to ground water in other regions. For example, Skougstad and Horr (1963) analyzed 175 ground-water samples from throughout the United States and noted that 60 percent contained less than 0.2 mg/L of strontium. Davis and DeWiest (1970) report that concentrations of strontium in most ground water generally range between 0.01 and 1.0 mg/L. Of the 372 ground-water samples analyzed for strontium in this report, however, only about 22 percent contained strontium concentrations less than 0.2 mg/L. Almost 25 percent of the wells sampled in the West Fork White River basin contained strontium concentrations greater than 1.0 mg/L. Figures 23a and b display the spatial distribution of ground-water strontium levels for the unconsolidated and bedrock aquifer systems in the West Fork White River basin.

The unconsolidated aquifer systems generally have lower median strontium concentrations than the bedrock aquifer systems. The lowest median strontium concentrations of all the aquifer systems are observed in the ground-water samples from the unconsolidated White River and Tributaries Outwash Aquifer system and subsystem. The unconsolidated aquifer systems with the highest median strontium concentrations are the Tipton Till Plain Aquifer system and subsystem. The lowest median strontium concentrations in the bedrock aquifer systems are observed in samples from the Pennsylvanian bedrock systems. The Mississippian/Buffalo Wallow, Stephensport, and West Baden Group Aquifer system has the highest median strontium concentration of all the

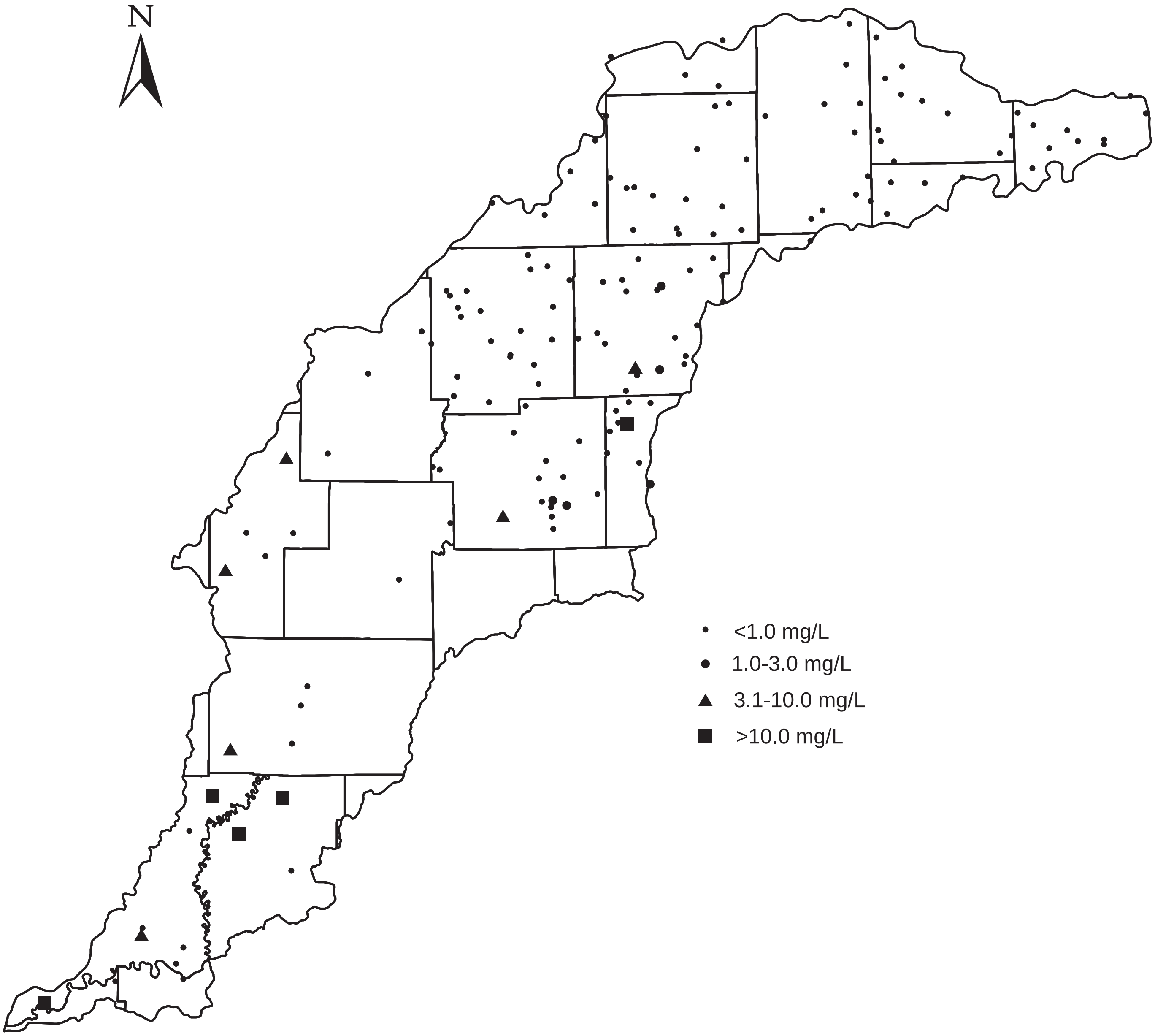


Figure 22a. Distribution of Nitrate-Nitrogen concentrations for sampled wells - Unconsolidated aquifers

aquifer systems (appendix 4).

Elevated concentrations of strontium are apparent in the bedrock aquifers in some areas of Monroe, Greene, and Owen Counties, and in the unconsolidated and bedrock aquifers of Randolph County. At the time of this report, no enforceable drinking-water standards have been established for strontium. However, the non-enforceable lifetime *health advisory* for strontium is set at 17.0 mg/L. Four samples from wells completed in the Mississippian/Blue River and Sanders Group Aquifer system in Monroe County and one sample from the Tipton Till Plain Aquifer subsystem in Randolph County contain strontium concentrations in excess of the health advisory (see appendix 4). In addition to these 5 wells, fifteen others have strontium concentrations greater than 5 mg/L. Seven of these were in Randolph County and all but one of the rest were in Greene, Owen and Monroe Counties.

Sources of strontium in ground water are generally the trace amounts of strontium present in rocks. The strontium-bearing minerals celestite ($SrSO_4$) and strontianite ($SrCO_3$) may be disseminated in limestone and dolomite. Also, celestite is associated with gypsum deposits, which occur in the rocks of the Blue River and Sanders Group. These rocks are located in Greene, Owen, and Monroe Counties. Silurian rocks of several different lithologies may be the source of high strontium and concentrations in Randolph County.

Because strontium and calcium are chemically similar, strontium atoms may also be adsorbed on clay particles by ion exchange (Skougstad and Horr, 1963). Ion-exchange processes may thus reduce strontium concentrations in ground water found in clay-rich sediments.

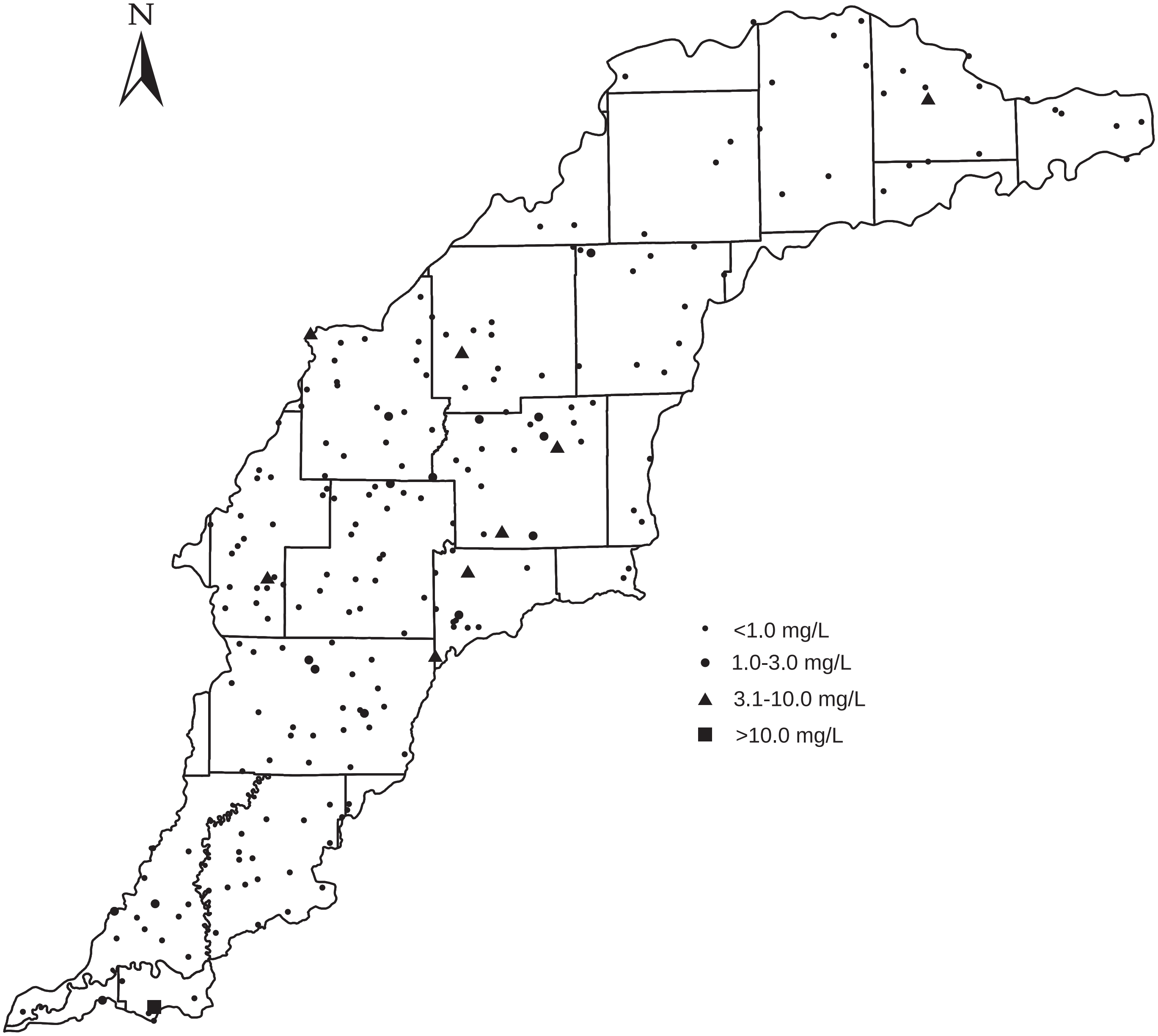


Figure 22b. Distribution of Nitrate-Nitrogen concentrations for sampled wells - Bedrock aquifers

Zinc

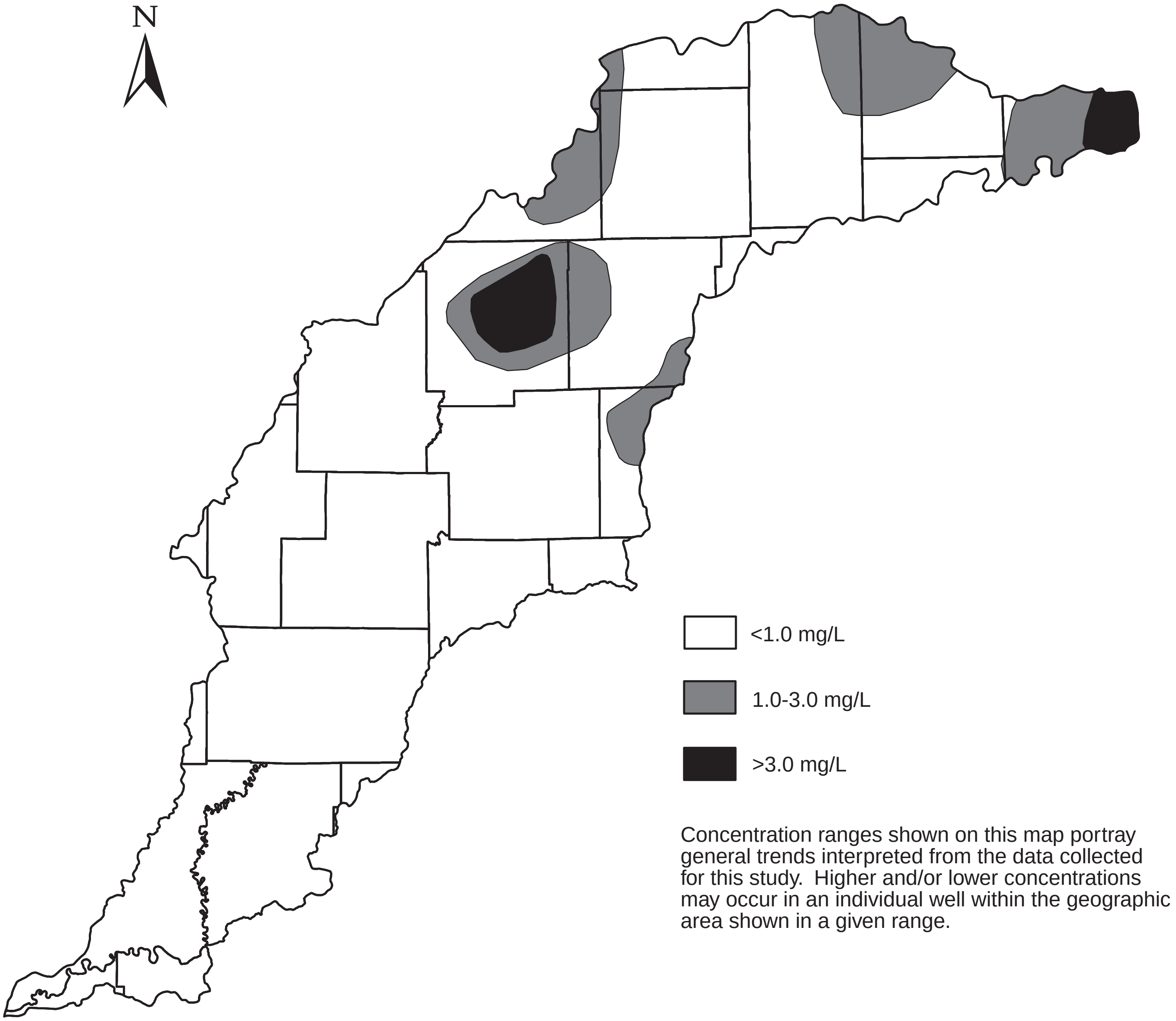
Generally, significant dissolved quantities of the metal zinc occur only in low pH or high-temperature ground water (Davis and DeWiest, 1970). Concentrations of zinc in ground-water samples from the West Fork White River basin are plotted in figures 24a and b. Three hundred eleven of the ground-water samples analyzed (approximately 84 percent) contain levels below the detection limit of 0.1 mg/L for zinc. None of the samples analyzed contain zinc in concentrations above the 5 mg/L SMCL established for this constituent (appendix 2).

Lead

Naturally occurring minerals that contain lead are widely dispersed, but have low solubility in most natural ground water. The co-precipitation of lead with manganese oxide and the adsorption of lead on organic and inorganic sediment surfaces help to maintain low lead concentration levels in ground water (Hem, 1985). Much of the lead present in tap water may come from anthropogenic sources, particularly lead solder used in older plumbing systems. Because natural concentrations of lead are normally low and because there are so many uncertainties involved in collecting and analyzing samples, lead was not analyzed in this study.

Total dissolved solids

Total dissolved solids (TDS) are a measure of the total amount of dissolved minerals in water. Essentially, TDS rep-



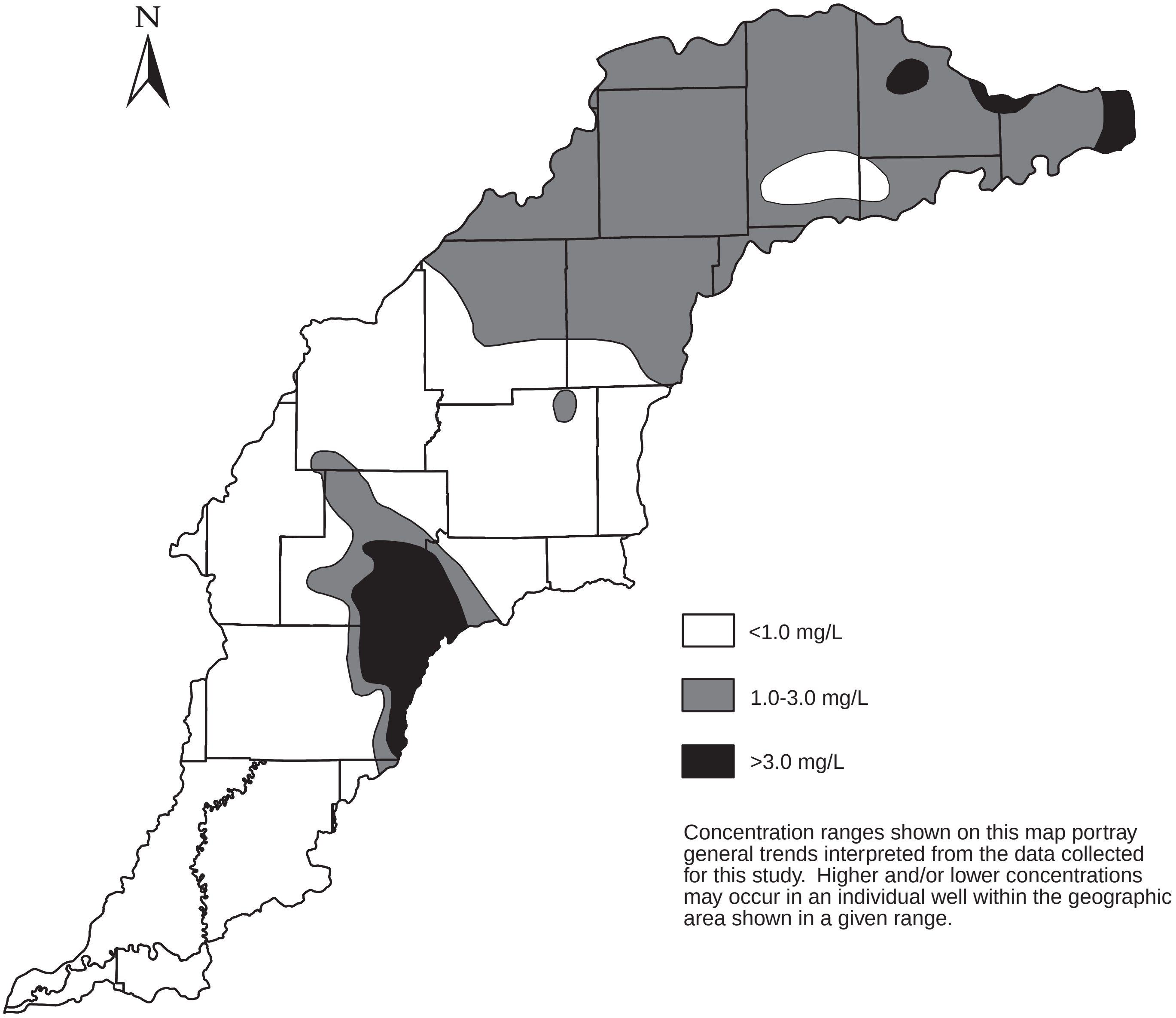
Concentration ranges shown on this map portray general trends interpreted from the data collected for this study. Higher and/or lower concentrations may occur in an individual well within the geographic area shown in a given range.

Figure 23a. Generalized areal distribution for Strontium - Unconsolidated aquifers

resents the sum of concentrations of all dissolved constituents in a water sample. In general, if a ground-water sample has a high TDS level, high concentrations of major constituents will also be present in that sample. The secondary maximum contaminant level (SMCL) for TDS is established at 500 mg/L. Drever (1988), however, defines fresh water (water sufficiently dilute to be potable) as water containing TDS of less than 1000 mg/L.

More than 81 percent of the samples collected from wells in the West Fork White River basin contain TDS levels that exceed the SMCL. The lowest median TDS level is observed in samples from the Mississippian/Buffalo Wallow, Stephensport and West Baden Groups Aquifer system, which is the only aquifer system having a median TDS level below the SMCL (appendix 4); however, this system also displays the greatest variability in TDS levels. The lowest median TDS level in the unconsolidated aquifer systems is slightly above the SMCL and is observed in samples from the White River and Tributaries Outwash Aquifer system (appendix 4).

Although the lowest median values for TDS occur in a bedrock aquifer system, in general TDS values are higher in the bedrock aquifer systems in the basin than in the unconsolidated deposits. Median TDS levels are more variable in the bedrock aquifer systems than in the unconsolidated systems, as both the highest and lowest median TDS levels occur in the bedrock systems. Three of the bedrock aquifer systems, the Devonian and Mississippian/New Albany Shale, the Pennsylvanian/Carbondale Group, and the Pennsylvanian/McLeansboro Group, have the highest median TDS levels of all aquifer systems, which are approximately 700 mg/L. Some of the highest TDS levels are observed in the Pennsylvanian/Raccoon Creek Group Aquifer system. Of the 16 bedrock well samples exceeding 1000 mg/L, eleven occur in this aquifer system. In contrast, only one of the unconsolidated aquifer systems has a median TDS level above 600 mg/L, which is the White River and Tributaries Outwash



Concentration ranges shown on this map portray general trends interpreted from the data collected for this study. Higher and/or lower concentrations may occur in an individual well within the geographic area shown in a given range.

Figure 23b. Generalized areal distribution for Strontium - Bedrock aquifers

Subsystem at 635 mg/L. Figures 25a and b display the spatial distribution of ground-water TDS levels for the unconsolidated and bedrock aquifer systems in the West Fork White River Basin.

Because of the wide range in solubility of different minerals, one of the principal influences on TDS levels in ground water is the minerals that come into contact with the water. Water in contact with highly soluble minerals will probably contain higher TDS levels than water in contact with less soluble minerals. Amount of carbonate materials and ground-water residence time also exert substantial control over the levels of chemical constituents in ground water.

In an aquifer where ground-water flow is very sluggish and flushing of the aquifer is minimal, ground water can reach a state of chemical saturation with respect to dissolved solutes. Areas of active ground-water flushing generally have lower TDS values.

Ion-exchange processes in clays can also increase TDS because, in order to maintain electrical charge balance, two *monovalent* sodium or potassium ions must enter solution for each *divalent* ion absorbed. Clay minerals can have high cation-exchange capacities and may exert a considerable influence on the proportionate concentration of the different cations in water associated with them (Hem, 1985). The exchange of calcium for sodium results in high sodium levels, and total dissolved solids increase in ground water when calcium ions are exchanged for sodium ions (Freeze and Cherry, 1979).

Shale and other fine-grained sedimentary rocks (referred to as hydrolyzates) are composed, in large part of clay minerals and other fine-grained particulate matter that has formed by chemical reactions between water and silicates. Shale and similar rocks may be porous but do not transmit water readily because openings are very small and are poorly interconnected. Many such rocks were originally deposited in saltwater, and some of the solutes may remain in the pore space and

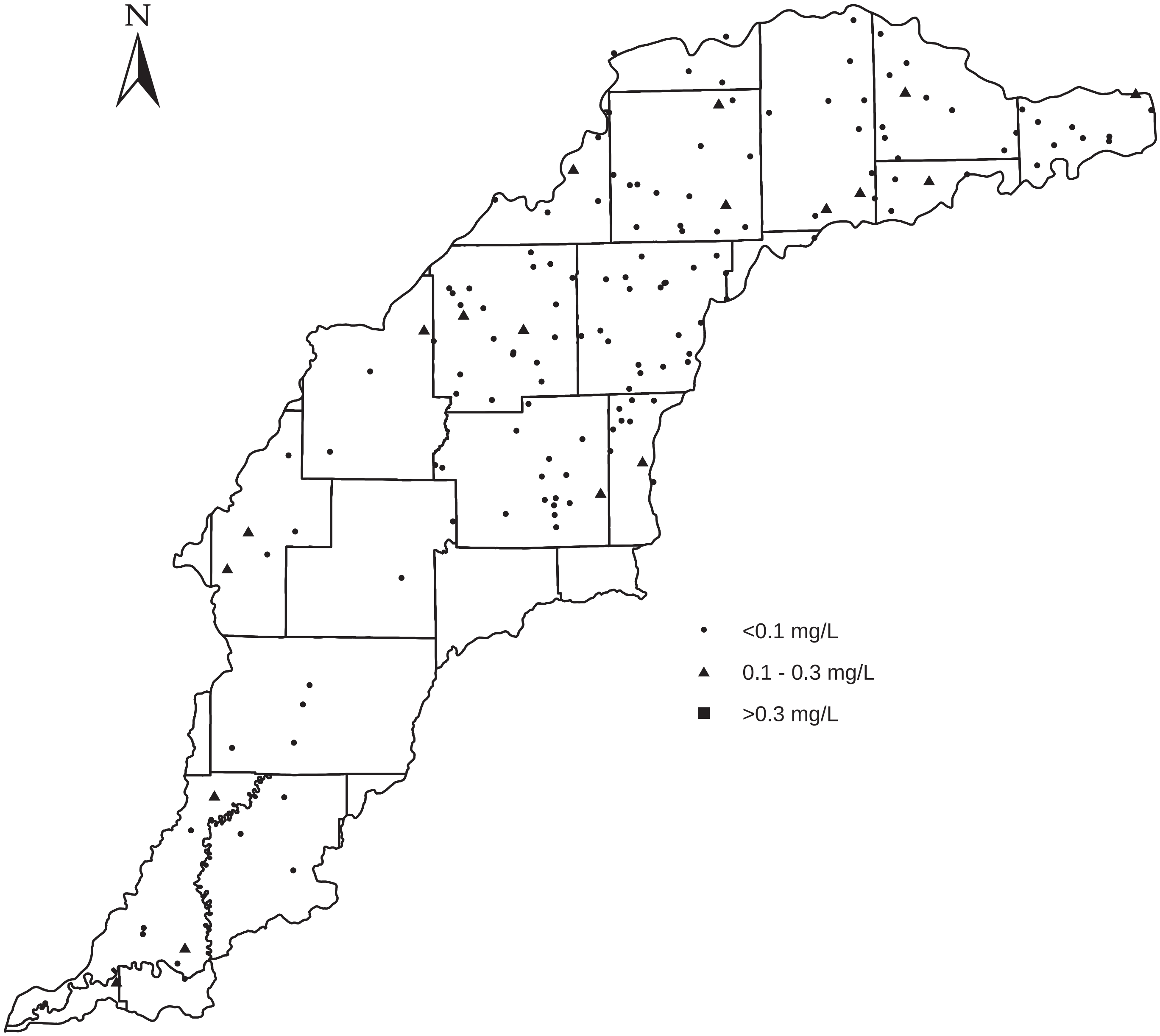


Figure 24a. Distribution of Zinc concentrations for sampled wells - Unconsolidated aquifers

attached to the particles for long periods after the rock has been formed. As a result, the water obtained from a hydrolyzate rock may contain rather high concentrations of dissolved solids. If they are interbedded with rocks that are more permeable, there can be migration of water and solutes from the hydroyzates into the aquifers with which they are interbedded. Although it is not necessarily true for all waters associated with hydrolyzates, such waters commonly share one dominant characteristic; sodium is their principal cation.

The high TDS levels in the Pennsylvanian bedrock aquifer systems could reflect long residence times and cation exchange in bedrock systems that contain a high percentage of shale. The high TDS level is a factor that prevents deep bedrock formations from being considered practical sources of potable ground water in the West Fork White River basin.

Total dissolved solids levels may also be influenced by ground-water pollution. Road salting, waste disposal, mining, landfills, and runoff from urban or agricultural areas are some human factors that may add dissolved constituents to ground water. Coal mining in the Pennsylvanian bedrock may also play an important role in the high TDS values in those aquifer systems within and adjacent to the mines.

Radon

Radon is a radioactive noble gas produced by the decay of radium. Uranium minerals in rocks are the source of radium. The primary source of the radon gas in ground water is the radium in the aquifer material (Hem, 1985). Radon subsequently undergoes decay by emitting an alpha particle (positively charged helium nucleus). When ingested or inhaled over an extended period of time, radon and some of its decay products can cause cancer. Radon levels are measured in pic-

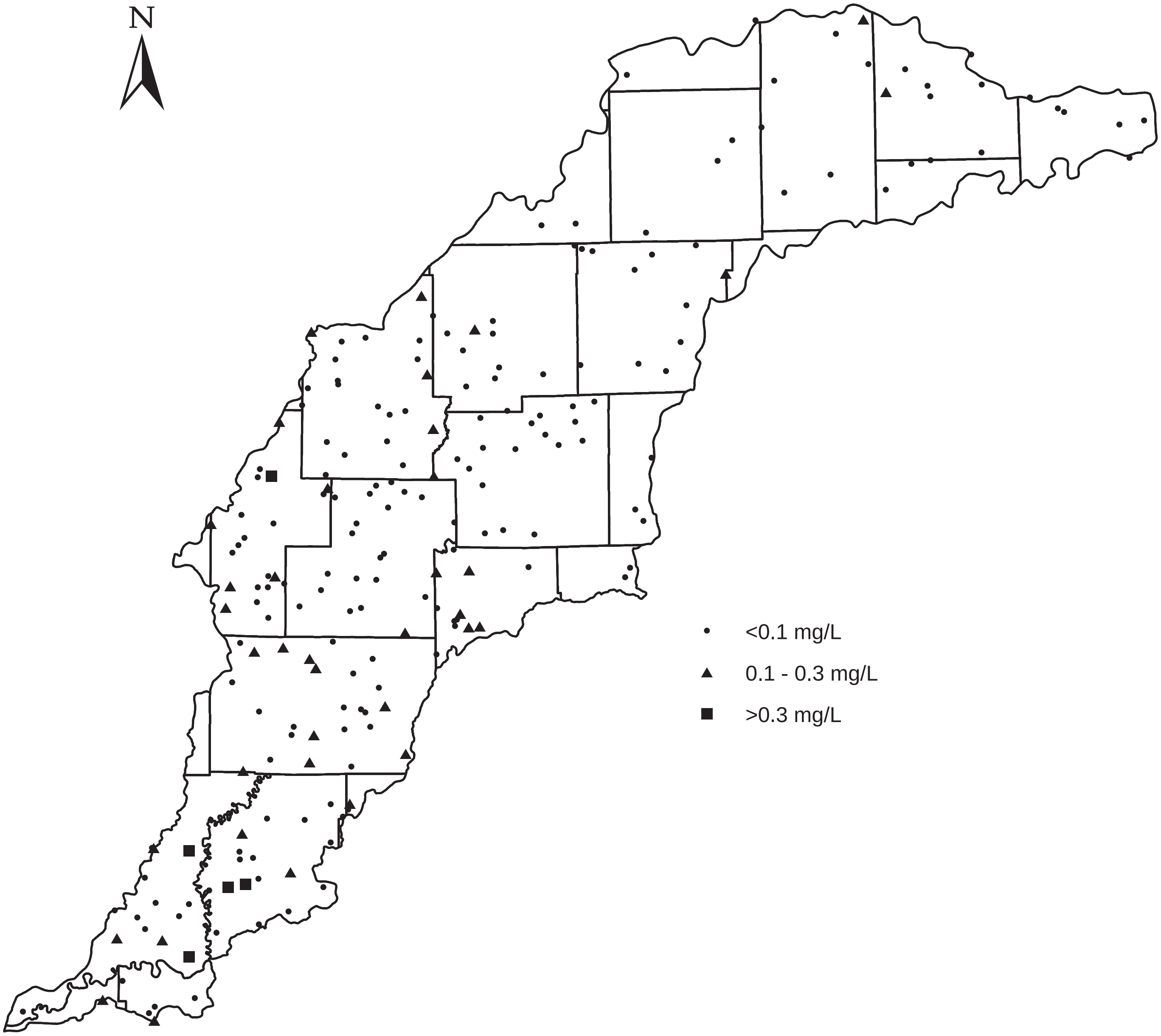


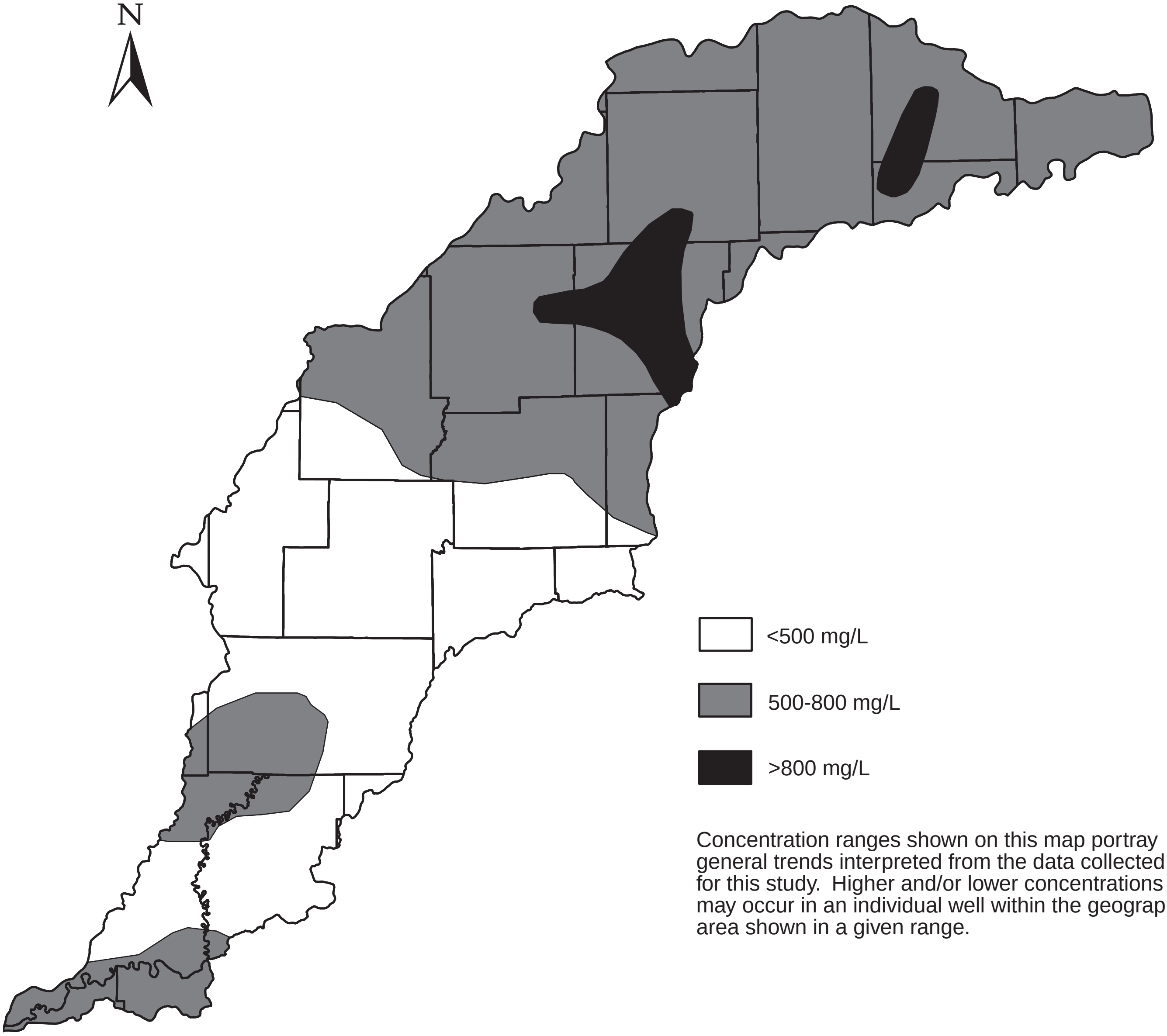
Figure 24b. Distribution of Zinc concentrations for sampled wells - Bedrock aquifers

ocuries per liter (pCi/L). An activity of one pCi/L is approximately equal to the decay of two atoms of radon per minute in a liter of air or water. At present, no Maximum Contaminant Level (MCL) has been established for radon in drinking water; however, the Environmental Protection Agency has proposed an MCL of 300 pCi/L

One hundred seventy-six of the 372 ground-water samples taken for this study were analyzed for radon. The bedrock aquifers generally exhibit greater variability in median radon activity than the unconsolidated aquifers (appendix 4). The Mississippian/Borden Group and the Blue River and Sanders Groups have the highest median activity in the bedrock aquifer systems. In the unconsolidated aquifer systems, the Dissected Till and Residuum aquifer system has the highest median radon activity. Fourteen samples have activity greater than 1000 pCi/L. All but one of these are from bedrock aquifers. Ten are from the Mississippian aquifer systems. Four aquifer systems: (Buried Valley, Lacustrine and Backwater Deposits, Devonian and Mississippian/New Albany Shale, and Mississippian/Buffalo Wallow, Stephensport, and West Baden Group) have fewer than 4 samples, so they are not included in the median comparison.

Pesticides

Because agriculture is an important form of land use in Indiana, pesticides are widely used in the state to control weeds and insects. In 1990, for example, a reported 28 million pounds of corn and soybean pesticides were used throughout the state (Risch, 1994). The widespread use of pesticides has created concerns about possible adverse affects that these chemicals may have on the environment. Among these concerns is the possibility that pesticides may contami-



Concentration ranges shown on this map portray general trends interpreted from the data collected for this study. Higher and/or lower concentrations may occur in an individual well within the geographic area shown in a given range.

Figure 25a. Generalized areal distribution for Total Dissolved Solids - Unconsolidated aquifers

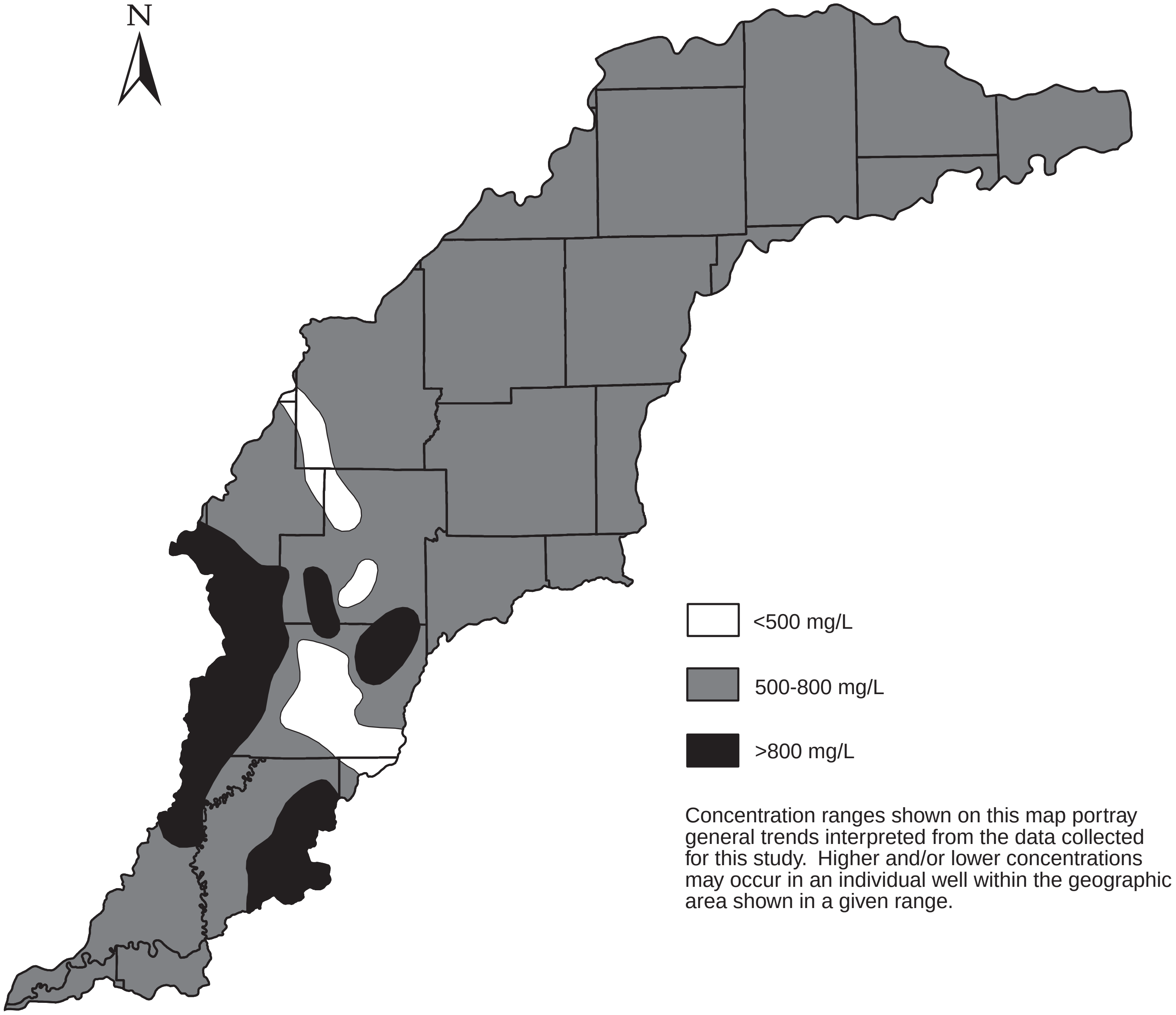
nate ground-water supplies.

Through a cooperative effort, the U.S. Geological Survey and the Indiana Department of Environmental Management have developed a statewide-computerized database containing analyses of pesticides in ground-water samples. This database contains the results of 725 ground-water samples collected during 6 statewide and 15 localized studies between December 1985 and April 1991. Sources of data consist of the U.S. Geological Survey, the Indiana Department of Environmental Management, the Indiana Department of Natural Resources, and the U.S. Environmental Protection Agency. A comprehensive summary of the pesticide database was written by Risch (1994).

The pesticide database includes 47 water sample analyses from 28 different wells in the West Fork White River basin that were sampled in August 1989 through February 1990 as a part of a cooperative effort between the Indiana Department of Environmental Management (IDEM) and the Indiana Department of Natural Resources (IDNR). The 28 wells are a subset of 372 wells sampled for inorganics by the DOW-IGS as part of the West Fork White River basin water resource assessment that were selected by Department of Environmental Management staff for pesticide analysis (figure 26). The inorganic chemical analyses for the 28 samples are included in appendix 1.

The 28 wells were sampled for 53 pesticides and 4 *metabolites*. Fifteen of the wells were developed in bedrock; thirteen in unconsolidated materials. No pesticides or Volatile Organic Compounds (VOCs) were detected in the samples (Indiana Department of Environmental Management, [1990]).

A major focus of a private well-water testing program in Indiana (Wallrabenstein and others, 1994) is to collect information on the presence of *triazine* herbicide and alachlor (Lasso) in rural water supplies. The private testing program, which is sponsored by the Indiana Farm Bureau, Soil and Water Conservation Districts, County Health Departments,



Concentration ranges shown on this map portray general trends interpreted from the data collected for this study. Higher and/or lower concentrations may occur in an individual well within the geographic area shown in a given range.

Figure 25b. Generalized areal distribution for Total Dissolved Solids - Bedrock aquifers

Resource Conservation and Development Districts, County Extension Offices, and other local entities, uses *immunoassay* analyses to screen for triazine herbicides and alachlor. Nitrate levels in rural water supplies are also examined, as discussed on the previous pages of this chapter under the heading of **Nitrate**.

The *triazine* immunoassay screen indicates the presence of one or more of the common triazine herbicides including atrazine (AAtrex), cyanazine (Bladex), and simazine (Princep), and some triazine *metabolites*. The alachlor screen indicates the presence of alachlor (Lasso), metolachlor (Dual), metalaxyl (Ridomil) or one of the related *acetanilide* herbicides. The alachlor screen may also react to various alachlor metabolites. The immunoassay procedures, thus do not indicate which specific pesticide(s) is (are) present, but will confirm the absence of triazine- or acetanilide-pesticides at concentrations above the method detection limit (MDL). In the assessment of data collected during the private-well screening program, the researchers used the term "triazine" to refer to triazine herbicides and their metabolites, and used the term "acetanilide" in reference to alachlor, metolachlor and related metabolites (Wallrabenstein and others, 1994).

The results of the triazine and alachlor screening were assessed in terms of two standards; the *detection limit* (DL) and the maximum contaminant level (MCL). The MCLs used for this study were those for atrazine (3.0 µg/L) and alachlor (2.0 µg/L). Samples were categorized into one of the following four groups: 1) no triazine or acetanilide detected; 2) concentrations above DL, but less than one-half MCL; 3) concentrations above one-half MCL up to the MCL; 4) concentrations above the MCL. The detection limits for triazine and acetanilide for this study are reported as 0.05 micrograms per liter (µg/L) or parts per billion (ppb) and 0.2 µg/L, respectively. Because of the ambiguity in the analysis, well owners whose samples contained levels of triazine in the range of 3.0 µg/L or acetanilide in the range of 2.0 µg/L were encouraged

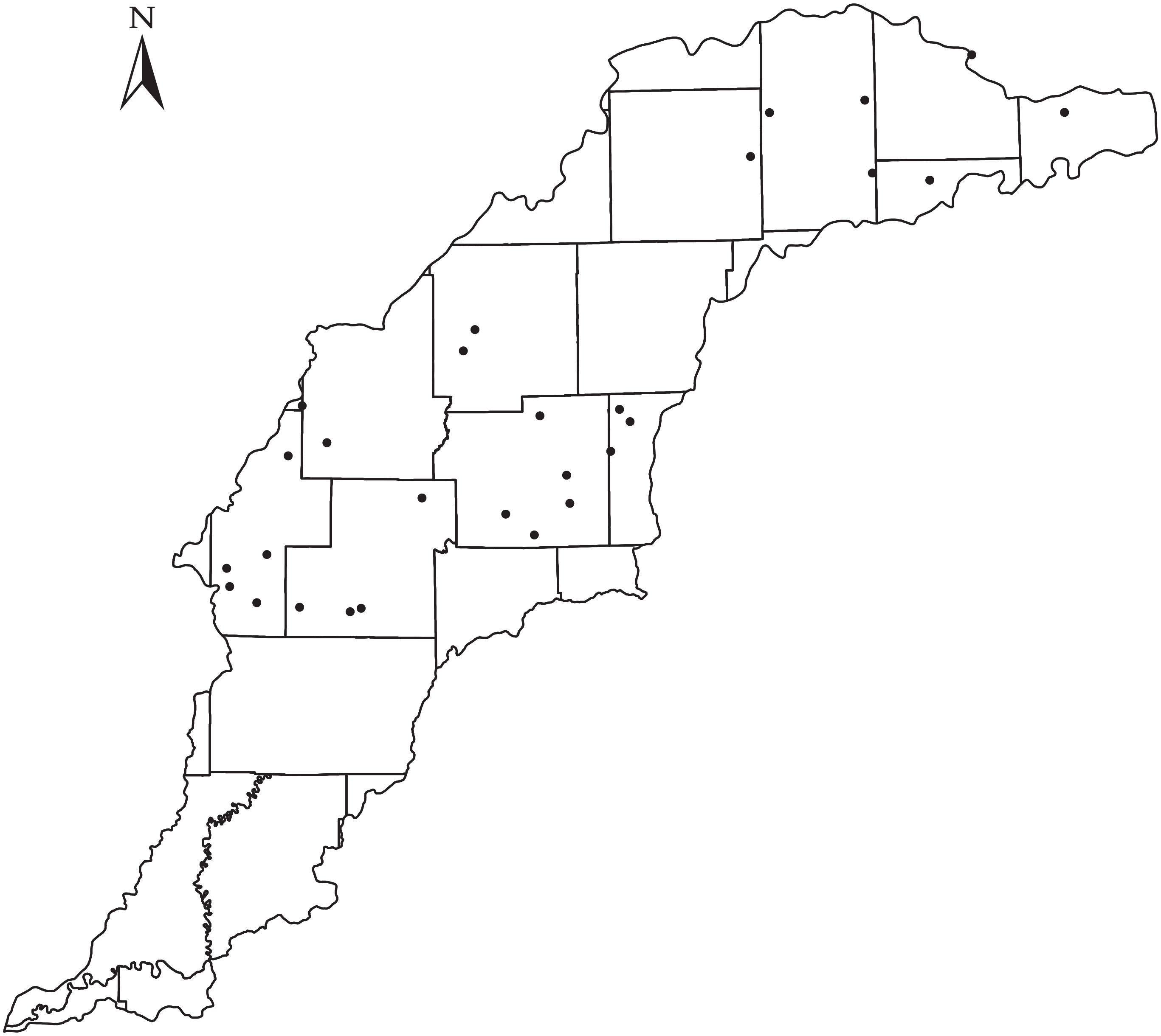


Figure 26. Location of pesticide samples for West Fork White Study (Cooperative effort between Indiana Department of Natural Resources - Division of Water and Indiana Depatment of Environmental Management - Ground Water Section)

to have another sample analyzed with gas chromatographic methods (Wallrabenstein and others, 1994).

All but three of the 29 counties (table 1) that lie partially within the West Fork White River basin participated in the Farm Bureau study: Greene, Pike, and Randolph. However, only the statistics for the counties that have more than 50 percent of their area encompassed within the West Fork White River basin were closely examined for inclusion in this discussion: Clay, Daviess, Delaware, Hamilton, Hendricks, Knox, Madison, Marion, Morgan, Owen, and Putnam. Statistics for counties that have less than 50 percent, but more than 35 percent of their area in the basin (Boone, Johnson, Monroe, and Tipton) were also briefly examined to provide a comprehensive picture of triazine and alachlor values in the basin.

Ninety-six percent of the samples analyzed for the major counties in the basin had concentrations of acetanilide below the detection limit of 0.2 mg/L. However, some samples from all but 3 of the counties (Marion, Monroe, and Tipton) contained acetanilide concentration levels above detection. Nine samples, or approximately 0.3 percent of samples taken, reported concentrations greater than 2.0 mg/L. Hendricks, Clay, and Johnson Counties had the highest number of samples at the higher levels. However, Knox and Clay Counties, both counties having small sample sizes, had the highest percentage of detectable levels of acetanilide.

Ninety-four percent of the samples analyzed had concentrations of Triazine below the detection limit of 0.05 mg/L. However, samples from each county under consideration contained triazine concentration levels above detection limits.

Only two counties, Davies and Putnam, had samples exceeding 3 mg/L.

Throughout the state, over 90 percent of the water samples analyzed for the Indiana Farm Bureau pesticide study contained no detectable amounts of triazine or acetanilide. The MCL for triazine was exceeded in only 0.1 percent of all samples. Approximately 1.6 percent of all samples contained acetanilide levels above 2.0 µg/L, however, the majority of acetanilide detects were believed to be caused by a soil metabolite of alachlor (Wallrabenstein and others, 1994). In general, triazine and acetanilide were most frequently detected in shallow (less than 50 feet deep) wells. Furthermore, samples collected from dug or driven wells (generally shallow) contained a higher percentage of detects than samples collected from drilled wells. The occurrence of detectable concentrations of triazine and acetanilide in ground water suggests that shallow, poorly-constructed (not well-sealed) wells may be especially susceptible to pesticide contamination.

In 1991, the U.S. Geological Survey (USGS) began the National Water-Quality Assessment (NAWQA) Program. The long-term goals of the NAWQA Program are to describe the status and trends in the quality of the Nation's surface and ground water and to provide a sound scientific understanding of the primary natural and human factors affecting the quality of these resources (Hirsch and others, 1988). The White River basin in Indiana was one of the basins chosen for study. The study includes both the West Fork and the East Fork White River Water Management basins of Indiana.

Synthesizing data analysis was a major component of the NAWQA program. One of the first topics addressed in the program was pesticides. Carter and others (1995) presented a retrospective analysis of available pesticide data, 1972-92, for the White River Basin (West Fork and East Fork). It included data on the occurrence of pesticides in streams, stream-bottom sediments, fish, and ground waters. Of 101 wells sampled throughout the White River Basin for a variety of pesticides, detectable concentrations of pesticides were found at only 4 wells. Water from three of the four wells was contaminated with atrazine. The metabolite-to-parent compound ratio for atrazine is higher in ground water than in surface water. Based on limited amounts of data, atrazine concentrations in ground water at wells appear to fluctuate seasonally; atrazine concentrations are found to be more elevated later in the year in ground water than in surface waters. This time lag may be because the travel time of atrazine through the unsaturated zone to the aquifers is relatively long, or because the aquifers are storing contaminated water from nearby surface-water sources during the spring flush of herbicides. All of the wells where detectable amounts of atrazine were found are in outwash aquifers, indicating that this aquifer type may be particularly susceptible to water-soluble pesticide contamination.

Overall, shallow ground water in regions of high hydraulic conductivity have higher water-soluble pesticide concentrations in shallow ground water than ground water in regions of low hydraulic conductivity. The physical properties of overlying material seem to be the main factors determining the concentrations of pesticides in shallow aquifers and ground-water wells, although a variety of other factors, such as land use and farming practices, also can affect observed concentrations.

From June 1994 through August 1995, additional data were collected in the White River basin for the NAWQA program to determine the occurrence of pesticides in the shallow ground water of the basin (Fenelon and Moore, 1996a).

Findings of the study:

- Most of the pesticides that were analyzed for, including all 11 insecticides, were not detected above the reporting limit in any well.
- Seven herbicides and one atrazine metabolite (desethyl atraziane, a breakdown product of atrazine) were detected at least once. Of these eight compounds, only four-atrazine, desethyl atrazine, metolachlor, and metribuzin-were detected more than twice. The highest measured concentration of any compound detected was 0.19 mg/L(micrograms per liter) of alachlor, whereas the most frequently detected compound was desethyl atrazine (14 of 94 samples).
- No pesticide [sampled for] was present in a concentration that exceeded a U.S. Environmental Protection Agency (USEPA) national drinking-water standard or guideline.
- The occurrence of pesticides in shallow ground water in the White River Basin contrasts with conditions observed in the White River at a site near the mouth of the river at Hazleton, Indiana (Crawford, 1995). A significantly greater frequency of detections and much higher concentrations of atrazine and metolachlor were observed in the river than in the ground water.
- The greatest percentage of wells (42 percent) where at least one pesticide was detected are on agricultural land overlying fluvial deposits.
- Pesticides in ground water underlying agricultural areas of the till plain and glacial lowland were uncommon.
- The lowest percentage (12 percent) of wells where at least one pesticide was detected are on urban land overlying fluvial deposits.

Other recent ground-water sampling studies

Other primary topics addressed by the National Water-Quality Assessment (NAWQA) Program besides pesticides are: nutrients, volatile organic compounds and aquatic biology. The following is a summary of the findings of the White River study regarding nutrients and volatile organic compounds in ground water.

Martin and others (1996) assessed water-quality in the White River Basin by examining analysis of selected information on nutrients, 1980-92. Ground-water-quality data from 101 wells were used to determine the effect of aquifer type, well depth, well type, and season on nutrient concentrations in ground water. Median concentrations of ammonia were highest (0.25 mg/L) in till aquifers composed of buried sand and gravel lenses, probably because of biochemical reduction of nitrate to ammonia. Concentrations of nitrate in till aquifers were low, probably because till reduced the downward percolation of soil water and because reducing conditions enabled denitrification and biochemical reduction of nitrate to ammonia. Median concentrations of nitrate were highest in karst aquifers, probably because macropore, sinkholes, and other *solution* features provided a direct connection of surface and ground water through preferential flow paths from the clayey mantle to the karst aquifer. Concentrations of ammonia generally were higher in deep wells, whereas concentrations of nitrate generally were higher in shallow wells. High ammonia concentrations at depth may have been caused by nitrate by the downward percolation of nitrogen-containing soil water from the land surface. Refer to the **Nitrate** section of this report for additional details.

Another component of the White River Basin study is to determine the occurrence of volatile organic compounds (VOCs) in the shallow ground water of the basin. VOCs are of national concern because some of the compounds are *toxic* and (or) *carcinogenic*. Fenelon and Moore (1996b) present the findings from VOC data collected from 100 monitoring wells from June 1994 through August 1995. The study includes both the West Fork and the East Fork White River Water Management basins of Indiana.

Findings of the study:

- Twelve of the 58 VOCs that were analyzed for in ground water samples were detected at or above the reporting limit in at least 1 of the 91 shallow wells.
- Chloroform (trichloromethane) was the most commonly detected VOC, whereas the highest measured VOC concentration was 39 mg/L (microgram per liter) of 1,1-dichloroethene.
- No VOC had a measured concentration in ground water that exceeded a national drinking-water standard or guideline for public water supplies.
- Samples from shallow wells in the nine pairs of shallow and deep wells had a greater frequency of detections and higher concentrations of VOCs than samples from the deep wells.
- VOCs were detected in only 4 of the 66 wells in agricultural settings.
- Most of the ground water with detectable VOCs in the White River Basin underlies urban land. Slightly more than half of the shallow wells in urban settings, as compared to six percent of the shallow wells in agricultural settings, had at least one VOC detected above the reporting limit.
- Chloroform was the most frequently detected VOC (40 percent of wells) in ground water underlying urban land. The median detected concentration of chloroform in urban settings was 0.5 mg/L; all of the chloroform detections were in Indianapolis.
- A likely source of the low concentrations of chloroform in ground water underlying urban land in the White River Basin is chlorinated public-supply water.
- Atmospheric deposition is probably a minor source of chloroform in ground water.

Ground-water contamination

A ground-water supply, that under natural conditions would be acceptable for a variety of uses, can be adversely affected by contamination from human activities. Contamination, as defined by the Indiana Department of Environmental Management, occurs when levels of contaminants are in excess of public drinking-water standards, or health protection guidance levels promulgated by the USEPA.

Over the past 100 years industrial and agricultural practices that accompany development have created ample opportunity for ground-water contamination in the West Fork White River basin. Numerous potential sources for ground-water contamination exist in the West Fork White River basin, including sanitary landfills, sewage treatment plants, industrial facilities, agricultural operations, septic and underground storage tanks, and road-salt storage facilities.

Some cases of actual ground-water contamination have been identified in the basin. The Indiana Department of Environmental Management (IDEM), Ground-Water Section, maintains a database of Indiana sites having 'confirmed' ground-water contamination. The 1998 and 2000 Indiana Water Quality Reports produced by the Indiana Department of Environmental Management, Office of Water Management, Planning Branch provide an overview of the ten highest priority sources of ground-water contamination in Indiana and the associated contaminants impacting ground-water quality; a summary of Indiana ground-water protection efforts is also included. In these reports, IDEM summarizes the ground water contamination sites in ground water in the White, West Fork White, and Patoka River basins by hydrogeologic settings developed by Fleming and others, 1995. Nitrates were identified by IDEM as the contaminant most often encountered in ground water.

Susceptibility of aquifers to surface contamination

Because contaminants can be transmitted to the ground-water system by infiltration from the surface, the susceptibility of an aquifer system to contamination from surface sources depends in part on the type of material that forms the surface layer above the aquifer. In general, sandy surficial sediments can easily transmit water from the surface, but provide negligible filtering of contaminants. Clay-rich surficial deposits, such as glacial till, generally have lower vertical *hydraulic conductivity* than sand and gravel deposits, thereby limiting the movement of contaminated water. However, the presence of fractures can locally decrease the effectiveness of a till in protecting ground water. The differences in basic hydrologic properties of sands and clays make it possible to use surficial geology to estimate the potential for ground-water contamination.

The highly complex relationships of the various glacial deposits in the West Fork White River basin preclude site-specific comments about susceptibility of the regional aquifer systems to contamination. However, a few gross generalizations can be made here. Additional detail on susceptibility of hydrogeologic settings in the state are available in Fleming and others, 1995.

The **Tipton Till Plain** aquifer system consists chiefly of intratill lenses of outwash sand and gravel that are highly variable in depth and lateral extent and are confined by variably thick clay or till sequences. It generally is considered to have low susceptibility to surface contamination.

The **Tipton Till Plain Subsystem** aquifer system is composed primarily of glacial tills that contain intratill sand and gravel of limited thickness and extent. It is similar to the Tipton Till Plain aquifer system but is generally considered moderately vulnerable to surface contamination. This system is located in many areas where the bedrock is shallow and till cover overlying the sand and gravel is thin.

The **Dissected Till and Residuum** aquifer system, consisting of thin, eroded residuum and predominantly pre-Wisconsin till overlying bedrock dominates the southern portions of the basin. Because of the low permeability of the surface materials, this system is not very susceptible to contamination from surface sources.

The water-bearing units of the **White River and Tributaries Outwash** aquifer system are unconfined, usually fairly shallow, and are characterized by thick sequences of sand and gravel with little clay. This aquifer system is highly susceptible to contamination due to its lack of clay layers and shallow water levels.

White River and Tributaries Outwash Subsystem aquifer system, adjacent to the White River and Tributaries Outwash Aquifer system, consists of thick zones of sand and gravel that have been covered by a layer of clay or till. In general, this system is highly susceptible to surface contamination. Although the overlying clay or till may provide some protection to the confined portions of the White River and Tributaries Outwash Subsystem Aquifer system, in many places surficial valley train deposits coalesce with the deeper outwash deposits making them more vulnerable. Two small areas of this system in Gibson and Knox Counties have thick layers of clay overlying the sand and gravel making them moderately susceptible to surface contamination.

The **Lacustrine and Backwater Deposits** aquifer system that is made up of discontinuous bodies of deposits extending along areas of outwash close to the West Fork White River Valley. These bodies are marked by thick deposits of soft silt and clay that have low susceptibility to surface contamination

The **Buried Valley** aquifer system has a low susceptibility to surface contamination because outwash sediments within the bedrock valleys are generally overlain by tills. Although lenses of outwash sand and gravel may occur within the tills, the predominance of fine-grained sediments above the bedrock valleys limits the migration of contaminants from surface sources to the deep aquifers.

The susceptibility of bedrock aquifer systems to surface contamination is dependant on the nature of the overlying sediments, because the bedrock throughout the basin is overlain by unconsolidated deposits. Just as recharge for bedrock aquifers cannot exceed that of overlying unconsolidated deposits, susceptibility to surface contamination will not exceed that of overlying deposits. However, because the bedrock aquifer systems have complex fracturing systems, once a contaminant has been introduced into a basin bedrock aquifer system, it will be difficult to track. The outcrop/subcrop area of the **Blue River and Sanders Groups** is well known for significant karst development. Because of the shallow rock, open joints, and *solution* channels the aquifer system is quite susceptible to contaminants introduced at and near land surface. In the outcrop/subcrop area of the **Buffalo Wallow, Stephensport, and West Baden Groups** the rock is predominantly shallow and contains numerous, irregular joints. In limited areas some karst has developed in the limestone beds. These conditions warrant considering the aquifer system as a whole to be somewhat susceptible to contaminants introduced at and near land surface. In areas where the **Silurian and Devonian Carbonates** are overlain directly by unconfined sand and gravel outwash, the bedrock is highly susceptible to surface contamination. In general, the Pennsylvanian bedrock aquifer systems are not very susceptible to contamination from the land surface.

Regional estimates of aquifer susceptibility can differ considerably from local reality. Variations within geologic environments can cause variation in susceptibility to surface contamination. Also, man-made structures such as poorly-constructed water wells, unplugged or improperly-abandoned wells, and open excavations, can provide contaminant pathways which bypass the naturally-protective clays. In contrast, man-made structures can also provide ground-water protection that would not normally be furnished by the natural environment. For example, large containment structures can inhibit infiltration of both surface water and contaminants. Current regulations administered by the Indiana Department of Environmental Management (IDEM) contain provisions for containment structures, thereby permitting many operations to occur that would otherwise provide an increased contamination risk to soils and the ground water. Other regulations administered by the IDNR regulate the proper construction of new wells and sealing (plugging) of abandoned wells, whether related to petroleum or water production.

Protection and management of ground-water resources

Major ground-water management and protection activities in Indiana are administered by the Indiana Department of Environmental Management (IDEM), Indiana Department of Natural Resources (IDNR), and the Indiana State Department of Health (ISDH). An expanded cooperative effort in the form of the Inter-Agency Ground-Water Task Force involves representatives of these three agencies as well as the State Chemist, State Fire Marshal, and members of local government, labor, and the business, environmental and agricultural communities. The Task Force was first formed in 1986 to develop a state ground-water quality protection and management strategy and is mandated by the 1989 Ground Water Protection Act (IC 13-7-26) to coordinate the implementation of this strategy. The strategy is an agenda of state action to prevent, detect, and correct contamination and depletion of ground water in Indiana (Indiana Department of Environmental Management, 1986). The 1989 act also requires the IDEM to maintain a registry of contamination sites, operate a clearinghouse for complaints and reports of ground-water pollution, and investigate incidents of contamination that affect private supply wells.

The 1998 and 2000 Indiana Water Quality Reports produced by the Indiana Department of Environmental Management, Office of Water Management, Planning Branch provide a summary of Indiana ground-water protection efforts.

GLOSSARY

ablation-the melting of a glacier and associated depositional processes. An ablation complex is a heterogeneous assemblage of till-like sediment, sand and gravel, and lake deposits formed during the disintegration of a glacier

accretionary-in this usage, describes the gradual addition of new land to old by the deposition of sediment carried by stream flow

acetanilide-a white, crystalline organic powder (CH3CONHC6H5) used chiefly in organic synthesis and in medicine for the treatment of headache, fever and rheumatism

alluvial-pertaining to or composed of alluvium

alluvium-fine- to coarse-grained sediment deposited in or adjacent to modern streams and derived from erosion of surface sediments elsewhere in the watershed or from valley walls

anhydrite-a mineral consisting of anhydrous calcium sulfate: CaSO4; it represents gypsum without its water of crystallization, and it alters readily to gypsum. It usually occurs in white or slightly colored, granular to compact masses

anion-an atom or molecule that has gained one or more electrons and possess a negative electrical charge

anthropogenic-relating to the impact or influence of humans or human activities on nature

aquifer-a saturated geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients

aquifer system-a heterogeneous body of permeable and poorly permeable materials that functions regionally as a water-yielding unit; it consists of two or more aquifers separated at least locally by confining units that impede ground-water movement, but do not affect the overall hydraulic continuity of the system

aquitard-a confining layer that retards but does not prevent the flow of water to or from an adjacent aquifer

arenaceous-said of a sediment or sedimentary rock consisting wholly or in part of sand-size fragments, or having a sandy texture or the appearance of sand

argillaceous-pertaining to, largely composed of, or containing clay-sized particles or clay minerals

artesian-see confined

backwater-water held or forced back, as by a dam, flood, tide, etc.

basal tills-refers to tills originating from the zone of the glacier near the bed

base flow-the portion of stream flow derived largely or entirely from ground-water discharge

basement rocks-the crust of the Earth below sedimentary deposits

bioclastic vuggy dolomite-a calcium magnesium carbonate rock which consists primarily of fragments or broken remains of organisms (such as shells) and which contains small cavities usually lined with crystals of a different mineral composition from the enclosing rock

calcareous-describes a rock or sediment that contains calcium carbonate

carbonate-in this usage, a rock consisting chiefly of carbonate minerals which were formed by the organic or inorganic precipitation from aqueous solution of carbonates of calcium, magnesium, or iron; e.g. limestone and dolomite

carcinogenic-capable of producing a cancer

cation-an atom or molecule that has lost one or more electrons and possesses a positive charge

clastic-pertaining to a rock or sediment composed principally of broken fragments that are derived from preexisting rocks or minerals and that have been transported some distance from their places of origin; also said of the texture of such a rock

colluvial-pertaining to colluvium

colluvium-loose rock debris at the foot of a slope or cliff deposited by rock falls, landslides and slumpage

cone of depression-a depression in the ground water table or potentiometric surface that has the shape of an inverted cone and develops around a well from which water is being withdrawn. It defines the area of influence of a well

confined-describes an aquifer which lies between impermeable formations; confined ground-water is generally under pressure greater than atmospheric; also referred to as artesian

contact-a plane or irregular surface between two types or ages of rock

contaminant (drinking water)-as defined by the U.S. Environmental Protection Agency, any physical, chemical, biological, or radiological substance in water, including constituents which may not be harmful

contemporaneous-formed or existing at the same time

cuesta-a hill or ridge with a gentle slope on one side and a steep slope on the other

cyclothem-a cycle applied to sedimentary rocks to describe a series of beds deposited during a single sedimentary cycle of the type that prevailed during the Pennsylvanian Period. Cyclothems are typically associated with unstable shelf or interior basin conditions in which alternate marine transgressions and regressions occur; nonmarine sediments usually occur in the lower half of a cyclothem, marine sediments in the upper half

debris-flow-body of sediment that has moved downslope under the influence of gravity; may be derived from a wide variety of pre-existing sediments that are generally saturated and may be deposited on or against unstable substrates, such as glacial ice; flowage occurs when the sediments lose their cohesive strength and liquify. Mud flows are a variety of debris flow composed primarily of fine-grained sediment such as silt and clay. Historically, debris flows formed by flowage of soft till have been referred to as flow till. Because ancient mudflows frequently resemble glacial till they are sometimes referred to as till-like sediment

detection limit-is the amount of constituent that produces a signal sufficiently large that 99 percent of the trials with the amount will produce a detectable signal 5X the instrumental detection limit

differential erosion-erosion that occurs at irregular or varying rates, caused by the differences in the resistance and hardness of surface materials: softer and weaker rocks are rapidly worn away; whereas harder and more resistant rocks remain to form ridges, hills, or mountains

disconformity-term used to refer to rock formations that exhibit parallel bedding but have between them a time break in deposition

discharge-see discharge area

discharge area-region where ground water is moving toward, and generally appearing at the land surface or in a surface water body

divalent-having a valence of two, the capacity to unite chemically with two atoms of hydrogen or its equivalent

dolomitic-dolomite-bearing, or containing dolomite; esp. said of a rock that contains 5 to 50 percent of the mineral dolomite in the form of cement and/or grains or crystals; containing magnesium

down-dip-a direction that is downwards and parallel to the dip (angle from the horizontal) of a structure or surface

drainage basin-the land area drained by a river and its tributaries; also called watershed or drainage area

drawdown (ground water)-the difference between the water level in a well before and during pumping

end moraine-see moraine, end

epicontinental-situated on the continental shelf or on the continental interior

escarpment-a long, more or less continuous cliff or relatively steep slope facing in one general direction, breaking the continuity of the land by separating two level or gently sloping surfaces, and produced by erosion or by faulting

esker-narrow, elongate ridge of ice-contact stratified drift believed to form in channels under a glacier

evapotranspiration-a collective term that includes water discharged to the atmosphere as a result of evaporation from the soil and surface-water bodies and by plant transpiration

evaporite-see evaporitic deposits

evaporitic deposits-of or pertaining to sedimentary salts precipitated from aqueous solutions and concentrated by evaporation

exposure-in this usage, (geology) an area of a rock formation or geologic structure that is visible, either naturally or artificially, i.e. is unobscured by soil, vegetation, water, or the works of man; also, the condition of being exposed to view at the earth's surface

facies-features, such as bedding characteristics or fossil content, which characterize a sediment as having been deposited in a unique environment

fan-body of outwash having a fan shape and an overall semi-conical profile; generally deposited where a constricted meltwater channel emerges from an ice margin into a large valley or open plain. The fan head represents the highest and most ice-proximal part of the fan and commonly emanates from an end moraine or similar ice marginal feature. Ice-contact fans were deposited up against or atop ice and are commonly collapsed and pitted. Meltwater along the toe of the fan commonly occupies fan-marginal channels

fault-(structural geology) a fracture or a zone of fractures along which there has been displacement of the sides relative to one another parallel to the fracture

flow till-see debris flow

flowing well-a well completed in a confined aquifer in which the hydrostatic pressure is greater than atmospheric pressure, and the water rises naturally to an elevation above land surface

fluvial-of or pertaining to rivers

fossiliferous-containing fossils, which are preserved plant or animal imprints or remains

gamma-ray logs-the radioactivity log curve of the intensity of natural gamma radiation emitted from rocks in a cased or uncased borehole. It is used for correlation, and for distinguishing shales and till (which are usually richer in naturally radioactive elements) from sand, gravel, sandstone, carbonates, and evaporites

geode-a hollow or partly hollow and globular or subspherical body, from 2.5 cm to 30 cm or more in diameter, found in certain limestone beds and rarely in shales

glacial lobe-segment of a continental ice sheet having a distinctive flow path and lobate shape that formed in response to the development of regional-scale basins (e.g., Lake Erie) on the surface that the ice flowed across. The shapes and flow paths of most of the individual glacial lobes in this part of the upper Midwest were largely related to the forms of the Great Lake basins. Each lobe was tens of thousands of square miles in size and had flow patterns and histories that were distinct from one another

glacial terrain-geographic region or landscape characterized by a genetic relationship between landforms and the underlying sequences of sediments

glaciolacustrine-pertaining to, produced by, or formed in a lake or lakes associated with glaciers

ground-water discharge-in this usage, the part of total runoff which has passed into the ground and has subsequently been discharged into a stream channel

gypsum-a widely distributed mineral consisting of hydrous calcium sulfate

health advisories (HAs)-provide the level of a contaminant in drinking water at which adverse non-carcinogenic health effect would not be anticipated with a margin of safety

hummocky-describes glacial deposits arranged in mounds with intervening depressions

hydraulic conductivity-a parameter that describes the conductive properties of a porous medium; often expressed in gallons per day per square foot; more specifically, rate of flow in gallons per day through a cross section of one square foot under a unit hydraulic gradient, at the prevailing temperature

hydraulic gradient-the rate of change in total head per unit of distance of flow in a given direction

hydrostatic pressure-the pressure exerted by the water at any given point in a body of water at rest. The hydrostatic pressure of ground water is generally due to the weight of water at higher levels in the zone of saturation

ice-contact fans-see fan

ice-contact stratified drift-glacial sediment composed primarily of sand and gravel that was deposited on, against, or within glacier ice. These deposits typically have highly irregular surface form due to the collapse of the adjacent ice

igneous-describes rocks that solidified from molten or partly molten material

immunoassay-is a quantitative or qualitative method of analysis for a substance which relies on an antibody or mixture of antibodies as the analytical reagent. Antibodies are produced in animals in response to a foreign substance called an antigen. The highly sensitive and specific reaction between antigens and antibodies is the basis for immunoassay technology

incised-describes the result of the process whereby a downward-eroding stream deepens its channel or produces a narrow, steep-walled valley

infiltration-the process (rate) by which water enters the soil surface and which is controlled by surface conditions

ion exchange-the process of reciprocal transfer of ions

kame-irregular ridge or roughly conical mound of sand and gravel with a hummocky surface; usually formed in contact with disintegrating ice

karst-topography characterized by closed depressions or sinkholes, caves, and underground drainage formed by dissolution of limestone, dolomite, or gypsum

lacustrine-pertaining to, produced by, or formed in a lake or lakes

lacustrine sediment-sediment deposited in lakes; usually composed of fine sand, silt, and clay in various combinations

lithologic-describes the physical character of a rock; includes features such as composition, grain size, color, and type of bedding

lithology-the description of rocks, esp. in hand specimen and in outcrop, on the basis of such characteristics as color, mineralogic composition, and grain size

loam-describes a soil composed of a mixture of clay, silt, sand, and organic matter

mass movement-a unit movement of a portion of the land surface; gravitative transfer of material down a slope

maximum contaminant level-the maximum permissible level of a contaminant in water which is delivered to the free-flowing outlet of the user of a public water system

median-middle value of a set of observations arranged in order of magnitude

meltwater-water resulting from the melting of snow or glacial ice

metabolite-a product of metabolic action

methemoglobinemia-a disease, primarily in infants, caused by the conversion of nitrate to nitrite in the intestines, and which limits the blood's ability to transport oxygen

monovalent-having a valence of one, the capacity to unite chemically with one atom of hydrogen or its equivalent

moraine-unsorted, unstratified glacial drift deposited chiefly by the direct action of glacial ice

moraine, end-a ridgelike accumulation of drift built along any part of the outer margin of an active glacier; often arcuate in shape, end moraines mark places along which the terminus of a glacier remained for relatively long periods. Terminal moraines mark the ultimate extent of a particular glacier, whereas recessional moraines are deposited where the ice-margin stabilized for a period of time during the retreat of the glacier

moraine, ground-material (primarily till) deposited from a glacier on the ground surface over which the glacier moved, and generally forming a region of low relief

muck-a highly organic dark or black soil less than 50 percent combustible

mud flow-see debris flow

outwash-sediment deposited by meltwater out in front of an ice margin; usually composed of sand and/or gravel. An outwash plain is a broad tract of low relief covered by outwash deposits, whereas an outwash terrace is a relatively small flat or gently sloping tract that lies above the valley of a modern stream

outwash plain-see outwash

outwash terrace-see outwash

overconsolidated-refers to the consistency of unconsolidated sediment that is much harder than would be expected from its present depth of burial; fine-grained glacial sediments such as till are commonly overconsolidated due to such processes as burial by ice or younger sediments, frequent wetting and drying, and freezing and thawing

paraconformably-this type of unconformity is a kind of disconformity in which no erosion surface is discernible or in which the contact is a simple bedding plane, and in which the beds above and below the break are parallel

paired wells-in this usage, refers to multiple closely spaced observations wells each set at a different depth for the purpose of determining the hydrostatic pressure on different aquifers at the same location

percolate (geology)-to seep downward from an unsaturated zone to a saturated zone

periglacial-said of the processes, conditions, areas, climates, and topographic features at the immediate margins of former and existing glaciers and ice sheets, and influenced by the cold temperature of the ice

permeability-the capacity of a porous medium to transmit a fluid; highly dependent upon the size and shape of the pores and their interconnections

physiographic region-an area of characteristic soils, landforms, and drainage that have been developed on geologically similar materials

physiography-in this usage, a description of the physical nature (form, substance, arrangement, changes) of objects, esp. of natural features

pinnacle reefs-a term used in the Michigan Basin to apply to an isolated stromatoporoid-algal reef mound, now dolomitized, in the Middle Silurian rocks of the subsurface

piezometric surface-an imaginary surface representing the level to which water from a given aquifer will rise under the hydrostatic pressure of the aquifer

Pleistocene-geologic epoch corresponding to the most recent ice age; beginning about 2 million years ago and ending approximately 10,000 years ago

porosity-the amount of pore space; specifically, the ratio of the total volume of voids to the total volume of a porous medium

postdepositional-occurring after materials had been deposited

potable-water which is palatable and safe to drink: ie., fit for human consumption

potentiometric surface-an imaginary surface representing the total head of ground water in a confined aquifer that is defined by the level to which water will rise in a well

pre Wisconsin-general term that refers to the part of the Ice Age prior to about 75,000 years ago, during which many other glacial episodes at least as extensive as those of the Wisconsin Age took place

prodeltaic-the part of a delta that is below the effective depth of wave erosion, lying beyond the delta front, and sloping gently down to the floor of the basin into which the delta is advancing and where clastic river sediment ceases to be a significant part of the basin-floor deposits

proglacial-occurring or being deposited directly in front of a glacier

provenance-a place of origin; specifically the area from which the constituent materials of a sedimentary rock or facies are derived; also, the rocks of which this area is composed

pumping test-a test conducted by pumping a well at a constant rate for a period of time, and monitoring the change in hydraulic head in the aquifer

recharge (ground water)-the process by which water is absorbed and added to the zone of saturation

reducing-describes the process of removing oxygen from a compound

reef-a ridgelike or moundlike structure, layered or massive, built by sedentary calcareous organisms, esp. corals, and consisting mostly of their remains

regression-(stratigraphy) the retreat or contraction of the sea from land areas, and the consequent evidence of such withdrawal

relict-said of a topographic feature that remains after other parts of the feature have been removed or have disappeared

residuum-(weathering) residue

runoff, (total)-the part of precipitation that appears in surface-water bodies; it is the same as stream flow unaffected by artificial manipulation

saline-describes water that contains a high concentration of dissolved solids, typically greater than 10,000 milligrams per liter

sandstone-a medium-grained clastic sedimentary rock composed of abundant rounded or angular fragments of sand size set in a fine-grained matrix (silt or clay) and more or less firmly united by a cementing material

secondary maximum contaminant level-recommended, nonenforceable standards established to protect aesthetic properties of drinking water, such as taste and odor

sedimentary rock-formed by the deposition of sediment

seismic-pertaining to an earthquake or earth vibration, including those that are artificially induced

shale-a fine-grained detrital sedimentary rock, formed by the consolidation (esp. by compression) of clay, silt, or mud

skewed-describes the state of asymmetry of a statistical frequency distribution, which results from a lack of coincidence of the mode, median, and arithmetic mean of the distribution

slack water-a quiet part of, or a still body of water

sluiceway-valley or channel that conducted large amounts of glacial meltwater through and/or away from a glacier; may or may not be occupied by a modern stream; commonly associated with one or more former ice margins

solution-(geology) a process of chemical weathering by which mineral and rock materials passes into solution; e.g. removal of the calcium carbonate in limestone by carbonic acid derived from rain-water containing carbon dioxide acquired during its passage through the atmosphere

source area-general geographic region that furnished the sediment supply for a particular deposit. Sediments deposited by different rivers or glaciers can often be distinguished because their respective source areas differ in terms of the composition of bedrock and other sediments they contain; see provenance

static water level-the level of water in a well that is not being affected by withdrawal of ground water

stratigraphy-the geologic study of the formation, composition, sequence and correlation of unconsolidated or rock layers

storage coefficient-the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head

subcrop-a "subsurface outcrop" that describes the areal limits of a truncated rock unit at the buried surface of an unconformity

subjacent-being lower, but not necessarily lying directly below

swale-a slight depression, sometimes swampy, in the midst of generally level land

tectonic-said of or pertaining to the forces involved in, or the resulting structures or features of, tectonics or earth movements

terminal moraine-see moraine, end

till-unsorted sediment deposited directly from glacier ice with little or no reworking by meltwater or mass movement; usually contains particles ranging in size from clay to boulders

till-like sediment-see till and debris flow

till plain-an extensive area with a flat to undulating surface, underlain by till and commonly covered by ground moraines and subordinate end moraines

topography-the relief and contour of a surface, especially land surface

toxic-describes materials which are or may become harmful to plants or animals when present in sufficient concentrations

transgression-the spread or extension of the sea over the land areas

transmissivity-the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient

triazine-any of a group of chemicals containing three nitrogen and three carbon atoms arranged in a six member ring and having the formula $C3H3N3$; also any of various derivative of these compounds including several used as herbicides

tunnel valley-wide, linear channel oriented perpendicular to an ice margin and eroded into the substrate below the ice sheet. A tunnel valley typically represents a major route for meltwater draining part of an ice sheet, and exiting the front of that ice sheet

unconfined-describes an aquifer whose upper surface is the water table which is free to fluctuate under atmospheric pressure

unconformably-not succeeding the underlying rocks in immediate order of age or not fitting together with them as parts of a continuous whole

unconformity-a substantial break or gap in the geologic record where a rock unit is overlain by another that is not next in stratigraphic succession

valley train-large, elongated body of outwash localized within the confines of a topographic valley

water table-the upper surface of the zone of saturation below which all voids in rock and soil are saturated with water

watershed-see drainage basin

Wisconsin Age-the most recent period of major glacial activity during the ongoing ice age, perhaps beginning as long as 75,000 years ago and continuing until about 10,000 years ago

SELECTED REFERENCES

American Farm Bureau Federation, 1987, Water quality self-help checklist: American Farm Bureau Federation pamphlet

Arihood, L.D., 1982, Groundwater resources of the White River Basin, Hamilton and Tipton Counties, Indiana: U.S. Geological Survey Water-Resources Investigations 82-48, 69 p.

Arihood, L.D., and Lapham, W.W., 1982, Ground-water resources of the White River basin, Delaware County, Indiana: U.S. Geological Survey Water-Resources Investigations 82-47, 69 p.

Ault, C.H., Austin, G.S., Bleuer, N.K., Hill, J.R., Moore, M.C., 1973, Guidebook to the geology of some Ice Age features and bedrock formations in the Fort Wayne area, Indiana: Indiana Geological Survey Guidebook, 62 p.

Bailey, Z.C., and Imbrigiotta, R.E., 1982, Ground-water resources of the glacial outwash along the White River, Johnson and Morgan Counties, Indiana: U.S. Geological Survey Water-Resources Investigations 82-4016, 87 p.

Barnhart, J.R., and Middleman, B.H., 1990, Hydrogeology of Gibson County, Indiana: Indiana Department of Natural Resources, Division of Water Bulletin 41, 17 p.

Basch, M.E., and Funkhouser, R.V., 1985, Irrigation impacts on ground-water levels in Jasper and Newton Counties, Indiana, 1981-84: Indiana Department of Natural Resources, Division of Water, Water Resources Assessment 85-1

Bates, R.L., and Jackson, J.A., eds., 1987, Glossary of Geology (3rd edition): Alexandria, Virginia, American Geological Institute, 788 p.

Bechert, C.H., and Heckard, J.M., 1966, Physiography, in Lindsey, A.A., ed., Natural features of Indiana: Indianapolis, Indiana Academy of Science, p. 100-115

Becker, L.E., 1974, Silurian and Devonian rocks in Indiana southwest of the Cincinnati Arch: Indiana Geological Survey, Bulletin 50

Becker, L.E., and Keller, S.J., 1976, Silurian reefs in southwestern Indiana and their relation to petroleum accumulation: Indiana Geological Survey Occasional Paper 19, 11 p.

Becker, L.E., Hreha, A.J., and Dawson, T.A., 1978, Pre-Knox (Cambrian) stratigraphy in Indiana, Indiana Geological Survey, Bulletin 57

Bergeron, M.P., 1981, Effect of irrigation pumping on the ground-water system in Newton and Jasper Counties, Indiana: U.S. Geological Survey, Water-Resources Investigation 81-38

Bleuer, N.K., 1974, Buried till ridges in the Fort Wayne area, Indiana, and their regional significance: Geological Society of America Bulletin, v.85, p. 917-920

_____1989, Historical and geomorphic concepts of the Lafayette Bedrock Valley System (so-called Teays Valley) in Indiana Department of Natural Resources, Geological Survey Special Report 46, 11 p.

_____1991, The Lafayette Bedrock Valley System of Indiana; concept, form, and fill stratigraphy, in Melhorn, W.N., and Kempton, J.P., eds., Geology and hydrogeology of the Teays-Mahomet Bedrock Valley System: Geological Society of America Special Paper 258, p. 51-77

Bleuer, N.K., Melhorn, W.N., Steen, W.J., and Bruns, T.M., 1991, Aquifer systems of the buried Marion-Mahomet trunk valley (Lafayette Bedrock Valley System) of Indiana, in Melhorn, W.N., and Kempton, J.P., eds., Geology and hydrogeology of the Teays-Mahomet Bedrock Valley System: Geological Society of America Special Paper 258, p. 79-89

Bradbury, K.R., and Rothschild, E.R., 1985, A computerized technique for estimating the hydraulic conductivity of aquifers from specific capacity data: Ground Water 23, p. 240?246

Brown, E.A., 1949, Ground-water resources of Boone County, Indiana: Indiana Department of Conservation, Division of Water Resources Bulletin 4, 152 p.

Bruns, T.M., Logan, S.M., and Steen, W.J., 1985, Maps showing bedrock topography of the Teays Valley, north-central Indiana: Indiana Geological Survey Miscellaneous Map 43, scale 1:100,000

Burger, A.M., Forsyth, J.L., Nicoll, R.S., and Wayne, W.J., 1971, Geologic map of the 1o x 2o Muncie Quadrangle, Indiana and Ohio, showing bedrock and unconsolidated deposits: Indiana Geological Survey Regional Geologic Map 5

Cable, L.W., and Robison, T.M., 1973, Hydrogeology of the principal aquifers in Sullivan and Greene Counties, Indiana: Indiana Department of Natural Resources, Division of Water Bulletin 35, 26 p.

_____1974, Ground-water resources of Montgomery County, Indiana: Indiana Department of Conservation, Division of Water Resources Bulletin 36, 20 p.

Cable, L.W., Watkins, F.A., Jr., and Robison, T.M., 1971, Hydrogeology of the principal aquifers in Vigo and Clay Counties, Indiana: Indiana Department of Natural Resources, Division of Water Bulletin 34, 34 p.

Carter, D.S., Lydy, M.J., and Crawford, C.G., 1995, Water-quality assessment of the White River Basin, Indiana-Analysis of available information on pesticides, 1972-92: U.S. Geological Survey Water-Resources Investigation Report 94-4024, 60 p.

Casey, G.D., 1996, Hydrogeologic framework of the midwestern basins and arches region in parts of Indiana, Ohio, Michigan, and Illinois: U.S. Geological Survey Professional Paper 1423-B, 46 p.

Crawford, C.G., 1995, Occurrence of pesticides in the White River, Indiana, 1991-95: U.S. Geological Survey Fact Sheet 233-95, 4 p.

Dalton, M.G., and Upchurch, S.B., 1978, Interpretation of hydro-chemical facies by factor analysis: Groundwater, 16(4), p. 228-233

Davis, S.N., and DeWiest, R.J.M., 1970, Hydrogeology: New York, John Wiley, 463 p.

Doheny, E.J., Droste, J.B., and Shaver, R.H., 1975, Stratigraphy of the Detroit River Formation (Middle Devonian) of northern Indiana: Indiana Geological Survey, Bulletin 53

Drever, J.I., 1988, The geochemistry of natural waters (2nd ed.): Englewood Cliffs, N.J., Prentice Hall, 437 p.

Droste, J.B., Abdulkareem, T.F., and Patton, J.B., 1982, Stratigraphy of the Ancell and Black River Groups (Ordovician) in Indiana: Indiana Geological Survey Occasional Paper 36, 15 p.

Droste, J.B., and Keller, S.J., 1989, Development of the Mississippian/Pennsylvanian unconformity in Indiana, Indiana Geological Survey Occasional Paper 55, 11 p.

Droste, J.B., and Patton, J.B., 1985, Lithostratigraphy of the Sauk Sequence in Indiana: Indiana Geological Survey Occasional Paper 47, 24 p.

Droste, J.B., and Shaver, R.H., 1982, The Salina Group (Middle and Upper Silurian) of Indiana: Indiana Geological Survey, Special Report 24

Dufor C.N., and Becker, E., 1964, Public water supplies of the 100 largest cities in the United States, 1962: U.S. Geological Survey, Water-Supply Paper 1812

Eberts, S.M., and George, L.L., 2000, Regional Ground-water flow and geochemistry in the Midwestern Basin and Arches Aquifer System in parts of Indiana, Ohio, Michigan, and Illinois: U.S. Geological Survey Regional Aquifer System Analysis, Professional Paper 1423-C, 103 p.

Erd, R.C., and Greenberg, S.S., 1960, Minerals of Indiana: Indiana Department of Conservation, Geological Survey, Bulletin No. 18

Eschman, D.F., 1985, Summary of the Quaternary history of Michigan, Ohio and Indiana: Journal of Geological Education 33, p. 161?167

Fenelon, J.M., 1998, Water Quality in the White River Basin, Indiana, 1992-96: U.S. Geological Survey Circular 1150, 34 p.

Fenelon, J.M., and Moore, R.C., 1996a, Occurrence of pesticides in ground water in the White River Basin, Indiana, 1994-95: U.S. Geological Survey Fact Sheet 084-96, 4 p.

_______ 1996b, Occurrence of volatile organic compounds in ground water in the White River Basin, Indiana, 1994-95: U.S. Geological Survey Fact Sheet 138-96, 4 p.

Fetter, C.W., 1988, Applied hydrogeology (2nd ed.): Columbus, Ohio, Merrill Publishing, 592 p.

Fleming, A.H., Brown, S.E., and Ferguson, V.R., 1993, The hydrogeologic framework of Marion County, Indiana-Atlas emphasizing hydrogeologic terrain and sequence: Indiana Geological Survey Open-File Report 93-5, 67 p.

Fleming, A.H., ed., and others, 1994, Atlas of hydrogeologic terrains and settings in Indiana, northern part: Indiana Geological Survey Open-File Report 94-17.

Fleming, A.H., ed., Bonneau, P., Brown, S.E., Grove, G., Harper, D., Herring, W., Lewis, E.S., Moeller, A.J., Powell, R., Reehling, P., Rupp, R.F., and Steen, W.J., 1995, Atlas of hydrogeologic terrains and settings of Indiana: Indiana Geological Survey Open-File Report 95-7. This report supercedes Indiana Geological Survey Report 94-17, "Atlas of Hydrogeologic terrains and settings of Indiana: northern part".

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: New Jersey, Prentice?Hall

GeoTrans Inc., 1983, Assessment of Prudential pumping on the ground-water system of Jasper and Newton Counties, Indiana: Reston Va., report to J.R. Nesbitt

Gillies, D.C., 1976, Availability of ground water near Carmel, Hamilton County, Indiana: U.S. Geological Survey Water Resources Investigations Report 76-46, 27 p.

Geosciences Research Associates, Inc., 1982, Hydrogeologic atlas of Indiana: Bloomington, Ind., 31 p.

Gray, H.H., 1972, Lithostratigraphy of the Maquoketa Group (Ordovician) in Indiana: Indiana Geological Survey Special Report 7, 31 p.

_____1978, Buffalo Wallow Group, Upper Chesterian (Mississippian) of southern Indiana: Indiana Geological Survey Occasional Paper 25, 28 p.

_____1979, The Mississippian and Pennsylvanian Systems in the United States-Indiana: U.S. Geological Survey Professional Paper 1110-K, 20 p.

_____1982, Map of Indiana showing topography of the bedrock surface: Indiana Geological Survey, Miscellaneous Map 36, scale 1:500,000

_____1983, Map of Indiana showing thickness of unconsolidated deposits: Indiana Geological Survey, Miscellaneous Map 38, scale 1:500,000

_____1988, Relict drainageways associated with the glacial boundary in southern Indiana: Indiana Geological Survey Special Report 45, 23 p.

_____1989, Quaternary geologic map of Indiana: Indiana Geological Survey, Miscellaneous Map 49, scale 1:500,000

_____2000, Physiographic divisions of Indiana: Indiana Geological Survey, 15 p.

Gray, H.H., Ault, C.H., and Keller, S.J., 1987, Bedrock geologic map of Indiana: Indiana Geological Survey, Miscellaneous Map 48, scale 1:500,000

Gray, H.H., Wayne, W.J., and Wier, C.E., 1970, Geologic map of the 1o x 2o Vincennes Quadrangle and parts of adjoining quadrangles, Indiana and Illinois, showing bedrock and unconsolidated deposits: Indiana Geological Survey Regional Geologic Map 3.

Gray, H.H., and others, 1972, Geologic map of the 1o x 2o Cincinnati Quadrangle, Indiana and Ohio, showing bedrock and unconsolidated deposits: Indiana Geological Survey Regional Geologic Map 7.

_____1979, Geologic map of the 1o x 2o Indianapolis Quadrangle, Indiana and Illinois, showing bedrock and unconsolidated deposits: Indiana Geological Survey Regional Geologic Map 1

Gutstadt, A.M., 1958, Cambrian and Ordovician stratigraphy and oil and gas possibilities in Indiana: Indiana Department of Conservation, Geological Survey, Bulletin 14

Hartke, E.J., and Hill, J.R., 1976, Environmental geologic maps for land use evaluations in Morgan County, Indiana: Indiana Geological Survey Occasional Paper 17, 10 p.

Hasenmueller, N.R. and Nauth, D.D., Radon: Indiana Geological Survey, Information Circular, v. 1, no. 2, 4 p.

Heckard, J.M., 1964, Water resources of Morgan County, with emphasis on ground-water availability: Indiana Department of Natural Resources, Division of Water, 1 sheet.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey, Water?Supply Paper 2254

_____1993, Factors affecting stream water quality, and water-quality trends in four basins in the conterminous United States, 1905-90, in Paulson, R.W., Chase, E.B., Williams, J.S., and Moody, D.W., eds., National water summary 1990-91; hydrologic events and stream water quality: U.S. Geological Survey Water-Supply Paper 2400

Herring, W.C., 1971, Water resources of Hamilton County, with emphasis on ground-water availability: Indiana Department of Natural Resources, Division of Water, 1 sheet.

_____1974, Water resources of Marion County, with emphasis on ground-water availability: Indiana Department of Natural Resources, Division of Water, 1 sheet.

_____1976, Technical atlas of the ground-water resources of Marion County, Indiana: Indiana Department of Natural Resources, Division of Water, 53 p.

Hill, R.A., 1940, Geochemical patterns in Coachella Valley, California: American Geophysical Union Trans., 21, p. 46-49

Hirsch, R.M., Alley, W.M., and Wilber, W.G., 1988, Concepts for a National Water-Quality Assessment Program: U.S. Geological Survey Circular 1021, 42 p.

Hoggatt, R.E., 1975, Drainage areas of Indiana streams: U.S. Geological Survey, unnumbered report, 231 p.

Hoggatt, R.E., Hunn, J.K., and Steen, W.J., 1968, Water resources of Delaware County, Indiana: Indiana Department of Natural Resources, Division of Water Bulletin 37, 57 p.

Homoya, M.A., Abrell, D.B., Aldrich, J.R., and Post, T.W., 1985, The natural regions of Indiana: Indiana Academy of Science, Proc., v. 94, p. 245-268

Hoover, M.E., and Durbin, J.M., 1994, White River Basin, in Fenelon, J.M., Bobay, K.E., and others, Hydrogeologic atlas of aquifers in Indiana: U.S. Geological Survey Water-Resources Investigations Report 92-4142, p. 113-133.

Indiana Department of Environmental Management, 1986, The protection of Indiana's ground water-strategy and draft implementation plan

_____[1990], 305{b} Report, 1988-1089

_____[1995], 305(b) Report, 1992-1993

_____1998, 305(b) Report, 1996, IDEM/34/02/002/1998

_____2000, Indiana Water Quality Report, 2000, IDEM/34/02/001/2000

Indiana Department of Natural Resources (Clark, G.D., ed.), 1980, The Indiana water resource-availability, uses, and needs: Governor's Water Resource Study Commission

Indiana Water Pollution Control Board, 1992, 327 IAC 2-1 Water quality standards

Jacques, D.V., and Crawford, C.G., 1991, National Water-Quality Assessment Program-White River Basin: U.S. Geological Survey Open-File Report 91-169, 2 p.

Johnson, G.H., and Keller, S.J., 1972, Geologic map of the 1o x 2o Fort Wayne Quadrangle, Indiana, Michigan, and Ohio, showing bedrock and unconsolidated deposits: Indiana Geological Survey Regional Geologic Map 8

Keller, S.J., 1983, Analysis of subsurface brines in Indiana: Indiana Geological Survey, Occasional Paper 41

Lapham, W.W., 1981, Ground-water resources of the White River Basin, Madison County, Indiana: U.S. Geological Surey Water-Resources Investigations 81-35, 112 p.

Lapham, W.W., and Arihood, L.D., 1984, Ground-water resources of the White River Basin, Randolph County, Indiana: U.S. Geological Survey, Water-Resources Investigations Report 83-4267, 86 p.

Lehr, J.H., Gass, T.E., Pettijohn, W.A., and DeMarre, J., 1980, Domestic water treatment: New York, McGraw-Hill, 264 p.

Leverett, F., 1897, The water resources of Indiana and Ohio: U.S. Geological Survey Annual Report 18 (1896-1897), pt. 4, p. 419-560

Leverett, F., and Taylor, F.B., 1915, The Pleistocene of Indiana and Michigan and the history of the Great Lakes: U.S. Geological Survey Monograph 53, 529 p.

Lindsey, A.A. (ed.), 1966, Natural features of Indiana: Indiana Academy of Science and Indiana State Library

Lindsey, A.A., Schmeiz, D.V., and Nichols, S.A., 1970 (reprinted edition), Natural areas in Indiana and their preservation: Report of the Indiana Natural Areas Survey, Notre Dame, Indiana

Lineback, J.A., 1970, Stratigraphy of the New Albany Shale in Indiana: Indiana Geological Survey Bulletin 44, 73 p.

Lineback, J.A., Bleuer, N.K., Mickelson, D.M., Farrand, W.R., and Goldthwait, R.P., (Richmond, G.M., and Fullerton, D.S., eds.), 1983, Quaternary geologic map of the Chicago 4° x 6° Quadrangle, United States: U.S. Geological Survey, Miscellaneous Investigations Series, Map I?1420 (NK?16), scale 1:1,000,000

Linsley, R.K., Jr., Kohler, M.A., and Paulhus, J.L.H., 1982, Hydrology for engineers (3d ed.): New York, McGraw?Hill

Madison, R.J., and Brunett, J.O., 1984, Overview of the occurrence of nitrate in ground water of the United States, in National Water Summary 1984: U.S. Geological Survey, Water?Supply Paper 2275

Malott, C.A., 1922, The physiography of Indiana, in Indiana Department of Conservation, Handbook of Indiana Geology: Division of Geology

Manahan, S.E., 1975, Environmental chemistry: Boston, Willard Grant Press, 532 p.

Martin, J.D., Crawford, C.G., Frey, J.W., and Hodgkins, G.A., 1996, Water-quality assessment of the White River Basin, Indiana-Analysis of available information on nutrients, 1980-92: U.S. Geological Survey Water-Resources Investigantions Report 96-4192, 91 p.

Melhorn, W.N., and Kempton, J.P. [ed], 1991, Geology and hydrogeology of the Teays-Mahomet bedrock valley system: Geological Society of America, Inc., Special Paper 258, 128 p.

Meyer, W., Reussow, J.P., and Gillies, D.C., 1975, Availability of ground water in Marion County, Indiana: U.S. Geological Survey Open-File Report 75-312, 87 p.

Moore, R.C., and Fenelon, J.M., 1996, Occurrence of nitrate in ground water in the White River Basin, Indiana, 1994-95: U.S. Geological Survey Fact Sheet 110-96, 4 p.

Nyman, D.J., and Pettijohn, R.A., 1971, Ground Water, in Wabash River Coordinating Committee, Wabash River basin comprehensive study: U.S. Geological Survey and U.S. Army Corps of Engineers, Louisville District, volume VII, appendix G, 100 p.

O'Hearn, M., and Gibb, J.P., 1980, Groundwater discharge to Illinois streams: Illinois State Water Survey, Contract Report 246

Pettyjohn, W.A., and Henning, R., 1979, Preliminary estimate of ground-water recharge rates, related streamflow and water quality in Ohio: Department of Geology and Mineralogy, Ohio State University Report No. 552

Pinsak, A.P., and Shaver, R.H., 1964, The Silurian formations of northern Indiana: Indiana Department of Conservation, Geological Survey, Bulletin 32

Piper, A.M., 1944, A graphical procedure in the geochemical interpretation of water analysis: American Geophysical Union Trans., v. 25, p. 914-923

Rexroad, C.B., and Droste, J.B., 1982, Stratigraphy and conodont paleontology of the Sexton Creek Limestone and the Salamonie Dolomite (Silurian) in northwestern Indiana: Indiana Geological Survey, Special Report 25

Risch, M.R., 1994, A summary of pesticides in ground-water data collected by government agencies in Indiana from December 1985 to April 1991: U.S. Geological Survey Open-File report 93-133, 30 p.

Risch, M.R., and Cohen, D.A., 1995, A computerized data base of Nitrate concentrations in Indiana ground water: U.S. Geological Survey Open-File Report 95-468, 17 p.

Rosenshein, J.S., and Hunn, J.D., 1968, Geohydrology and ground-water potential of Lake County, Indiana: Indiana Department of Natural Resources, Division of Water, Bulletin 31

Rupp, J.A. 1991, Structure and isopach maps of the Paleozoic rocks of Indiana: Indiana Geological Survey, Special Report 48, 106 p.

Sasman, R.T., Schicht, R.J., Gibb, J.P., O'Hearn, M., Benson, C.R., and Ludwigs, R.S., 1981, Verification of the potential yield and chemical quality of the shallow dolomite aquifer in DuPage County, Illinois: Illinois State Water Survey, Circular 149

Schneider, A.F., 1966, Physiography, in Lindsey, A.A. (ed.), Natural features of Indiana: Indiana Academy of Science and Indiana State Library

Searcy, J.K., 1959, Flow duration curves; Manual of Hydrology, part 2, Low?flow techniques: U.S. Geological Survey, Water?Supply Paper 1542?A

Shaver, R.H., 1974, The Muscatatuck Group (New Middle Devonian Name) in Indiana: Indiana Geological Survey, Occasional Paper 3, 7 p.

Shaver, R.H., and others, 1961, Stratigraphy of the Silurian rocks of northern Indiana: Indiana Geological Survey Field Conference Guidebook 10, 62 p.

_____ 1978, The search for a Silurian reef model: Great Lakes area: Indiana Geological Survey Special Report 15, 36 p.

Shaver, R.H., Ault, C.H., Burger, A.M., Carr, D.D., Droste, J.B., Eggert, D.L., Gray, H.H., Harper, D., Hasenmueller, N.R., Hasenmueller, W.A., Horowitz, A.S., Hutchison, H.C., Keith, B.D., Keller, S.J., Patton, J.B., Rexroad, C.B., and Wier, C.E., 1986, Compendium of Paleozoic rock?unit stratigraphy in Indiana, a revision: Indiana Geological Survey, Bulletin 59, 203 p.

Skougstad, M.W., and Horr, C.A., 1963, Chemistry of strontium in natural water: U.S. Geological Survey, Water-Supply Paper 1496

Smith, B.S., 1983, Availability of water from the outwash aquifer, Marion County, Indiana: U.S. Geological Survey Water-Resources Investigation Report 83-4144, 70 p.

Smith, C.R., and Krothe, N.C., 1983, Hydrogeology of the Carbondale and Raccoon Creek Groups, Pennsylvanian System, Vigo, Clay, and Sullivan Counties, Indiana: Indiana University Water Resources Research Center, 93 p.

Steen, W.J., 1968, Water resources of Hendricks County with emphasis on ground-water availability: Indiana Department of Natural Resources, Division of Water, 1 sheet.

_____1970, Water resources of Madison County, with emphasis on ground-water availability: Indiana Department of Natural Resources, Division of Water, 1 sheet.

Steen, W.J., Bruns, T.M., and Perry, A.O., 1977, Water resources of Boone County, with emphasis on ground-water availability: Indiana Department of Natural Resources, Division of Water, 1 sheet.

Stewart, J.A., Keeton, C.R., Hammil, L.E., Nguyen, H.T., and Majors, D.K., 2001, Water Resources Data, Indiana Water Year 2000: U.S. Geological Survey, Water-Data Report IN-00-1, 450 p.

Sullivan, D.M., 1972, Subsurface stratigraphy of the West Baden Group in Indiana: Indiana Geological Survey Bulletin 47, 31 p.

Swann, D.H., 1968, A summary geologic history of the Illinois Basin, in Geology and petroleum production of the Illinois Basin, a symposium: Ill. and Ind.-Ky. Geol. Socs., p. 3-22

Tanner, G.F., 1986, The Mt. Carmel Fault and associated features in south-central Indiana: Bloomington, Ind., Indiana University, Master's thesis, 66 p.

Thomas, J.M., 1980, Water chemistry of the early Pennsylvanian Mansfield Formation aquifer system in Clay County, Indiana: Bloomington, Ind., Indiana University, Master's thesis, 76 p.

Todd, D.K., 1980, Ground?water hydrology (2nd ed.): New York, John Wiley, 336 p.

Tucker, W.M., 1922, Hydrology of Indiana, in Indiana Department of Conservation, Handbook of Indiana geology: Division of Geology

Turco, R.F., and Konopka, A.E., 1988, Agricultural impact on groundwater quality: Purdue University, Water Resources Research Center, Technical Report 185

Uhl, J.E., 1966, Water resources of Johnson County, with emphasis on ground water availability: Indiana Department of Natural Resources, Division of Water, 1 sheet.

_____1973, Water resources of Henry County, Indiana, with emphasis on ground-water availability: Indiana Department of Natural Resources, Division of Water, 1 sheet.

_____1975, Water Resources of Hancock County, Indiana, with emphasis on ground-water availability: Indiana Department of Natural Resources, Division of Water, 1 sheet.

Uhl, J., and Kingsbury, T., 1957, Irrigation in Indiana using ground?water sources: Indiana Department of Conservation, Division of Water Resources

U.S. Environmental Protection Agency, 1973, Water quality criteria, 1972: Environmental Studies Board, Committee on Water Quality Criteria, U.S. Government Printing Office

_____1976, Quality criteria for water: U.S. Government Printing Office

_____2001, Drinking water regulations and health advisories, updated September 7, 2001 (http://www.epa.gov/safewater/mcl.html): Office of Water, 8 p.

Wallrabenstein, L.K., Richards, R.P., Baker, D.B., and Barnett, J.D., 1994, Nitrate and pesticides in private wells of Indiana: Indiana Farm Bureau Inc.

Walton, W.C., 1962, Selected analytical methods for well and aquifer evaluation: Illinois State Water Survey, Bulletin 49

_____1970, Groundwater resource evaluation: New York, McGraw?Hill

Wangsness, D.J., Miller, R.L., Bailey, Z.C., and Crawford, C.G., 1981, Hydrology of area 32, eastern region, Interior Coal Province, Indiana: U.S. Geological Survey Water-Resources Investigations Open-File Report 82-566, 43 p.

Watkins, R.A., Jr., and Jordan, D.G., 1961, Ground-water resources of west-central Indiana-preliminary report, Greene County: Indiana Department of Natural Resources, Division of Water Bulletin 11, 225 p.

_____1962a, Ground-water resources of west-central Indiana-preliminary report, Sullivan County: Indiana Department of Natural Resources, Division of Water Bulletin 14, 345 p.

_____1962b, Ground-water resources of west-central Indiana-preliminary report, Clay County: Indiana Department of Natural Resources, Division of Water Bulletin 16, 309 p.

_____1963a, Ground-water resources of west-central Indiana-preliminary report, Vigo County: Indiana Department of Natural Resources, Division of Water Bulletin 17, 358 p.

_____1963b, Ground-water resources of west-central Indiana-preliminary report, Owen County: Indiana Department of Natural Resources, Division of Water Bulletin 18, 99 p.

_____1964a, Ground-water resources of west-central Indiana-preliminary report, Putnam County: Indiana Department of Natural Resources, Division of Water Bulletin 21, 83 p.

_____1964b, Ground-water resources of west-central Indiana-preliminary report, Parke County: Indiana Department of Natural Resources, Division of Water Bulletin 23, 125 p.

_____1965, Ground-water resources of west-central Indiana-preliminary report, Montgomery County: Indiana Department of Natural Resources, Division of Water Bulletin 27, 107 p.

Wayne, W.J., 1956, Thickness of drift and bedrock physiography of Indiana north of the Wisconsin glacial boundary: Indiana Department of Conservation, Geological Survey, Report of Progress 7

_____1958, Glacial geology of Indiana: Indiana Department of Conservation, Geological Survey, Atlas of mineral resources of Indiana, Map 10

_____1963, Pleistocene formations in Indiana: Indiana Department of Conservation, Geological Survey, Bulletin 25, 85 p.

_____1965, The Crawfordsville and Knightstown Moraines in Indiana: Indiana Department of Conservation, Geological Survey Report of Progress 28, 15 p.

_____1968, The Erie Lobe margin in east-central Indiana during the Wisconsin glaciations: Proceedings of the Indiana Academy of Science, v. 77, p. 279-291

_____1975, Urban geology of Madison County, Indiana: Indiana Geological Survey Special Report 10, 24 p

Wayne, W.J., Johnson, G.H., and Keller, S.J., 1966, Geologic map of the 1° x 2° Danville Quadrangle, Indiana and Illinois, showing bedrock and unconsolidated deposits: Indiana Geological Survey Regional Geologic Map 2

Wier, C.E., Glore, C.R., and Agnew, A.F., 1973, Sandstone aquifers in eastern Sullivan County, Indiana: in Proceedings of the Indiana Academy of Science, 1973, v. 82, p. 297-302

Wright, H.E., Jr., and Frey, D.G., eds., 1965, The Quaternary of the United States: Princeton, N.J., Princeton University Press, 922 p.

Appendix 1. Results of chemical analysis

{All values in milligrams per liter except as noted}

{Well locations displayed in Plate 9}

Aquifer systems: Unconsolidated--BV - Buried Valley Aquifer System; DTR - Dissected Till and Residuum Aquifer System; LB - Lacustrine and Backwater Deposits Aquifer System; TTP - Tipton Till Plain Aquifer System; TTPS - Tipton Till Plain Aquifer Subsystem; WR - White River and Tributaries Outwash Aquifer System; WRS - White River and Tributaries Outwash Aquifer Subsystem
Bedrock--DM - Devonian and Mississippian—New Albany Shale Aquifer System; M-B - Mississippian—Borden Group Aquifer System; M-BRS - Mississippian—Blue River and Sanders Groups Aquifer System;
M-BSW - Mississippian—Buffalo Wallow, Stephensport, and West Baden Groups Aquifer System; P-RC - Pennsylvanian—Raccoon Creek Group Aquifer System; P-C - Pennsylvanian—Carbondale Group Aquifer System;
P-M - Pennsylvanian—McLeansboro Group Aquifer System

Date sampled: month/year

Location Number	IDNR/DOW Well ID Number	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Total Hardness	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	NO_3 as N	Total Dissolved Solids[3]
BOONE COUNTY																					
51	85857	20N	2E	13	132	TTP	7/89	*7.81*	205	49.5	19.8	41.4	0.7	2.2	<0.1	293.0	2	<1	1.9	<0.7	483
52	85805	18N	2E	14	170	TTP	7/89	*7.80*	232	53.2	24.2	44.7	0.9	2.1	<0.1	338.5	5	<1	0.8	<0.7	550
53	85790	19N	2E	20	132	TTP	7/89	*7.63*	227	53.6	22.6	40.6	0.9	1.5	<0.1	333.0	2	<1	2.3	<0.7	542
54	85795	19N	2E	2	167	TTP	7/89	*7.52*	231	58.9	20.4	38.2	0.9	2.2	<0.1	335.3	2	<1	1.2	<0.7	544
55	85788	18N	2E	32	200	M-B	7/89	*7.88*	126	26.9	14.3	84.6	2.6	0.2	<0.1	311.8	5	4	0.9	<0.7	526
56	86310	18N	1E	22	148	TTP	7/89	*7.14*	374	88.8	37.1	69.3	1.8	8.4	<0.1	498.3	34	<1	0.9	<0.7	862
57	85810	18N	1E	33	110	M-B	7/89	*7.77*	266	60.7	27.9	26.7	1.1	0.4	0.4	331.3	3	6	1.6	<0.7	542
67	85800	18N	1W	16	54	TTP	8/89	*7.58*	384	104.7	29.9	4.9	0.4	3.9	0.2	277.9	12	78	0.3	<0.7	583
BROWN COUNTY																					
133	85859	10N	3E	28	54	M-B	8/89	*7.43*	315	83.1	26.3	40.1	0.9	<0.2	0.1	354.1	10	22	0.2	<0.7	623
134	86822	10N	3E	16	75	M-B	8/89	*7.67*	103	24.8	9.9	100.1	1.9	<0.2	<0.1	271.1	22	16	1.1	<0.7	512
CLAY COUNTY																					
131	85794	12N	5W	27	100	P-RC	8/89	*7.76*	234	65.2	17.4	14.1	1.2	0.5	0.8	235.7	2	6	0.3	<0.7	403
143	86295	13N	6W	35	60	DTR	8/89	*7.36*	241	58.1	23.3	9.8	0.4	<0.2	<0.1	185.2	19	6	0.2	9.51	395
144	198671	13N	6W	9	160	P-RC	8/89	*7.83*	57	14.4	5.1	150.9	3.1	<0.2	<0.1	380.7	2	3	0.5	<0.7	653
166	85869	9N	6W	7	100	P-RC	8/89	*6.21*	113	26.5	11.5	5.8	0.2	1.0	0.2	105.3	2	11	0.1	<0.7	201
169	3882	9N	7W	16	200	P-C	8/89	*6.36*	964	178.7	126.2	36.8	1.1	1.7	1.6	232.3	12	717	0.3	<0.7	1374
170	86807	10N	7W	33	75	P-RC	8/89	*6.60*	312	85.6	23.9	38.3	1.2	7.3	1.1	248.8	50	74	0.2	<0.7	597
171	85823	10N	7W	21	34	WR	8/89	*6.51*	318	78.8	29.6	9.1	0.3	<0.2	0.8	248.8	14	32	0.3	4.88	499
172	85868	11N	7W	35	108	P-RC	8/89	*7.86*	84	20.0	8.3	115.1	1.6	0.2	<0.1	321.2	2	<1	1.0	<0.7	546
173	85818	10N	6W	21	100	P-RC	8/89	*6.37*	320	76.2	31.7	45.6	0.8	4.3	1.4	182.8	8	207	0.1	<0.7	612
174	85813	10N	6W	8	55	WR	8/89	*6.86*	267	83.9	13.9	8.5	0.4	4.7	<0.1	229.8	10	25	0.2	<0.7	437
175	212172	11N	7W	26	69	WR	8/89	*7.31*	270	69.2	23.7	36.7	0.6	2.7	<0.1	326.3	5	<1	0.5	<0.7	544
176	85863	11N	7W	11	280	P-RC	8/89	*8.18*	13	3.2	1.3	187.8	1.1	<0.2	<0.1	403.7	3	<1	0.9	<0.7	695
189	86747	12N	6W	16	120	P-RC	9/89	*7.00*	188	48.4	16.4	54.6	1.2	<0.2	<0.1	314.3	2	<1	0.6	<0.7	513
238	82119	11N	6W	26	46	WR	6/90	*6.93*	258	76.5	16.2	11.6	<1	6.9	0.1	218.7	10	36	<1	<0.7	434
239	82118	11N	6W	16	106	P-RC	6/90	*6.81*	436	93.2	49.4	106.5	4.1	2.1	0.3	317.2	3	335	<1	<0.7	987

Location Number	IDNR/DOW Well ID Number	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Total Hardness	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	NO_3 as N	Total Dissolved Solids[3]
CLAY COUNTY continued																					
240	82124	12N	6W	7	260	P-RC	6/90	*7.80*	55	13.9	4.9	176.5	1.9	<0.2	<0.1	379.5	50	3	1.2	<0.7	717
241	82125	9N	7W	18	140	P-RC	6/90	*8.88*	15	3.4	1.6	168.1	1.5	<0.2	<0.1	416.9	1	<1	2.2	<0.7	671
242	82126	12N	5W	34	176	P-RC	6/90	*7.97*	35	8.8	3.1	111.0	1.8	<0.2	<0.1	263.4	4	5	<1	<0.7	458
244	82117	11N	7W	34	172	P-RC	6/90	*7.48*	146	32.2	16.0	82.5	1.3	0.3	<0.1	305.1	8	4	<1	<0.7	522
245	82103	10N	7W	4	255	P-RC	6/90	*8.58*	15	2.8	2.0	435.6	1.8	1.1	<0.1	544.3	266	28	4.2	<0.7	1400
246	82104	10N	6W	20	120	P-RC	6/90	*6.70*	96	22.6	9.6	44.0	<1	<0.2	<0.1	88.8	19	36	<1	7.68	286
247	82105	10N	6W	27	225	P-RC	6/90	*8.97*	2	<2	<1	392.0	1.2	<0.2	<0.1	797.2	52	<1	4.7	<0.7	1380
248	82106	10N	6W	32	80	P-RC	6/90	*6.72*	317	73.1	32.8	42.1	1.5	0.8	0.3	362.6	13	19	<1	<0.7	632
249	82107	10N	6W	31	320	P-RC	6/90	*9.22*	1	<2	<1	484.1	1.2	0.2	<0.1	735.5	250	5	3.8	<0.7	1580
253	82099	9N	6W	20	185	P-RC	6/90	*8.22*	14	3.8	1.1	186.3	0.8	<0.2	<0.1	408.6	8	<1	1.0	<0.7	699
351	82116	11N	7W	19	180	P-C	7/90	*5.55*	147	29.6	17.7	83.3	1.5	<0.2	<0.1	328.6	7	1	<1	<0.7	551
DAVIESS COUNTY																					
302	82071	3N	7W	16	205	P-C	7/90	*7.15*	97	24.8	8.4	97.9	1.9	0.2	<0.1	299.6	16	<1	<1	<0.7	521
303	82063	2N	7W	19	125	P-C	7/90	*6.27*	365	89.2	34.5	19.0	0.9	0.4	<0.1	403.6	<1	3	<1	<0.7	660
304	82065	2N	6W	7	235	P-C	7/90	*8.87*	6	<2	0.7	264.8	1.0	<0.2	<0.1	566.8	14	<1	2.5	<0.7	954
305	82064	2N	6W	2	225	P-RC	7/90	*6.97*	64	12.7	7.9	142.9	2.9	0.8	<0.1	369.5	3	<1	1.6	<0.7	628
306	82088	5N	5W	31	265	P-RC	7/90	*8.84*	3	<2	<1	290.1	1.0	<0.2	<0.1	645.8	4	<1	3.6	<0.7	1060
307	82089	5N	5W	22	285	P-RC	7/90	*8.89*	12	2.8	1.2	327.7	1.4	<0.2	<0.1	694.9	44	<1	3.2	<0.7	1200
310	82090	5N	5W	36	340	P-RC	7/90	*8.14*	3	<2	0.5	329.9	1.0	<0.2	<0.1	720.1	4	6	5.2	<0.7	1220
311	82084	4N	5W	22	185	P-RC	7/90	*7.97*	2	<2	<1	159.3	0.6	<0.2	<0.1	283.8	2	67	<1	<0.7	579
312	82087	5N	6W	22	125	WR	7/90	*6.86*	339	89.4	28.1	6.3	<1	<0.2	<0.1	223.5	17	23	<1	14.68	514
313	82086	5N	6W	32	260	P-RC	7/90	*7.04*	211	57.0	16.8	33.7	0.5	1.8	<0.1	266.8	7	<1	<1	<0.7	450
314	82079	4N	7W	26	275	P-C	7/90	*7.58*	110	30.6	8.1	172.0	1.8	<0.2	<0.1	486.4	2	4	1.0	<0.7	822
315	82075	3N	5W	21	265	P-RC	7/90	*8.01*	18	3.9	2.0	177.1	1.3	<0.2	<0.1	388.7	4	<1	2.7	<0.7	667
316	82072	3N	6W	2	315	P-RC	7/90	*8.33*	23	3.6	3.4	827.1	3.0	3.2	<0.1	863.2	760	5	3.4	<0.7	2660
317	82073	3N	6W	1	65	LB	7/90	*6.41*	255	72.1	18.2	24.9	<1	2.5	<0.1	285.5	2	6	<1	<0.7	484
318	82074	3N	6W	7	180	P-RC	7/90	*7.95*	24	3.8	3.6	1040.0	3.7	3.4	<0.1	993.7	992	<1	2.2	<0.7	3260
319	82080	4N	7W	35	260	P-C	7/90	*7.01*	79	18.7	7.9	161.5	1.8	<0.2	<0.1	412.6	26	3	1.3	<0.7	729
320	82081	4N	7W	36	145	P-C	7/90	*6.66*	164	45.6	12.3	78.5	1.2	<0.2	<0.1	308.3	2	8	<1	<0.7	536
321	82070	3N	7W	14	225	P-C	7/90	*7.34*	140	33.0	14.0	134.0	2.3	0.7	<0.1	433.9	2	<1	<1	<0.7	726
322	82069	3N	8W	24	114	P-C	7/90	*6.40*	334	96.0	23.0	4.0	<1	3.6	0.3	245.9	12	54	<1	<0.7	502
324	82083	4N	7W	11	175	P-C	7/90	*6.07*	251	68.1	19.6	5.9	<1	<0.2	<0.1	223.4	1	26	<1	<0.7	405
325	82082	4N	7E	14	44	WR	7/90	*7.14*	222	60.9	17.0	4.4	2.1	<0.2	<0.1	127.9	11	44	<1	12.88	361
DELAWARE COUNTY																					
1	3082	21N	10E	31	238	SD	7/89	*7.20*	409	103.0	36.9	10.1	1.0	1.3	<0.1	344.0	4	41	0.4	<0.7	629
2	1302	20N	10E	7	76	TTP	7/89	*7.01*	558	136.0	53.2	10.4	1.1	2.7	<0.1	389.1	22	123	0.2	<0.7	835
3	1551	20N	10E	22	37	TTPS	7/89	*7.10*	508	127.3	46.2	17.0	1.1	2.2	<0.1	358.3	34	97	0.1	<0.7	770
4	18508	19N	11E	1	62	TTP	7/89	*7.17*	446	110.5	41.3	5.3	0.9	0.8	0.1	303.6	29	80	0.1	0.84	648
11	2752	21N	10E	12	121	SD	7/89	*7.17*	369	95.0	32.0	4.3	0.7	1.6	<0.1	343.5	6	22	0.1	<0.7	588

Location Number	IDNR/DOW Well ID Number	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Total Hardness	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	NO_3 as N	Total Dissolved Solids[3]
DELAWARE COUNTY continued																					
13	22887	21N	11E	32	101	SD	7/89	*7.20*	476	105.7	51.8	14.4	1.1	1.7	<0.1	377.6	10	119	0.3	<0.7	776
14	2577	21N	9E	22	96	SD	7/89	*7.14*	386	97.5	34.7	5.7	0.8	1.4	<0.1	332.0	8	50	0.2	<0.7	612
19	21868	19N	9E	6	45	TTP	7/89	*7.24*	370	93.6	33.1	19.2	0.9	0.9	<0.1	286.9	45	76	0.2	<0.7	627
24	85	20N	9E	6	165	SD	7/89	*7.37*	311	80.0	27.1	8.7	0.6	1.6	<0.1	336.4	3	8	0.3	<0.7	548
27	34565	22N	9E	30	111	TTP	7/89	*7.17*	365	92.2	32.7	8.4	0.7	2.0	<0.1	342.4	5	60	0.4	<0.7	630
33	2888	21N	9E	15	69	TTPS	7/89	*7.29*	391	96.3	36.7	6.9	0.7	2.3	<0.1	345.9	14	63	0.3	<0.7	651
326	82194	20N	9E	3	140	TTP	7/90	*6.84*	323	84.0	27.6	10.8	0.7	0.7	<0.1	347.3	<1	9	<1	<0.7	568
327	82195	20N	10E	7	108	SD	7/90	*6.73*	291	75.1	25.1	7.8	1.3	<0.2	<0.1	193.5	24	57	1.1	5.87	458
335	82189	19N	11E	14	65	TTP	7/90	*6.54*	404	107.5	33.1	3.7	0.7	2.3	<0.1	314.7	14	52	<1	<0.7	605
336	82190	19N	11E	19	181	SD	7/90	*6.65*	14	3.5	1.2	144.3	<1	<0.2	<0.1	339.3	<1	15	<1	<0.7	587
340	82188	19N	9E	20	96	TTP	7/90	*7.16*	377	96.9	32.9	2.3	0.6	2.2	<0.1	273.0	12	91	<1	<0.7	577
342	82193	20N	9E	31	109	TTP	7/90	*6.59*	360	92.7	31.4	5.7	0.7	1.8	<0.1	357.8	11	2	<1	<0.7	591
343	82204	21N	9E	29	38	TTP	7/90	*7.04*	371	98.6	30.4	5.7	0.8	2.6	<0.1	330.6	7	36	<1	<0.7	593
GIBSON COUNTY																					
276	82047	1N	10W	34	115	P-M	7/90	*6.55*	407	92.9	42.6	34.3	0.6	<0.2	<0.1	220.0	102	87	<1	2.48	654
277	82046	1N	10W	24	51	DTR	7/90	*6.89*	342	92.3	27.1	12.4	0.5	0.8	0.6	359.7	2	<1	<1	<0.7	586
GREENE COUNTY																					
120	34698	7N	4W	2	250	M-BSW	8/89	*7.46*	1384	368.6	112.8	25.9	1.2	1.8	<0.1	179.6	23	1106	1.1	<0.7	1879
121	34656	7N	4W	28	100	P-RC	8/89	*7.79*	222	49.2	24.2	7.6	0.4	<0.2	<0.1	190.9	5	27	0.1	1.76	360
122	34668	7N	4W	21	61	M-BSW	8/89	*7.84*	260	55.1	29.9	16.4	0.6	0.3	0.2	247.8	2	19	0.2	<0.7	435
123	34645	7N	5W	24	83	M-BSW	8/89	*7.67*	293	74.2	26.3	18.3	0.6	0.7	0.4	245.3	8	58	0.2	<0.7	495
124	40934	6N	5W	1	184	P-RC	8/89	*7.98*	193	44.7	19.8	41.7	0.9	2.2	<0.1	273.1	3	2	0.5	<0.7	453
125	40650	6N	5W	29	235	P-RC	8/89	*7.22*	23	5.5	2.3	188.5	1.0	<0.2	<0.1	416.3	5	7	0.5	<0.7	593
126	40602	6N	5W	5	165	P-RC	8/89	*7.91*	253	66.1	21.4	22.3	0.5	3.8	0.1	279.5	4	<1	0.4	<0.7	464
127	34673	7N	4W	24	185	M-BSW	8/89	*7.99*	187	40.6	20.7	97.1	0.7	<0.2	<0.1	306.0	5	66	0.4	<0.7	609
161	30636	8N	5W	2	290	P-RC	8/89	*8.30*	40	11.0	3.1	271.0	1.5	<0.2	<0.1	361.8	3	255	1.3	<0.7	993
163	28602	8N	5W	29	165	P-RC	8/89	*7.70*	184	47.2	16.1	10.5	0.6	<0.2	0.1	153.1	5	27	0.2	1.22	305
164	28642	8N	5W	17	60	P-RC	8/89	*6.57*	242	49.8	28.5	17.3	0.6	<0.2	<0.1	199.3	11	35	0.3	2.44	404
167	28761	8N	6W	10	245	P-RC	8/89	*8.85*	17	3.4	2.0	836.3	1.9	<0.2	<0.1	737.9	730	<1	2.9	<0.7	2475
168	28729	8N	7W	13	105	P-RC	8/89	*7.34*	74	17.1	7.7	164.5	1.4	<0.2	<0.1	399.9	8	12	0.7	<0.7	709
192	30630	8N	4W	27	243	P-RC	9/89	*7.61*	210	48.9	21.4	33.5	1.0	<0.2	<0.1	260.3	1	19	0.3	<0.7	451
193	86723	7N	6W	36	155	P-RC	9/89	*7.94*	54	13.6	4.9	88.3	0.9	<0.2	<0.1	201.4	34	2	0.3	<0.7	397
194	40930	6N	6W	2	144	P-RC	9/89	*7.16*	198	54.1	15.3	12.7	0.3	0.6	<0.1	219.8	2	<1	0.2	<0.7	361
195	34808	6N	6W	12	60	WR	9/89	*7.58*	173	48.4	12.6	2.8	0.2	1.1	<0.1	142.3	4	27	0.1	<0.7	278
196	40573	6N	6W	29	130	P-RC	9/89	*7.26*	107	29.5	8.2	87.6	0.8	<0.2	<0.1	298.0	2	3	0.2	<0.7	501
197	34816	11N	7W	16	36	DTR	9/89	*7.32*	324	91.0	23.6	16.3	0.5	<0.2	0.3	234.2	17	86	0.3	5.53	560
198	40940	6N	4W	31	285	P-RC	9/89	*7.42*	68	16.6	6.6	57.7	0.8	<0.2	<0.1	195.0	3	<1	0.4	<0.7	329
199	34655	7N	4W	34	345	P-RC	9/89	*8.92*	3	0.6	0.4	221.1	0.7	<0.2	<0.1	516.2	1	5	2.0	<0.7	836
200	40776	6N	3W	20	280	M-BSW	9/89	*6.86*	210	37.0	28.8	33.0	0.7	<0.2	<0.1	178.2	1	122	1.2	<0.7	453

Location Number	IDNR/DOW Well ID Number	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Total Hardness	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	NO_3 as N	Total Dissolved Solids[3]
GREENE COUNTY continued																					
202	30625	8N	4W	15	305	P-RC	9/89	*6.98*	453	120.0	37.3	60.7	0.8	0.4	<0.1	167.3	3	432	0.2	<0.7	875
204	85808	10N	2W	19	165	M-BRS	9/89	*6.65*	319	79.6	29.4	4.6	0.3	<0.2	<0.1	301.4	4	16	0.5	0.77	515
254	82098	8N	7W	3	142	P-C	6/90	*8.36*	65	14.5	7.0	200.8	2.0	<0.2	<0.1	513.9	5	<1	1.5	<0.7	854
255	82094	7N	7W	4	285	P-C	6/90	*6.53*	922	246.0	74.9	97.9	2.1	1.6	0.2	432.2	5	688	1.3	<0.7	1660
256	82095	7N	6W	19	205	P-RC	6/90	*8.04*	10	1.9	1.4	326.1	1.6	0.3	<0.1	593.3	91	<1	3.8	<0.7	1150
257	82097	7N	7W	19	38	WRS	6/90	*8.62*	2	<2	<1	324.5	1.6	<0.2	<0.1	757.2	36	<1	2.9	<0.7	1270
258	82096	7N	5W	5	25	WR	6/90	*6.51*	286	80.0	20.9	16.0	4.2	0.5	0.6	153.0	34	108	<1	<0.7	460
301	82093	6N	7W	35	140	P-C	7/90	*6.83*	71	15.2	8.0	183.4	2.4	<0.2	<0.1	460.7	7	13	<1	<0.7	798
HAMILTON COUNTY																					
35	85867	19N	6E	18	90	TTPS	7/89	*7.32*	419	108.0	36.4	11.9	0.7	2.7	<0.1	333.3	28	87	0.4	<0.7	690
39	85862	19N	5E	21	300	SD	7/89	*7.51*	247	49.6	30.0	48.4	2.7	0.8	<0.1	296.0	52	5	0.6	<0.7	555
45	85768	18N	3E	4	172	TTP	7/89	*7.58*	281	74.9	23.0	8.0	0.6	1.1	<0.1	268.3	4	27	0.6	<0.7	476
46	86305	17N	5E	1	110	TTP	7/89	*7.72*	311	81.7	26.0	3.2	0.5	1.1	<0.1	278.7	4	38	0.3	<0.7	502
47	86557	20N	5E	11	96	TTP	7/89	*7.41*	311	74.7	30.2	20.6	0.9	1.3	<0.1	334.0	3	7	1.2	<0.7	562
48	86562	20N	5E	9	91	TTP	7/89	*7.30*	386	100.3	33.0	14.6	0.7	2.3	<0.1	375.0	20	42	0.4	<0.7	682
205	82177	18N	3E	3	163.5	TTP	6/90	*7.40*	243	60.5	22.4	31.8	0.7	0.4	<0.1	301.5	1	11	<1	<0.7	506
206	82185	19N	3E	30	121	TTP	6/90	*7.63*	262	62.5	25.8	38.1	0.6	1.9	0.1	348.9	1	<1	1.4	<0.7	566
207	82178	18N	4E	7	84	TTP	6/90	*7.82*	288	71.1	26.9	18.3	0.7	2.1	<0.1	324.5	2	<1	<1	<0.7	526
208	82170	17N	3E	3	105	TTP	6/90	*7.68*	266	67.4	23.7	27.1	0.7	1.7	<0.1	319.3	3	<1	<1	<0.7	522
209	82169	17N	3E	2	136	SD	6/90	*7.54*	323	77.7	31.4	19.4	0.7	0.5	<0.1	332.3	21	3	<1	<0.7	570
211	82180	18N	4E	34	50	WR	6/90	*7.13*	442	119.2	35.3	61.3	1.6	3.6	<0.1	332.4	135	94	<1	<0.7	862
215	82187	19N	5E	2	65	SD	6/90	*7.52*	396	100.6	35.2	6.9	0.9	0.4	<0.1	357.7	6	38	<1	<0.7	632
216	82186	19N	4E	12	108	TTP	6/90	*8.03*	301	78.9	25.3	4.0	0.5	1.4	<0.1	267.5	3	28	<1	<0.7	475
217	82179	18N	4E	14	69	WR	6/90	*7.41*	405	111.7	30.6	5.8	0.8	1.5	<0.1	303.8	12	83	<1	<0.7	623
218	82181	18N	5E	22	45	TTP	6/90	*7.83*	365	95.3	31.0	8.1	0.6	3.6	<0.1	315.3	9	32	<1	<0.7	574
219	82175	17N	5E	4	70	TTP	6/90	*6.88*	334	88.0	27.8	2.9	0.5	0.5	0.1	283.0	2	48	<1	<0.7	520
220	82173	17N	4E	3	85	WR	6/90	*8.00*	341	86.5	30.5	9.2	0.7	1.4	<0.1	296.0	4	46	<1	<0.7	545
HANCOCK COUNTY																					
101	86746	16N	5E	23	150	TTP	8/89	*7.65*	350	81.5	35.7	28.4	0.9	1.6	<0.1	369.4	2	17	1.0	<0.7	630
350	82176	17N	7E	16	84	TTP	7/90	*6.03*	336	87.7	28.4	5.8	<1	1.3	<0.1	322.1	3	9	<1	<0.7	540
HENDRICKS COUNTY																					
64	86731	17N	2E	17	178	DM	8/89	*7.85*	295	66.6	31.3	33.3	0.7	2.2	<0.1	351.0	2	<1	1.8	<0.7	576
65	85803	17N	1E	27	96	TTP	8/89	*7.78*	311	78.1	28.3	8.0	0.5	2.2	<0.1	276.6	2	30	0.9	<0.7	501
66	86726	17N	1E	29	137	TTP	8/89	*7.78*	273	65.7	26.6	50.2	0.7	0.9	<0.1	368.4	2	<1	0.7	<0.7	606
68	86721	16N	2W	11	50	TTPS	8/89	*7.66*	378	101.4	30.4	3.7	0.4	<0.2	<0.1	281.6	4	62	0.3	<0.7	553
69	85824	16N	2W	16	90	TTPS	8/89	*7.78*	290	72.0	26.9	21.0	0.5	1.2	<0.1	308.4	8	<1	0.6	<0.7	516
70	86290	15N	1E	7	143	TTPS	8/89	*7.62*	349	89.3	30.6	23.9	0.7	1.8	<0.1	377.1	2	<1	0.7	<0.7	621
71	85829	16N	1W	33	115	M-B	8/89	*7.87*	157	33.9	17.6	80.8	2.6	0.2	<0.1	315.3	3	<1	2.9	<0.7	533
72	86265	15N	2W	12	82	M-B	8/89	*7.16*	505	130.0	43.8	29.0	0.9	<0.2	<0.1	362.4	73	66	0.1	<0.7	795

Location Number	IDNR/DOW Well ID Number	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Total Hardness	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	NO_3 as N	Total Dissolved Solids[3]
HENDRICKS COUNTY continued																					
73	86260	15N	2W	23	66	M-B	8/89	*7.88*	322	84.2	27.1	8.2	0.4	<0.2	<0.1	215.8	19	45	0.2	7.14	486
74	86270	15N	2W	8	78	M-B	8/89	*7.73*	354	93.2	29.5	13.0	0.8	0.5	<0.1	314.1	7	31	0.3	<0.7	569
75	85793	16N	2W	31	106	M-B	8/89	*7.76*	379	97.5	33.0	9.2	0.6	4.8	0.4	329.9	27	8	0.6	<0.7	593
76	86657	15N	1E	33	60	TTPS	8/89	*7.66*	354	87.5	33.0	8.4	0.6	2.4	<0.1	322.5	4	16	0.6	<0.7	557
77	108760	15N	1W	26	38	DTR	8/89	*7.75*	322	87.1	25.5	10.4	1.1	0.6	0.2	232.9	19	58	0.2	<0.7	489
78	86275	14N	1W	3	80	M-B	8/89	*7.39*	367	94.8	31.8	9.1	0.9	<0.2	<0.1	284.3	11	57	0.2	<0.7	560
79	86766	14N	1W	9	107	M-B	8/89	*7.79*	341	86.2	30.7	27.6	0.8	1.4	<0.1	371.9	7	<1	0.8	<0.7	619
80	86776	14N	2W	10	51	LB	8/89	*7.81*	1	0.2	0.1	181.8	0.2	<0.2	<0.1	331.9	12	28	0.4	<0.7	637
81	86637	14N	2W	22	95	LB	8/89	*7.68*	359	95.5	29.2	5.6	0.4	1.6	0.2	328.2	6	11	0.3	<0.7	561
82	86632	14N	1W	35	85	M-B	8/89	*7.67*	319	83.6	26.8	58.5	1.1	1.5	<0.1	403.6	14	7	0.5	<0.7	695
83	86757	15N	1E	14	108	TTPS	8/89	*7.88*	318	78.0	30.1	23.5	0.8	1.2	<0.1	332.2	4	7	1.1	<0.7	563
137	86771	14N	1W	29	66	BV	8/89	*7.20*	375	97.2	32.1	3.7	0.5	1.4	<0.1	284.9	10	64	0.2	<0.7	564
213	82166	17N	1E	20	268	TTP	6/90	*7.80*	292	67.2	30.2	51.7	1.3	1.9	<0.1	406.0	2	<1	<1	<0.7	655
214	82163	16N	2E	5	64	TTP	6/90	*7.88*	299	75.3	27.0	21.1	0.7	1.2	<0.1	322.7	1	4	1.1	<0.7	535
222	82149	15N	2W	18	95	DTR	6/90	*7.13*	319	81.9	27.9	15.2	0.5	1.2	<0.1	355.1	1	1	<1	<0.7	572
224	82140	14N	2W	14	88	M-B	6/90	*6.90*	350	90.4	30.3	11.3	0.8	0.4	0.2	283.0	15	62	<1	<0.7	563
259	82158	16N	2W	9	160	BV	7/90	*6.89*	266	65.1	25.2	40.4	0.8	1.4	<0.1	361.6	16	<1	<1	<0.7	600
260	82159	16N	2W	22	127	TTPS	7/90	*7.23*	271	70.9	23.0	24.3	0.5	1.9	<0.1	341.4	7	<1	<1	<0.7	553
261	82160	16N	2W	35	77	TTPS	7/90	*7.15*	294	65.6	31.8	31.1	0.7	1.3	<0.1	386.7	8	<1	<1	<0.7	617
262	82161	16N	1W	29	115	TTPS	7/90	*7.16*	321	76.5	31.7	15.2	0.7	1.8	<0.1	323.8	11	22	1.1	<0.7	567
263	82150	15N	1W	9	110	M-B	7/90	*6.95*	347	84.5	33.0	26.0	1.2	0.5	<0.1	383.3	13	23	<1	<0.7	660
264	82151	15N	1W	16	51	DTR	7/90	*6.87*	404	100.5	37.3	10.5	0.7	3.2	<0.1	331.0	25	56	<1	<0.7	647
265	82152	15N	1W	26	120	TTPS	7/90	*7.54*	163	32.0	20.1	86.5	1.8	0.7	<0.1	311.1	42	<1	2.4	<0.7	572
269	82162	16N	1E	24	156	TTPS	7/90	*7.28*	194	44.7	20.0	175.5	3.5	0.8	<0.1	616.6	4	<1	<1	<0.7	1010
356	82141	14N	1E	15	49	WR	7/90	*7.13*	335	89.7	27.0	4.6	0.6	1.7	<0.1	260.8	13	58	<1	<0.7	521
357	82142	14N	1E	10	82	M-B	7/90	*6.94*	335	88.6	27.6	15.7	0.8	0.6	<0.1	361.2	8	4	<1	<0.7	596
HENRY COUNTY																					
16	85852	18N	10E	6	41	TTP	7/89	*7.01*	422	106.0	38.3	5.7	0.8	0.7	0.1	319.7	26	109	0.1	<0.7	682
17	21769	19N	10E	30	135	SD	7/89	*7.11*	340	83.7	31.8	6.7	0.6	1.2	<0.1	336.6	3	20	0.3	<0.7	567
18	22084	19N	9E	27	225	SD	7/89	*7.30*	294	67.0	30.8	21.2	0.7	1.2	<0.1	332.9	8	6	0.4	<0.7	548
22	85847	18N	9E	7	258	SD	7/89	*7.45*	269	61.6	28.0	27.0	0.8	0.9	<0.1	308.5	5	14	0.4	<0.7	520
32	21809	19N	10E	36	93.5	TTP	7/89	*7.19*	384	98.3	33.7	3.2	0.6	0.3	<0.1	314.0	8	70	0.1	<0.7	604
337	82183	18N	9E	29	42.5	TTP	7/90	*6.28*	362	92.3	32.1	4.8	0.7	2.0	<0.1	310.4	8	45	<1	<0.7	571
339	82184	18N	9E	5	66	TTP	7/90	*6.78*	500	139.1	37.1	53.9	2.2	0.3	0.5	315.7	167	59	<1	<0.7	852
JOHNSON COUNTY																					
92	86826	13N	3E	18	42	DTR	8/89	*7.68*	416	106.4	36.5	9.9	0.6	2.4	0.1	367.9	5	33	0.6	<0.7	655
93	86732	13N	3E	8	86	TTP	8/89	*7.82*	287	72.6	25.7	32.1	1.3	3.6	<0.1	334.6	4	6	0.4	<0.7	563
94	86786	14N	3E	32	54	WR	8/89	*7.68*	456	120.9	37.6	19.1	0.9	2.4	<0.1	311.0	66	57	0.2	<0.7	691
102	86280	14N	3E	27	55	TTP	8/89	*7.88*	409	110.6	32.3	13.1	0.8	<0.2	<0.1	284.3	33	74	0.2	0.86	622

Location Number	IDNR/DOW Well ID Number	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Total Hardness	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	NO_3 as N	Total Dissolved Solids[3]
JOHNSON COUNTY continued																					
103	86325	13N	3E	9	62	DTR	8/89	*7.81*	302	78.5	25.7	3.3	0.4	<0.2	<0.1	197.7	8	36	0.2	11.07	447
104	86320	13N	3E	31	49	DTR	8/89	*7.74*	382	92.6	36.6	17.3	0.8	0.5	0.1	380.5	4	19	0.3	<0.7	646
110	85814	12N	3E	224	40	DTR	8/89	*7.63*	679	155.4	70.8	21.9	1.8	<0.2	<0.1	399.6	40	246	0.2	1.90	1041
111	85843	11N	3E	14	90	M-B	8/89	*7.63*	443	114.8	38.2	10.7	0.8	1.0	0.4	386.9	6	24	0.2	<0.7	679
112	85838	11N	3E	10	88	M-B	8/89	*7.88*	310	80.0	26.7	48.6	0.7	1.1	<0.1	385.7	3	<1	0.4	<0.7	640
359	82132	12N	3E	1	45	M-B	8/90	*6.79*	348	88.2	31.0	9.7	0.7	<0.2	0.4	312.2	15	29	<1	<0.7	565
360	82133	12N	3E	11	44	DTR	8/90	*6.78*	309	78.8	27.3	28.5	0.8	1.1	0.2	359.7	10	3	1.1	<0.7	602
361	82148	14N	4E	31	55	TTP	8/90	*6.80*	350	89.0	31.0	8.0	<1	0.3	0.2	356.7	11	32	<1	<0.7	618
KNOX COUNTY																					
274	82041	1S	12W	12	85	P-M	7/90	*6.82*	452	113.2	41.2	6.7	0.6	3.0	0.2	383.8	11	56	<1	<0.7	710
275	82042	1S	11W	4	51	WR	7/90	*7.27*	2	<2	<1	202.1	0.1	<0.2	<0.1	316.3	20	59	<1	13.33	736
283	82050	1N	8W	8	179	WRS	7/90	*7.01*	338	83.4	31.5	14.9	0.6	2.9	<0.1	409.2	9	<1	<1	<0.7	652
284	82049	1N	8W	3	200	P-C	7/90	*7.22*	377	91.6	36.2	23.1	0.6	1.0	<0.1	429.4	9	<1	<1	<0.7	697
285	82062	2N	8W	28	107	WRS	7/90	*7.05*	328	81.6	30.1	23.0	0.7	3.2	<0.1	391.6	11	<1	<1	<0.7	635
286	82078	4N	8W	10	74	LB	7/90	*6.80*	480	133.3	35.7	6.4	0.6	4.8	0.2	229.6	15	222	<1	<0.7	707
287	82077	4N	8W	27	103.5	P-M	7/90	*6.65*	316	61.9	39.3	131.3	2.2	0.7	0.3	454.7	81	71	1.2	<0.7	952
288	82076	4N	9W	25	108	P-M	7/90	*6.65*	63	12.6	7.6	13.0	<1	5.4	0.5	77.9	8	16	<1	<0.7	175
289	82067	3N	4W	10	70	P-M	7/90	*6.75*	419	101.4	40.2	23.3	0.8	2.1	0.2	366.2	30	47	<1	<0.7	704
290	82053	2N	10W	1	100	P-M	7/90	*6.95*	438	99.1	46.4	19.8	0.7	<0.2	<0.1	361.3	24	59	<1	1.81	709
291	82066	3N	9W	35	105	P-M	7/90	*6.24*	263	57.4	29.1	26.6	<1	<0.2	<0.1	249.8	22	40	<1	1.36	501
292	82068	3N	8W	34	235	P-C	7/90	*6.85*	109	27.4	9.8	109.8	1.2	<0.2	<0.1	339.8	5	<1	<1	<0.7	579
293	82061	2N	8W	5	245	P-C	7/90	*7.06*	100	24.0	9.7	232.4	1.3	<0.2	<0.1	491.5	84	<1	2.1	<0.7	959
294	82058	2N	9W	25	205	P-M	7/90	*6.80*	216	59.8	16.3	15.5	0.7	0.4	<0.1	243.8	1	4	<1	<0.7	411
295	82057	2N	9W	15	140	P-M	7/90	*7.48*	185	44.0	18.3	48.1	0.9	<0.2	<0.1	308.5	1	<1	<1	<0.7	500
296	82056	2N	9W	15	97	WRS	7/90	*7.65*	197	54.0	15.0	4.2	<1	1.1	0.1	180.9	2	13	<1	<0.7	321
297	82059	2N	9W	22	95	WRS	7/90	*7.32*	261	72.7	19.4	5.7	<1	<0.2	<0.1	206.3	26	4	<1	8.81	431
298	82054	2N	10W	24	50	P-M	7/90	*7.42*	132	31.1	13.3	138.0	1.6	<0.2	0.1	403.2	19	31	<1	<0.7	734
299	82060	2N	9W	9	165	P-M	7/90	*8.03*	15	4.0	1.3	150.8	0.7	0.3	<0.1	347.8	8	<1	<1	<0.7	593
300	82085	5N	7W	18	43	WR	7/90	*6.69*	402	106.5	33.0	12.3	<1	<0.2	<0.1	250.1	12	16	<1	32.53	638
MADISON COUNTY																					
15	85763	19N	8E	35	71	TTP	7/89	*7.21*	326	83.8	28.4	5.0	0.5	2.1	<0.1	336.4	2	14	0.2	<0.7	556
20	85785	20N	7E	11	120	TTP	7/89	*7.21*	323	82.4	28.7	6.2	0.6	3.3	<0.1	348.8	2	<1	0.2	<0.7	558
21	86497	21N	8E	17	76	TTP	7/89	*7.02*	371	96.8	31.4	6.2	0.7	2.2	<0.1	379.7	3	16	0.3	<0.7	630
23	85783	18N	8E	14	50	TTP	7/89	*7.12*	371	93.7	33.5	6.1	0.6	3.7	0.1	303.1	22	72	0.2	<0.7	608
25	85877	20N	8E	10	71	TTP	7/89	*7.33*	368	92.4	33.4	5.9	1.1	1.4	<0.1	318.0	13	50	0.2	<0.7	593
26	86492	21N	8E	14	200	SD	7/89	*7.17*	414	101.4	39.2	11.8	1.0	1.7	<0.1	392.4	3	63	0.3	<0.7	711
28	86507	22N	8E	21	116	TTP	7/89	*7.26*	366	94.4	31.6	9.7	0.7	1.7	<0.1	339.1	9	37	0.3	<0.7	609
29	86512	22N	8E	30	142	SD	7/89	*7.02*	448	109.6	42.4	23.5	2.0	<0.2	<0.1	363.8	87	58	0.4	<0.7	775
34	85872	19N	7E	36	112	SD	7/89	*7.43*	272	57.7	31.3	14.2	1.0	0.6	<0.1	314.5	1	<1	0.3	<0.7	497

Location Number	IDNR/DOW Well ID Number	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH^1	Total Hardness	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as CaCO$_3$^{2}	Chloride	Sulfate	Fluoride	NO$_3$ as N	Total Dissolved Solids^3
MADISON COUNTY continued																					
36	144989	20N	6E	22	85	TTP	7/89	*7.60*	349	90.3	30.2	3.5	0.7	0.9	<0.1	269.3	11	73	0.2	<0.7	544
37	86517	21N	6E	34	222	SD	7/89	*7.50*	332	83.2	30.3	8.3	0.8	0.4	<0.1	311.1	9	29	0.7	<0.7	550
38	86552	20N	6E	33	220	SD	7/89	*7.48*	364	76.5	42.0	83.9	7.6	0.3	<0.1	309.8	188	17	0.8	<0.7	801
40	85778	18N	6E	11	82	SD	7/89	*7.46*	342	81.9	33.4	8.1	0.7	1.4	<0.1	324.6	16	32	0.6	<0.7	578
41	85773	18N	7E	26	71	TTP	7/89	*7.57*	317	79.8	28.7	5.3	0.6	1.0	0.2	341.2	3	2	0.3	<0.7	547
338	82182	18N	8E	16	93	TTP	7/90	*6.77*	351	90.3	30.6	7.0	0.8	0.9	0.2	309.7	12	28	<1	<0.7	555
341	142321	20N	8E	33	43	TTP	7/90	*6.30*	456	116.7	39.9	5.7	0.8	2.3	<0.1	291.7	83	55	<1	<0.7	667
348	82206	22N	8E	22	220	SD	7/90	*7.29*	313	76.7	29.6	15.5	0.7	1.3	<0.1	361.5	2	7	1.1	<0.7	584
349	155320	18N	7E	34	229	TTP	7/90	*6.94*	325	82.5	28.9	16.4	0.8	1.0	<0.1	330.1	19	2	<1	<0.7	563
MARION COUNTY																					
42	66797	17N	5E	20	125	TTP	7/89	*7.59*	356	88.9	32.7	5.5	0.6	0.8	<0.1	306.1	20	49	0.6	<0.7	580
43	66692	17N	4E	35	140	TTP	7/89	*7.38*	397	105.9	32.1	17.3	0.8	3.3	<0.1	309.3	59	50	0.2	<0.7	652
44	65292	17N	3E	24	195	SD	7/89	*7.12*	381	97.7	33.5	37.2	1.0	<0.2	<0.1	311.1	79	47	0.4	<0.7	685
58	61544	16N	2E	1	78	TTP	7/89	*7.84*	300	69.3	30.9	21.2	0.7	1.6	<0.1	325.0	2	<1	1.0	<0.7	534
59	86736	16N	3E	4	57	TTP	7/89	*7.45*	497	132.4	40.5	71.9	1.5	3.1	0.2	380.8	123	78	0.2	<0.7	923
60	64109	16N	4E	8	82	WR	7/89	*7.47*	494	125.5	44.1	61.1	1.1	2.3	0.2	332.9	147	47	0.4	<0.7	844
61	86741	16N	4E	8	60	WR	7/89	*7.51*	424	112.4	34.8	56.1	1.0	<0.2	<0.1	317.8	97	44	0.2	1.90	748
62	64242	16N	5E	3	215	SD	7/89	*7.94*	374	89.4	36.8	20.1	0.8	1.6	<0.1	372.1	4	18	0.8	<0.7	637
63	63863	16N	5E	3	172	TTP	7/89	*7.82*	342	70.6	40.4	32.2	0.8	0.9	<0.1	351.0	2	36	1.0	<0.7	622
95	41612	14N	4E	5	43	TTP	8/89	*7.43*	483	127.5	39.9	39.1	0.9	<0.2	<0.1	371.9	59	65	0.2	2.12	803
96	232296	14N	4E	8	250	DM	8/89	*8.10*	213	42.2	26.4	69.3	2.0	<0.2	<0.1	309.5	21	19	0.6	<0.7	564
97	86791	14N	4E	2	97	TTP	8/89	*7.82*	390	97.3	35.9	55.4	0.9	1.4	<0.1	505.1	3	<1	0.8	<0.7	824
98	59138	15N	4E	26	47	TTP	8/89	*7.78*	422	97.5	43.4	13.8	0.9	1.4	<0.1	382.7	10	28	1.3	<0.7	675
99	86761	15N	4E	22	212	SD	8/89	*7.67*	310	63.7	36.8	56.3	2.3	<0.2	<0.1	295.2	31	62	2.7	<0.7	620
100	58664	15N	4E	15	50	TTP	8/89	*7.62*	663	171.7	57.1	65.3	1.5	5.5	<0.1	390.3	216	78	0.4	<0.7	1082
210	82171	17N	3E	23	50	WRS	6/90	*6.74*	428	104.8	40.6	20.4	0.9	1.2	<0.1	330.0	48	62	<1	<0.7	691
212	82174	17N	4E	13	143	SD	6/90	*7.50*	341	86.9	30.2	9.5	0.8	1.8	<0.1	340.2	1	13	<1	<0.7	569
270	82167	17N	2E	16	339	DM	7/90	*7.30*	306	61.6	37.0	69.1	3.8	<0.2	<0.1	346.5	39	57	1.5	<0.7	696
271	82168	17N	2E	22	55	DM	7/90	*7.11*	455	122.5	36.4	55.6	1.1	<0.2	<0.1	325.6	117	57	<1	2.94	807
272	82153	15N	2E	16	55	TTPS	7/90	*7.20*	314	78.9	28.4	13.5	0.5	1.2	<0.1	299.7	3	29	<1	<0.7	532
273	82143	14N	2E	4	56	M-B	7/90	*7.06*	674	175.7	57.1	58.2	0.9	<0.2	0.1	360.0	268	58	<1	<0.7	1070
362	82510	14N	3E	2	178	DM	8/90	*6.67*	408	108.5	33.4	39.5	1.1	1.3	<0.1	284.3	123	56	<1	<0.7	716
363	82145	14N	3E	2	47	WR	8/90	*7.14*	1	<1	<1	185.1	<1	<0.2	<0.1	269.8	51	53	<1	9.26	665
364	82146	14N	3E	21	71	WR	8/90	*6.79*	411	113.2	31.2	14.1	0.9	3.0	0.1	285.8	66	88	<1	<0.7	672
365	82147	14N	3E	11	81	TTP	8/90	*6.91*	338	90.8	27.2	3.7	<1	<0.2	0.6	330.7	9	7	<1	<0.7	550
366	82154	15N	2E	12	89	TTPS	8/90	*7.11*	291	72.1	27.0	15.8	0.7	0.9	<0.1	319.7	9	<1	<1	<0.7	525
367	82164	16N	3E	15	46	TTP	8/90	*7.02*	586	155.9	47.9	23.2	1.1	3.2	0.1	303.2	206	63	<1	<0.7	880
368	82172	17N	3E	34	116	SD	8/90	*6.97*	262	63.5	25.1	24.1	0.8	1.4	<0.1	315.2	12	<1	<1	<0.7	520
369	162210	16N	4E	26	190	SD	8/90	*6.86*	286	56.9	35.1	31.0	0.9	1.1	<0.1	337.2	10	23	<1	<0.7	577

Location Number	IDNR/DOW Well ID Number	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Total Hardness	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	NO_3 as N	Total Dissolved Solids[3]
MARION COUNTY continued																					
370	82155	15N	5E	6	174	TTP	8/90	*7.20*	267	51.2	33.8	47.1	0.9	0.8	<0.1	364.7	10	4	<1	<0.7	599
371	82165	16N	4E	17	62	WR	8/90	*6.88*	426	112.7	35.1	57.7	1.6	3.1	0.3	309.7	133	78	<1	<0.7	806
372	82156	15N	2E	14	67	TTPS	8/90	*7.06*	341	85.6	30.9	18.7	0.8	0.9	<0.1	354.7	18	14	<1	<0.7	612
MARTIN COUNTY																					
308	82092	5N	4W	19	315	P-RC	7/90	*6.12*	267	56.0	31.0	58.0	1.1	<0.2	1.4	138.0	3	203	<1	<0.7	528
309	82091	5N	4W	30	345	P-RC	7/90	*8.19*	8	1.7	0.8	202.2	0.8	<0.2	<0.1	434.2	2	8	3.9	<0.7	748
MONROE COUNTY																					
119	86832	9N	1W	30	80	M-BRS	8/89	*7.62*	309	84.1	24.1	7.5	0.4	<0.2	<0.1	258.0	11	33	0.8	<0.7	484
135	86837	9N	2W	15	43	M-BRS	8/89	*7.41*	268	50.6	34.6	36.2	1.1	<0.2	<0.1	281.5	12	37	0.9	1.11	535
136	222297	9N	2W	22	205	M-BRS	8/89	*7.66*	337	73.4	37.4	3.4	0.7	0.6	<0.1	256.7	2	135	1.9	<0.7	621
158	222303	9N	2W	18	225	M-BSW	8/89	*8.06*	347	76.8	37.9	2.8	0.7	<0.2	<0.1	241.0	1	82	1.7	<0.7	507
162	86827	8N	2W	18	65	M-BRS	8/89	*8.37*	303	76.8	27.0	11.7	0.6	<0.2	<0.1	255.7	11	34	1.2	3.21	508
225	82115	10N	1W	17	145	M-B	6/90	*7.17*	389	106.0	30.2	13.0	0.6	<0.2	<0.1	353.2	4	52	<1	<0.7	643
236	82113	10N	2W	4	145	M-B	6/90	*7.43*	269	70.0	23.0	34.8	0.6	2.5	<0.1	337.0	8	4	<1	<0.7	561
237	82114	10N	2W	14	120	M-B	6/90	*6.75*	478	155.8	21.6	21.2	<1	<0.2	<0.1	333.1	15	136	<1	7.23	796
266	82100	9N	2W	28	65	M-BRS	7/90	*7.16*	320	78.5	30.3	4.7	1.2	<0.2	<0.1	234.5	6	112	1.5	<0.7	553
267	82102	9N	2W	21	95	M-BRS	7/90	*7.22*	298	70.4	29.7	3.0	0.6	0.2	<0.1	245.9	4	90	1.9	<0.7	540
268	82101	9N	2W	26	105	M-BRS	7/90	*7.14*	301	73.0	28.8	4.7	0.5	<0.2	<0.1	252.9	5	76	1.8	<0.7	534
MORGAN COUNTY																					
84	86285	14N	1E	29	80	BV	8/89	*7.77*	363	93.7	31.4	5.0	0.6	3.1	<0.1	358.1	2	<1	0.6	<0.7	584
85	85809	13N	1E	8	90	M-B	8/89	*7.65*	366	95.2	31.2	4.1	0.5	<0.2	<0.1	317.5	3	31	0.3	<0.7	562
86	86836	13N	1W	13	84	BV	8/89	*7.67*	311	81.1	26.3	32.9	0.8	2.4	<0.1	364.4	2	<1	0.4	<0.7	599
87	86315	13N	1W	25	222	M-B	8/89	*7.42*	59	14.1	5.9	17.8	0.3	<0.2	<0.1	56.2	4	25	0.2	0.88	150
88	86777	12N	1E	3	60	WR	8/89	*7.62*	469	125.5	37.8	7.6	1.1	0.7	0.2	299.4	21	110	0.2	<0.7	676
89	86722	13N	1E	22	180	M-B	8/89	*7.43*	124	29.7	12.1	15.6	0.3	<0.2	<0.1	80.7	9	40	0.2	1.94	228
90	85775	13N	2E	8	105	M-B	8/89	*7.76*	372	95.0	32.8	16.1	0.7	1.1	<0.1	389.5	4	4	0.6	<0.7	639
91	86806	14N	2E	26	58	M-B	8/89	*7.75*	366	93.3	32.3	12.2	0.7	1.1	0.4	351.3	6	14	0.5	<0.7	600
105	86330	13N	2E	21	95	WRS	8/89	*7.68*	7	1.6	0.7	172.9	0.2	<0.2	<0.1	294.1	14	72	0.2	<0.7	629
106	85819	12N	1E	15	110	WR	8/89	*7.88*	254	66.9	21.3	8.9	0.4	<0.2	<0.1	194.4	8	40	0.2	0.75	393
107	86752	12N	1E	34	115	WR	8/89	*7.78*	282	75.6	22.7	5.5	0.4	0.8	0.2	263.5	2	6	0.2	<0.7	444
108	85833	11N	2E	6	48	DTR	8/89	*7.85*	188	50.9	14.9	11.7	0.3	<0.2	<0.1	163.9	5	18	0.3	1.20	316
109	85873	12N	2E	18	51	WR	8/89	*7.83*	306	79.6	26.2	6.4	0.4	<0.2	0.3	285.8	3	3	0.2	<0.7	478
113	86787	11N	1E	28	59	M-B	8/89	*7.50*	300	86.3	20.6	7.0	0.5	<0.2	<0.1	233.9	4	41	0.2	1.72	462
114	86782	11N	1E	23	160	WR	8/89	*7.71*	277	73.6	22.6	21.9	0.5	0.7	<0.1	297.2	11	<1	0.1	<0.7	502
118	86737	12N	2W	18	85	M-BRS	8/89	*7.28*	386	121.5	20.1	7.7	0.8	<0.2	<0.1	288.3	15	68	0.2	2.30	602
138	86831	13N	1W	6	110	M-B	8/89	*7.04*	499	127.5	43.9	11.7	0.6	<0.2	<0.1	377.4	19	77	0.2	3.00	764
139	86300	13N	1W	30	142	M-B	8/89	*7.88*	186	43.0	19.2	86.4	1.3	2.3	<0.1	372.5	6	<1	0.9	<0.7	621
140	85764	12N	2W	11	80	M-B	8/89	*7.61*	260	63.0	25.0	18.5	0.5	1.0	0.2	194.7	19	59	0.3	<0.7	434
141	86762	12N	2W	3	107	M-B	8/89	*7.53*	353	94.9	28.3	17.9	0.6	0.8	0.4	343.1	7	11	0.2	<0.7	592

Location Number	IDNR/DOW Well ID Number	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Total Hardness	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	NO_3 as N	Total Dissolved Solids[3]
MORGAN COUNTY continued																					
179	86727	13N	2E	28	60	M-B	9/89	*7.01*	314	83.8	25.5	4.9	0.3	<0.2	0.9	285.4	5	18	0.6	<0.7	498
180	86781	14N	2E	32	87	M-B	9/89	*6.63*	395	96.9	37.3	9.5	0.6	<0.2	<0.1	336.0	31	41	0.8	<0.7	638
181	85804	13N	1E	4	70	M-B	9/89	*6.52*	452	115.9	39.5	55.6	0.5	<0.2	<0.1	243.3	233	47	0.2	2.08	806
182	85828	11N	1E	11	100	WR	9/89	*7.68*	258	69.3	20.6	21.9	0.5	1.2	<0.1	269.6	22	<1	0.2	<0.7	473
183	85848	11N	1W	10	45	WR	9/89	*7.79*	283	77.1	22.1	5.8	0.5	<0.2	<0.1	218.5	14	26	0.2	8.63	457
184	85878	12N	1W	19	79	M-BRS	9/89	*8.36*	367	85.0	37.7	8.1	0.6	<0.2	<0.1	316.6	6	43	0.2	<0.7	576
226	82131	12N	2W	26	44	DTR	6/90	*7.14*	368	95.4	31.6	7.4	0.6	2.3	<0.1	302.4	12	51	<1	<0.7	577
227	82130	12N	1W	35	210	WR	6/90	*7.44*	248	69.6	18.0	3.5	<1	<0.2	<0.1	219.8	3	15	<1	1.13	390
228	82123	11N	1W	2	180	WR	6/90	*7.18*	1	<2	<1	111.1	<1	<0.2	<0.1	245.7	5	8	<1	<0.7	432
229	82121	11N	1W	22	60	M-B	6/90	*6.83*	435	116.5	35.0	13.8	0.6	<0.2	<0.1	355.7	16	64	<1	3.39	703
230	82122	11N	1W	30	125	M-B	6/90	*7.34*	298	76.0	26.3	35.3	1.0	3.6	<0.1	376.2	6	<1	<1	<0.7	616
231	82128	12N	2W	8	92	DTR	6/90	*7.09*	348	88.9	30.6	16.6	<1	1.7	0.3	386.5	5	7	<1	<0.7	632
232	82129	12N	2W	7	188	BV	6/90	*7.20*	288	73.8	25.2	56.4	0.9	3.1	<0.1	369.5	39	<1	<1	<0.7	657
358	82136	13N	1E	25	102	M-B	8/90	*7.10*	312	83.5	25.2	4.9	<1	<0.2	<0.1	261.3	12	40	<1	4.07	508
OWEN COUNTY																					
115	86767	11N	2W	16	94	DTR	8/89	*7.80*	312	74.5	30.8	8.1	0.5	0.3	<0.1	290.8	3	15	0.2	<0.7	495
116	86792	11N	2W	16	125	M-B	8/89	*7.69*	251	67.2	20.4	57.1	1.0	<0.2	0.2	322.4	24	4	0.3	<0.7	576
117	85774	12N	3W	35	185	M-BRS	8/89	*8.41*	47	8.9	6.0	177.8	4.1	<0.2	<0.1	356.6	47	14	3.0	<0.7	700
128	85784	12N	4W	27	130	M-BRS	8/89	*7.86*	193	40.2	22.6	13.9	0.9	<0.2	<0.1	201.3	1	7	0.6	<0.7	339
129	85779	12N	4W	23	160	M-BRS	8/89	*7.75*	378	105.7	27.9	9.4	0.5	1.6	<0.1	335.6	4	25	0.2	<0.7	593
130	85799	12N	5W	35	152	P-RC	8/89	*7.80*	145	28.5	18.0	71.6	2.5	0.3	<0.1	235.2	38	1	1.0	<0.7	455
159	176187	9N	4W	16	265	M-BSW	8/89	*8.05*	192	36.6	24.5	19.2	0.9	0.2	<0.1	202.1	1	15	1.7	<0.7	358
160	85874	9N	4W	18	84	M-BSW	8/89	*7.37*	250	59.8	24.4	14.5	0.2	3.5	0.1	266.6	3	2	0.4	<0.7	440
165	85864	9N	6W	12	100	P-RC	8/89	*7.82*	139	35.7	12.2	110.9	1.0	0.2	<0.1	338.0	7	15	0.6	<0.7	600
177	86802	10N	5W	33	100	P-RC	8/89	*6.78*	543	134.7	50.2	103.2	3.1	0.4	<0.1	383.4	8	364	0.2	<0.7	1140
178	86797	10N	4W	29	225	P-RC	8/89	*7.31*	361	46.9	59.4	12.6	1.1	<0.2	<0.1	282.7	3	85	0.2	<0.7	561
187	85769	12N	3W	28	125	M-BRS	9/89	*6.89*	308	80.2	26.2	25.8	0.6	2.4	<0.1	341.7	17	4	0.3	<0.7	582
190	85853	11N	4W	1	120	M-BSW	9/89	*7.52*	421	104.2	39.2	34.0	0.7	2.3	<0.1	420.2	7	72	0.4	<0.7	779
191	85858	11N	4W	30	185	P-RC	9/89	*6.92*	137	35.3	11.8	40.2	1.1	<0.2	<0.1	205.1	3	13	0.3	<0.7	363
201	85879	9N	3W	32	245	M-BSW	9/89	*6.86*	743	188.2	66.5	5.8	0.9	0.8	<0.1	195.0	3	580	2.0	<0.7	1100
203	85770	9N	3W	2	145	M-BRS	9/89	*6.94*	374	97.2	32.0	10.6	0.4	3.5	0.1	394.6	4	16	0.2	<0.7	651
233	82127	12N	3W	19	80	M-BRS	6/90	*6.47*	165	48.0	10.9	10.5	<1	<0.2	<0.1	136.0	7	30	<1	1.81	290
234	82109	10N	4W	11	80	M-BRS	6/90	*7.24*	475	106.4	51.0	7.4	0.9	2.1	<0.1	233.1	<1	241	1.6	<0.7	704
235	82110	10N	4W	26	217	M-BSW	6/90	*7.44*	214	48.5	22.7	2.2	0.6	<0.2	<0.1	156.3	<1	59	1.2	<0.7	334
243	82120	11N	4W	17	247	P-RC	6/90	*7.34*	232	61.9	18.8	25.5	1.5	<0.2	<0.1	234.3	3	29	<1	<0.7	432
250	82108	10N	5W	22	95	P-RC	6/90	*6.80*	424	108.7	37.2	31.8	1.4	0.6	0.2	349.2	12	111	<1	<0.7	736
251	215241	10N	3W	29	77	WR	6/90	*6.95*	419	115.2	32.0	19.8	1.1	<0.2	<0.1	334.2	32	53	<1	0.90	674
252	82111	10N	4W	1	125	M-BRS	6/90	*7.25*	279	62.6	29.9	6.4	0.6	0.6	<0.1	233.1	<1	40	1.9	<0.7	434

Location Number	IDNR/DOW Well ID Number	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Total Hardness	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	NO_3 as N	Total Dissolved Solids[3]
PARKE COUNTY																					
145	86652	14N	6W	36	80	P-RC	8/89	*7.19*	216	52.5	20.6	10.8	0.4	0.8	<0.1	218.5	3	6	0.2	<0.7	370
PIKE COUNTY																					
278	82048	1N	9W	19	58	P-M	7/90	*7.42*	306	72.8	30.2	29.1	0.9	0.7	<0.1	350.2	1	3	<1	<0.7	576
279	82045	1S	9W	11	360	P-M	7/90	*8.84*	5	<2	0.5	243.5	0.9	<0.2	<0.1	538.6	11	7	1.4	<0.7	903
280	82044	1S	9W	14	70	P-M	7/90	*6.60*	309	68.6	33.4	56.4	1.0	<0.2	0.1	406.9	10	12	2.0	<0.7	690
281	82043	1S	9W	2	50	P-M	7/90	*7.65*	6	<2	0.6	187.9	0.6	<0.2	<0.1	278.2	24	52	<1	19.88	701
282	82051	1N	8W	35	50	P-C	7/90	*6.63*	301	71.9	29.6	21.3	0.7	0.7	0.5	186.6	46	82	<1	<0.7	493
323	82052	1N	8W	21	97	WR	7/90	*5.87*	355	97.5	27.1	4.8	0.7	1.3	0.3	257.1	14	57	<1	<0.7	523
PUTNAM COUNTY																					
132	85789	12N	5W	15	140	P-RC	8/89	*7.94*	155	35.5	16.2	61.1	2.8	0.2	0.1	259.2	14	<1	0.8	<0.7	453
142	86811	13N	2W	18	65	M-B	8/89	*7.42*	433	111.2	37.8	8.7	0.6	0.8	0.3	388.6	9	20	0.3	<0.7	674
146	86647	14N	5W	19	190	P-RC	8/89	*7.63*	321	82.9	27.8	7.6	0.5	1.5	<0.1	302.0	2	9	0.2	<0.7	512
147	85834	15N	5W	35	94	M-BRS	8/89	*7.65*	374	94.7	33.4	5.9	0.6	1.1	<0.1	345.4	4	24	0.3	<0.7	594
148	85839	15N	5W	13	125	M-BRS	8/89	*7.75*	362	88.3	34.5	6.6	0.5	3.3	<0.1	331.4	5	12	0.3	<0.7	561
149	85844	15N	5W	8	70	P-RC	8/89	*7.46*	465	121.4	39.4	24.2	0.7	<0.2	<0.1	352.6	38	73	0.2	5.56	761
150	85849	15N	4W	16	83	M-BRS	8/89	*7.75*	339	80.7	33.6	4.5	0.7	0.4	<0.1	304.6	5	18	0.3	<0.7	522
151	85854	15N	3W	2	106	DTR	8/89	*7.71*	331	81.5	31.2	15.1	0.8	3.2	<0.1	361.0	2	<1	0.6	<0.7	586
152	85798	16N	3W	14	90	M-B	8/89	*7.65*	400	94.8	39.8	11.3	0.7	1.7	<0.1	393.7	5	1	0.8	<0.7	647
153	175254	15N	3W	14	161	M-B	8/89	*7.79*	355	91.8	30.6	22.9	0.7	3.8	<0.1	393.5	2	<1	0.7	<0.7	642
154	86751	14N	3W	1	65	M-B	8/89	*7.76*	376	96.0	33.2	8.6	0.5	4.7	0.2	368.2	6	6	0.4	<0.7	614
155	86756	14N	3W	33	65	M-BRS	8/89	*7.72*	397	100.0	36.0	8.5	0.5	2.9	0.2	362.3	22	13	0.4	<0.7	633
156	86642	14N	4W	35	90	M-BRS	8/89	*7.59*	370	92.6	33.8	7.9	0.4	2.1	<0.1	359.0	2	11	0.3	<0.7	596
157	86816	13N	4W	24	92	M-BRS	8/89	*7.76*	263	63.7	25.4	8.0	0.4	0.9	<0.1	254.0	2	8	0.3	<0.7	424
185	86796	13N	5W	36	103	M-BRS	9/89	*6.79*	363	98.6	28.4	18.5	0.4	0.5	<0.1	339.1	8	44	0.2	<0.7	621
186	86742	12N	3W	8	110	M-BRS	9/89	*6.98*	333	77.5	33.8	18.4	0.4	0.6	<0.1	351.2	17	<1	0.3	<0.7	584
188	86821	13N	5W	27	90	P-RC	9/89	*5.29*	45	11.0	4.3	4.8	0.4	<0.2	0.3	2.6	4	44	0.1	0.86	87
221	82135	13N	4W	1	50	M-BRS	6/90	*7.34*	312	84.2	24.8	5.1	<1	<0.2	<0.1	285.8	7	27	<1	1.13	507
223	82157	15N	3W	34	40	M-B	6/90	*6.80*	344	92.8	27.4	5.0	<1	0.6	0.4	336.1	3	10	<1	<0.7	559
352	82134	13N	5W	34	180	WR	7/90	*6.73*	112	30.7	8.6	2.7	<1	1.0	<0.1	113.9	2	<1	<1	<0.7	188
353	82138	14N	5W	14	145	M-BRS	7/90	*7.31*	87	14.7	12.2	121.7	4.5	<0.2	<0.1	315.2	32	10	<1	<0.7	584
354	82137	14N	5W	14	103	M-BRS	7/90	*6.19*	285	61.6	31.9	17.8	0.6	2.2	<0.1	319.7	6	10	<1	<0.7	527
355	82139	14N	4W	3	145	DTR	7/90	*7.00*	447	113.2	40.0	23.8	0.8	4.0	<0.1	424.6	36	55	<1	<0.7	799
RANDOLPH COUNTY																					
5	86582	19N	12E	27	66	TTP	7/89	*7.32*	345	73.8	39.1	15.0	1.0	2.2	<0.1	391.4	3	22	0.5	<0.7	658
6	86547	20N	12E	9	139	SD	7/89	*7.23*	430	102.3	42.5	9.2	1.0	2.0	<0.1	405.7	10	28	0.4	<0.7	705
7	86542	20N	12E	20	84	TTP	7/89	*7.08*	392	99.5	35.1	4.7	0.8	1.9	<0.1	350.8	5	48	0.2	<0.7	633
8	86572	19N	13E	18	45	TTP	7/89	*7.21*	356	89.3	32.3	5.1	0.7	1.4	<0.1	330.7	4	29	0.2	<0.7	575
9	86577	19N	13E	10	50	TTP	7/89	*7.15*	392	95.5	37.4	5.0	0.7	2.2	<0.1	333.7	8	53	0.3	<0.7	619

Location Number	IDNR/DOW Well ID Number	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Total Hardness	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	NO_3 as N	Total Dissolved Solids[3]
RANDOLPH COUNTY continued																					
10	86567	19N	14E	17	83	TTP	7/89	*7.48*	340	75.5	36.9	18.7	1.0	2.0	<0.1	386.4	<1	10	0.5	<0.7	635
12	86537	20N	13E	29	101	SD	7/89	*7.13*	396	97.0	37.4	25.0	0.9	<0.2	<0.1	311.7	70	68	0.1	0.70	687
30	86527	20N	15E	31	160	SD	7/89	*7.48*	310	72.7	31.3	14.1	0.9	2.2	<0.1	368.5	2	<1	0.7	<0.7	588
31	86532	20N	14E	12	45	TTPS	7/89	*6.98*	470	87.8	61.0	22.2	1.7	<0.2	<0.1	459.6	6	103	0.7	<0.7	870
328	82200	20N	15E	20	98	TTP	7/90	*6.58*	288	66.8	29.5	13.9	0.8	1.5	<0.1	354.3	<!	<1	1.4	<0.7	560
329	82199	20N	14E	33	306	SD	7/90	*7.31*	249	40.1	36.2	42.8	1.1	0.6	<0.1	299.0	24	8	1.1	<0.7	523
330	82191	19N	14E	27	221	SD	7/90	*6.47*	348	87.1	31.8	20.8	1.0	1.2	<0.1	389.2	4	24	1.3	<0.7	659
331	82192	19N	14E	8	204	TTP	7/90	*6.88*	308	68.2	33.4	30.2	0.9	1.9	<0.1	357.8	3	9	1.1	<0.7	593
332	82197	20N	13E	33	39	TTP	7/90	*6.86*	462	120.1	39.5	7.0	1.0	1.2	0.1	301.0	49	92	<1	<0.7	683
333	82198	20N	13E	19	91	SD	7/90	*6.68*	355	86.9	33.7	4.3	0.6	1.6	<0.1	313.2	3	53	<1	<0.7	574
334	82196	20N	12E	34	118	TTP	7/90	*7.01*	357	88.3	33.3	6.7	0.7	1.3	<0.1	345.6	<1	17	<1	<0.7	581
TIPTON COUNTY																					
49	86502	22N	5E	27	92	TTP	7/89	*7.61*	336	98.8	21.8	24.0	1.0	1.5	<0.1	408.7	2	14	0.5	<0.7	673
50	86522	21N	3E	21	243	SD	7/89	*7.66*	287	71.6	26.3	25.0	0.8	1.1	<0.1	359.7	2	<1	1.1	<0.7	578
344	82201	21N	3E	6	182	TTP	7/90	*6.56*	262	63.4	25.2	30.0	0.8	0.9	<0.1	321.8	2	<1	1.4	<0.7	528
345	82202	21N	4E	23	135	TTP	7/90	*6.21*	314	83.0	26.0	21.0	<1	1.1	<0.1	391.5	3	9	<1	<0.7	632
346	82203	21N	5E	33	98	TTP	7/90	*6.98*	237	49.0	28.0	28.0	1.9	3.2	<0.1	359.0	3	<1	<1	<0.7	558
347	82205	22N	6E	17	100	SD	7/90	*7.10*	330	82.9	30.0	6.5	0.8	2.0	<0.1	348.1	6	5	1.2	<0.7	568

[1] Results in standard pH units.

[2] Laboratory analysis.

[3] TDS values are the sum of major constituents expected in an anhydrous residue of a ground-water sample with bicarbonate converted to carbonate in the solid phase.

Appendix 2. Results of chemical analysis for strontium and zinc. (All values in milligrams per liter)

Location number	Strontium	Zinc
BOONE COUNTY		
51	1.6	<0.1
52	0.7	<0.1
53	3.8	0.1
54	1.5	<0.1
55	0.6	<0.1
56	2.1	<0.1
57	3.8	<0.1
67	0.4	<0.1
BROWN COUNTY		
133	0.3	<0.1
134	0.4	<0.1
CLAY COUNTY		
131	0.3	0.2
143	<0.1	<0.1
144	0.2	0.1
166	<0.1	<0.1
169	0.4	0.1
170	0.4	0.1
171	0.2	0.1
172	0.5	<0.1
173	0.2	0.2
174	0.1	<0.1
175	0.4	0.1
176	0.1	<0.1
189	0.3	0.6
238	0.1	<0.1
239	0.7	<0.1
240	0.2	<0.1
241	0.1	<0.1
242	0.1	<0.1
244	0.5	<0.1
245	0.3	<0.1
246	<0.1	<0.1
247	<0.1	<0.1
248	0.4	<0.1
249	<0.1	<0.1
253	<0.1	<0.1
351	0.5	0.1
DAVIESS COUNTY		
302	0.6	0.6
303	0.3	<0.1
304	<0.1	<0.1
305	0.3	<0.1
306	<0.1	<0.1
307	0.1	<0.1
310	<0.1	<0.1
311	<0.1	<0.1
312	0.1	<0.1
313	0.2	<0.1
314	0.3	<0.1
315	0.2	<0.1
316	0.4	0.1
317	0.1	<0.1
318	0.5	<0.1
319	0.4	<0.1
320	0.1	<0.1
321	0.6	0.4
322	0.1	<0.1
324	0.1	0.1
325	0.1	<0.1
DELAWARE COUNTY		
1	4.5	<0.1
2	1.1	<0.1
3	0.2	<0.1
4	0.1	<0.1
11	0.7	<0.1
13	3	<0.1
14	1.2	<0.1
19	0.2	<0.1
24	1.5	0.1
27	1.9	<0.1
33	0.5	<0.1
326	2.7	0.3
327	0.5	<0.1
335	0.3	<0.1
336	<0.1	<0.1
340	0.2	<0.1
342	0.5	<0.1
343	1	<0.1
GIBSON COUNTY		
276	0.2	0.3
277	0.2	0.1
GREENE COUNTY		
120	14.9	<0.1
121	0.1	<0.1
122	0.2	<0.1
123	0.3	<0.1
124	0.3	<0.1
125	0.1	0.1
126	0.3	0.1
127	0.1	0.1
161	0.2	<0.1
163	0.1	0.1
164	0.1	0.2
167	0.5	0.1
168	0.2	0.1
192	0.3	<0.1
193	0.2	<0.1
194	0.1	<0.1
195	0.1	<0.1
196	0.4	<0.1
197	0.1	<0.1
198	0.2	<0.1
199	<0.1	<0.1

Appendix 2. Results of chemical analysis for strontium and zinc continued.

Location number	Strontium	Zinc
GREENE COUNTY continued		
200	8.1	0.1
202	11.6	<0.1
204	3.6	0.1
254	0.4	<0.1
255	0.7	<0.1
256	0.2	<0.1
257	<0.1	<0.1
258	0.2	<0.1
301	0.4	0.1
HAMILTON COUNTY		
35	0.4	<0.1
39	1.1	<0.1
45	0.4	<0.1
46	0.3	<0.1
47	6.3	<0.1
48	0.6	0.2
205	0.8	<0.1
206	1.4	<0.1
207	1	<0.1
208	0.9	<0.1
209	2.1	<0.1
211	0.2	<0.1
215	0.7	<0.1
216	0.2	<0.1
217	0.2	<0.1
218	1.5	0.1
219	0.2	<0.1
220	0.8	<0.1
HANCOCK COUNTY		
101	0.7	<0.1
350	0.6	<0.1
HENDRICKS COUNTY		
64	2.3	<0.1
65	3.1	<0.1
66	0.8	<0.1
68	0.3	<0.1
69	0.6	<0.1
70	0.9	0.3
71	1.6	<0.1
72	0.1	0.1
73	0.1	<0.1
74	0.3	<0.1
75	0.5	<0.1
76	1.9	<0.1
77	0.2	<0.1
78	0.4	<0.1
79	1.7	<0.1
80	<0.1	<0.1
81	0.2	<0.1
82	0.9	<0.1
83	3.5	<0.1
137	0.3	<0.1
213	0.8	<0.1
214	2.3	<0.1
222	0.4	<0.1
224	0.7	<0.1
259	0.9	<0.1
260	0.9	<0.1
261	1	0.1
262	3.9	<0.1
263	2.3	<0.1
264	1	<0.1
265	4.2	<0.1
269	0.9	<0.1
356	0.2	<0.1
357	0.4	<0.1
HENRY COUNTY		
16	0.2	0.1
17	1	<0.1
18	1.2	<0.1
22	0.9	<0.1
32	0.1	<0.1
337	0.4	<0.1
339	0.8	<0.1
JOHNSON COUNTY		
92	0.9	<0.1
93	1.1	<0.1
94	0.2	<0.1
102	0.2	<0.1
103	0.1	<0.1
104	0.6	<0.1
110	0.3	<0.1
111	0.3	<0.1
112	0.4	<0.1
359	1.4	<0.1
360	3.6	0.3
361	1.3	<0.1
KNOX COUNTY		
274	0.1	<0.1
275	<0.1	<0.1
283	0.2	<0.1
284	0.3	0.7
285	0.4	0.1
286	0.2	<0.1
287	0.9	0.8
288	<0.1	0.1
289	0.3	<0.1
290	0.1	<0.1
291	0.1	<0.1
292	0.3	<0.1
293	0.2	<0.1
294	0.3	0.1
295	0.3	<0.1
296	<0.1	<0.1

Appendix 2. Results of chemical analysis for strontium and zinc continued.

Location number	Strontium	Zinc
KNOX COUNTY continued		
297	0.1	<0.1
298	0.3	0.1
299	0.1	<0.1
300	0.1	0.1
MADISON COUNTY		
15	0.6	<0.1
20	0.3	<0.1
21	1	<0.1
23	0.3	<0.1
25	1.6	<0.1
26	2.7	<0.1
28	1.5	<0.1
29	2.7	<0.1
34	0.6	<0.1
36	0.1	<0.1
37	2.1	<0.1
38	2.3	<0.1
40	0.3	<0.1
41	0.3	0.1
338	1	0.1
341	0.1	<0.1
348	1.4	0.1
349	0.7	<0.1
MARION COUNTY		
42	0.9	<0.1
43	0.4	<0.1
44	0.9	<0.1
58	2.1	<0.1
59	0.3	<0.1
60	0.8	<0.1
61	0.2	<0.1
62	2.8	0.3
63	1.2	<0.1
95	0.2	<0.1
96	1	<0.1
97	1.5	<0.1
98	1.8	<0.1
99	0.9	<0.1
100	0.4	<0.1
210	2.4	<0.1
212	1.2	<0.1
270	1	<0.1
271	0.4	<0.1
272	1.6	<0.1
273	0.3	<0.1
362	0.3	<0.1
363	<0.1	<0.1
364	0.2	<0.1
365	0.2	<0.1
366	1.1	<0.1
367	0.3	<0.1
368	1.4	<0.1
369	1.3	<0.1
370	0.8	<0.1
371	0.4	<0.1
372	0.6	<0.1
MARTIN COUNTY		
308	0.1	0.1
309	<0.1	<0.1
MONROE COUNTY		
119	2.8	0.1
135	8.4	0.1
136	49.8	<0.1
158	5.4	<0.1
162	15.3	<0.1
225	0.4	<0.1
236	0.4	<0.1
237	0.1	0.2
266	26.1	<0.1
267	35.6	<0.1
268	30	0.2
MORGAN COUNTY		
84	0.8	<0.1
85	0.3	<0.1
86	0.5	<0.1
87	<0.1	<0.1
88	0.2	<0.1
89	<0.1	<0.1
90	1.1	<0.1
91	0.8	<0.1
105	<0.1	<0.1
106	0.1	<0.1
107	0.1	<0.1
108	0.1	<0.1
109	0.1	<0.1
113	0.1	<0.1
114	0.4	<0.1
118	0.2	0.2
138	0.2	<0.1
139	1.8	<0.1
140	0.1	<0.1
141	0.2	<0.1
179	0.4	<0.1
180	1.1	<0.1
181	0.1	<0.1
182	0.2	<0.1
183	0.1	<0.1
184	0.1	<0.1
226	0.2	0.1
227	0.1	<0.1
228	<0.1	<0.1
229	0.2	<0.1
230	1	<0.1
231	0.2	<0.1

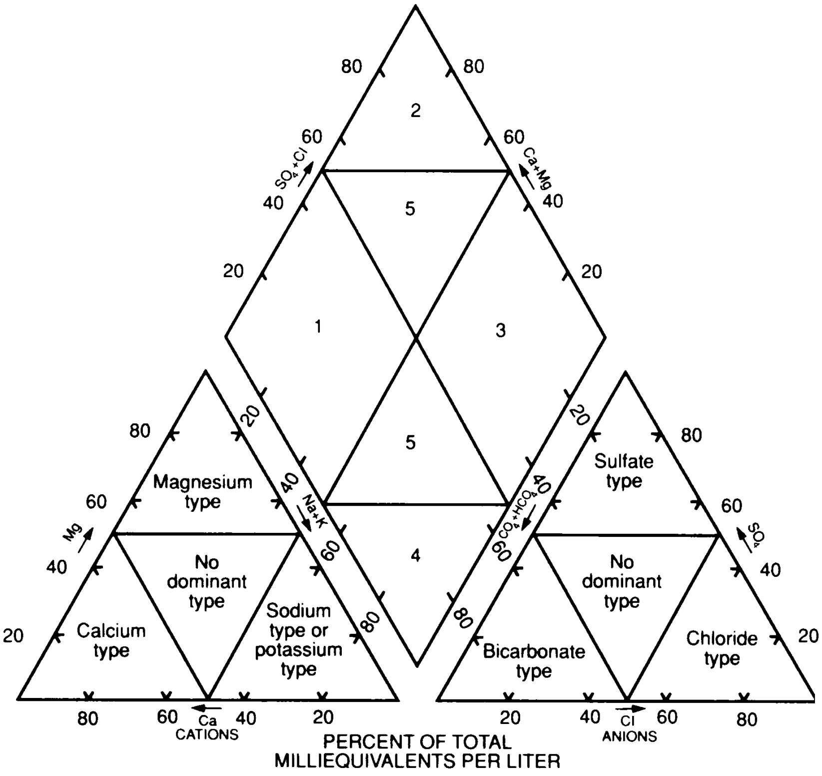
Appendix 2. Results of chemical analysis for strontium and zinc continued.

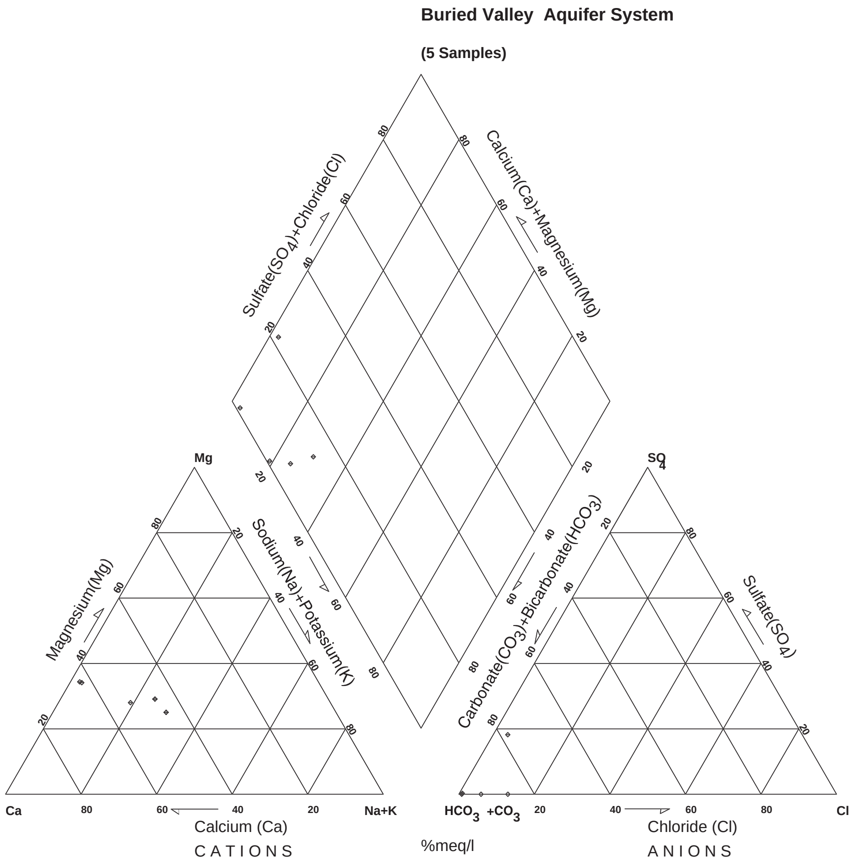
Location number	Strontium	Zinc
MORGAN COUNTY continued		
232	0.3	<0.1
358	0.1	<0.1
OWEN COUNTY		
115	0.2	<0.1
116	0.2	<0.1
117	0.3	<0.1
128	1.2	<0.1
129	0.2	<0.1
130	1.6	<0.1
159	6.6	<0.1
160	0.4	<0.1
165	0.2	<0.1
177	1.1	<0.1
178	1.4	<0.1
187	0.3	<0.1
190	0.5	<0.1
191	0.6	<0.1
201	10.5	0.1
203	0.5	<0.1
233	0.1	<0.1
234	4.5	<0.1
235	2.4	<0.1
243	1.2	<0.1
250	0.5	<0.1
251	0.3	<0.1
252	2.4	<0.1
PARKE COUNTY		
145	0.1	<0.1

Location number	Strontium	Zinc
PIKE COUNTY		
278	0.3	<0.1
279	<0.1	<0.1
280	0.5	0.1
281	<0.1	<0.1
282	0.1	<0.1
323	0.1	<0.1
PUTNAM COUNTY		
132	1.4	<0.1
142	0.3	0.1
146	0.1	<0.1
147	0.2	<0.1
148	0.4	<0.1
149	0.1	0.1
150	0.3	<0.1
151	1	0.2
152	0.4	0.2
153	1.3	<0.1
154	0.3	0.1
155	0.5	<0.1
156	0.3	<0.1
157	0.3	<0.1
185	0.3	<0.1
186	0.2	<0.1
188	<0.1	<0.1
221	0.1	<0.1
223	0.1	<0.1
352	0.1	<0.1
353	0.6	<0.1
354	0.9	<0.1
355	0.3	<0.1

Location number	Strontium	Zinc
RANDOLPH COUNTY		
5	14.5	<0.1
6	5.4	<0.1
7	0.9	<0.1
8	0.9	<0.1
9	0.4	<0.1
10	9.7	<0.1
12	0.5	<0.1
30	6.6	<0.1
31	17.9	0.2
328	5.5	<0.1
329	1.3	<0.1
330	6.8	<0.1
331	1.2	<0.1
332	1.2	<0.1
333	0.9	<0.1
334	2.1	<0.1
TIPTON COUNTY		
49	0.4	<0.1
50	2	<0.1
344	1.4	<0.1
345	0.4	<0.1
346	0.8	<0.1
347	1.3	<0.1

For additional data, including location information, see Appendix 1

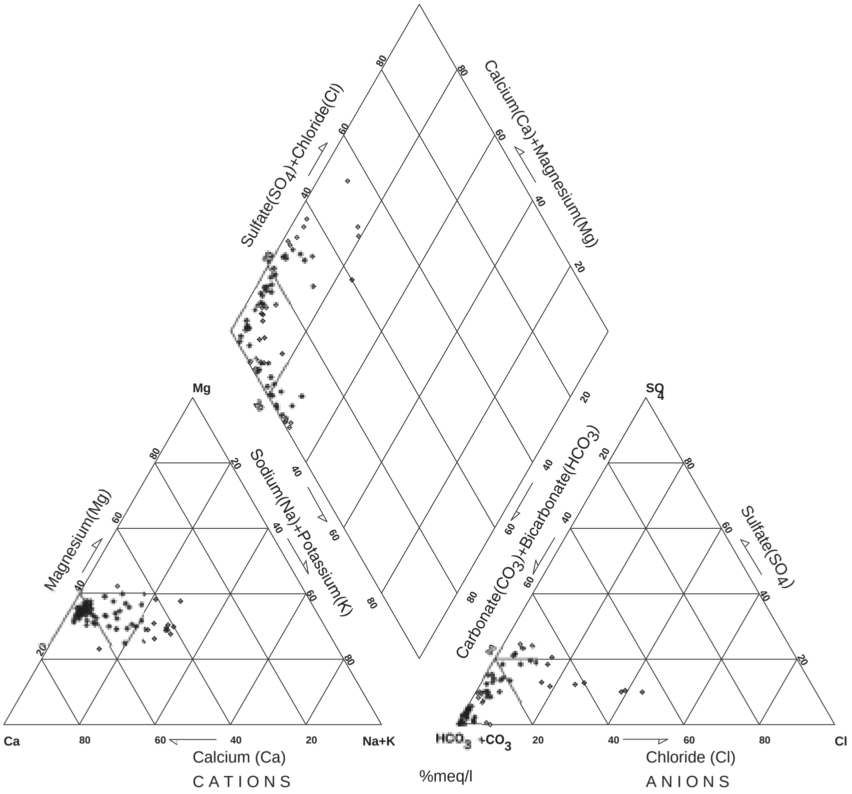




Appendix 3a. Piper trilinear diagrams of ground-water quality data for major unconsolidated aquifer systems

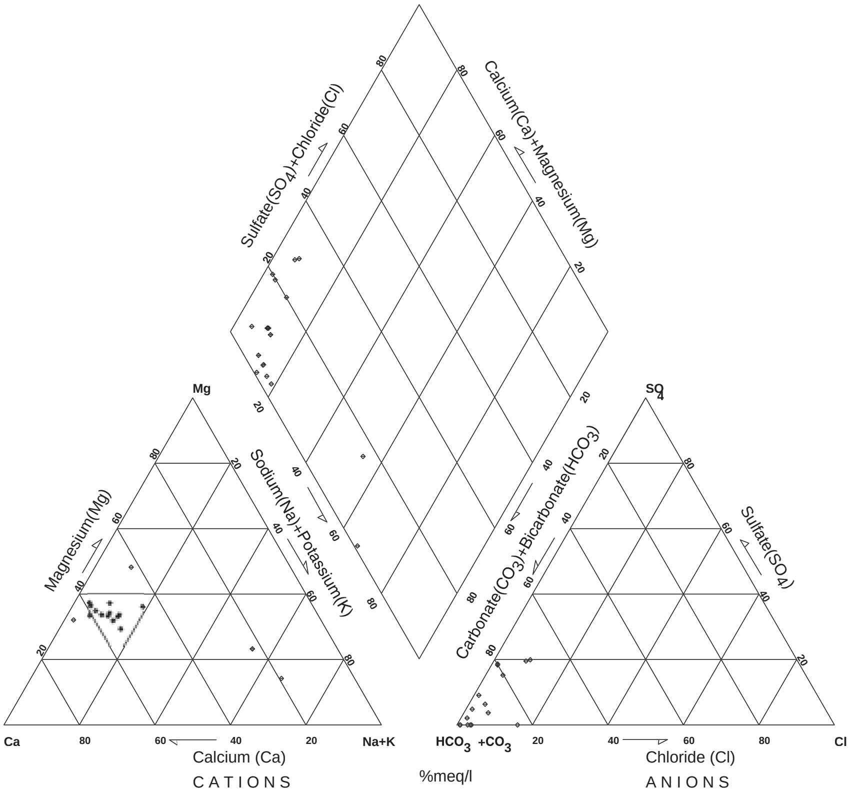
Tipton Tillplain Aquifer System

(75 Samples)



Tipton Tillplain Aquifer Subsystem

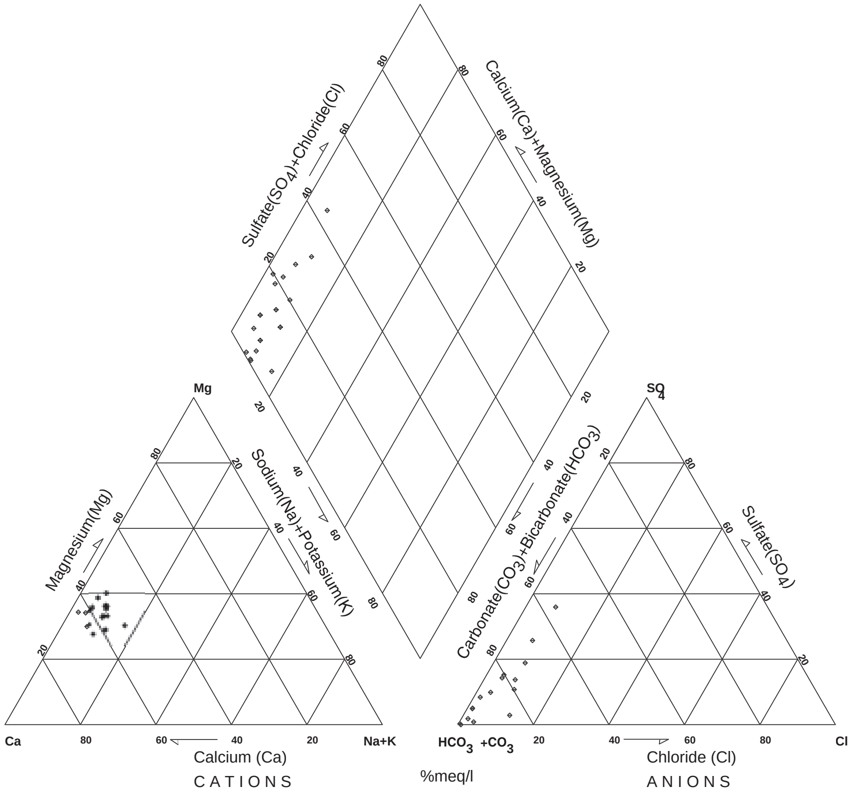
(17 Samples)



Appendix 3b. Piper trilinear diagrams of ground-water quality data for major unconsolidated aquifer systems

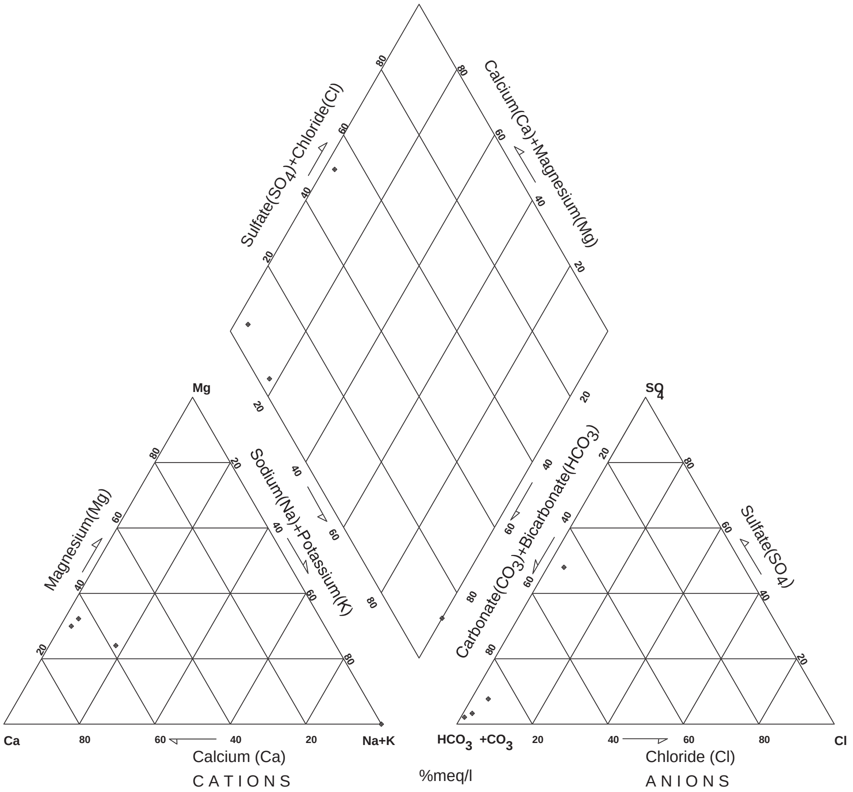
Dissected Till and Residuum Aquifer System

(17 Samples)



Lacustrine and Backwater Deposits Aquifer System

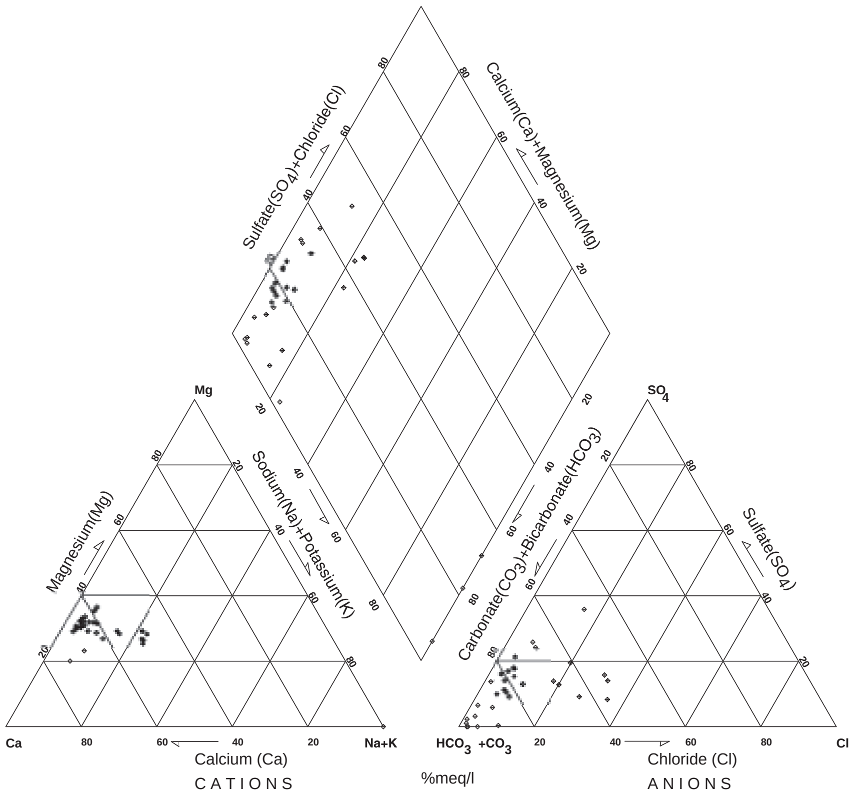
(4 Samples)



Appendix 3c. Piper trilinear diagrams of ground-water quality data for major unconsolidated aquifer systems

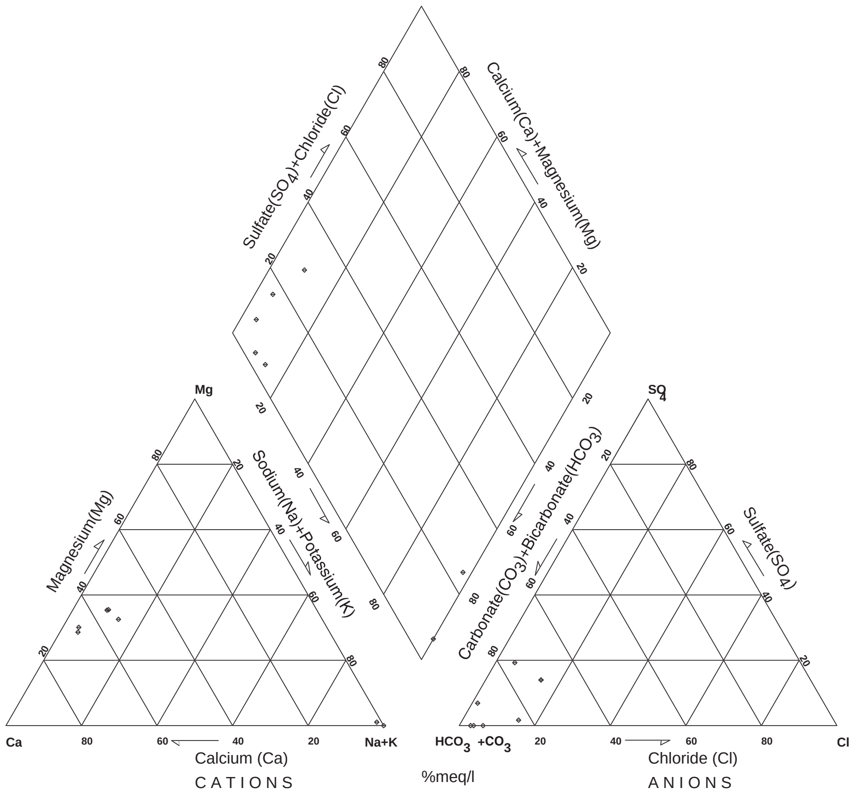
White River and Tributaries Outwash Aquifer System

(32 Samples)



White River and Tributaries Outwash Aquifer Subsystem

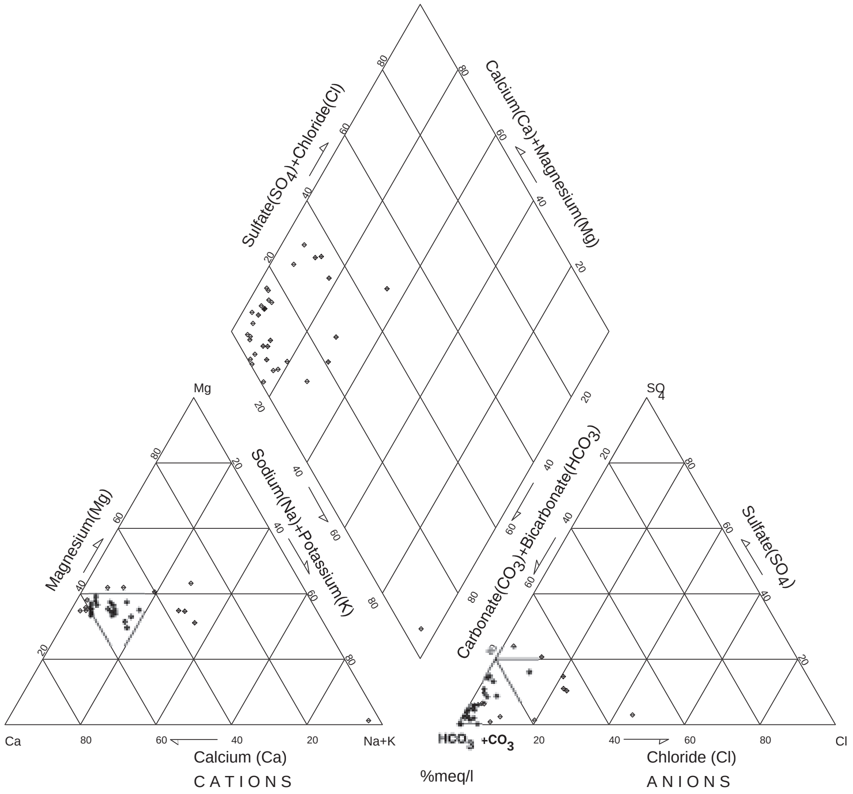
(7 Samples)



Appendix 3d. Piper trilinear diagrams of ground-water quality data for major unconsolidated aquifer systems

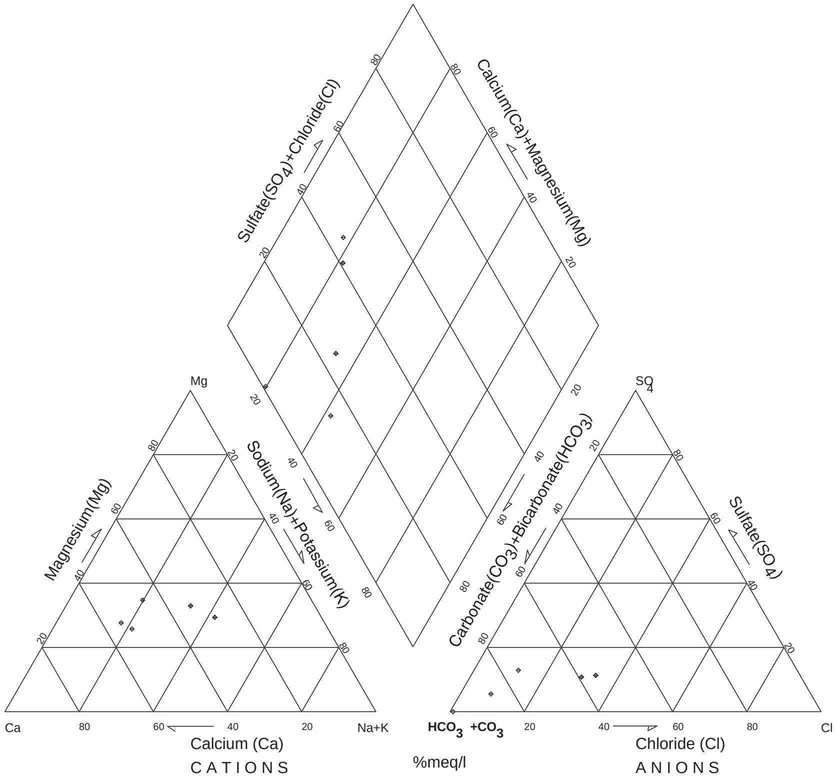
Silurian and Devonian Carbonates Aquifer System

(34 Samples)



Devonian & Mississippian--New Albany Shale Aquifer System

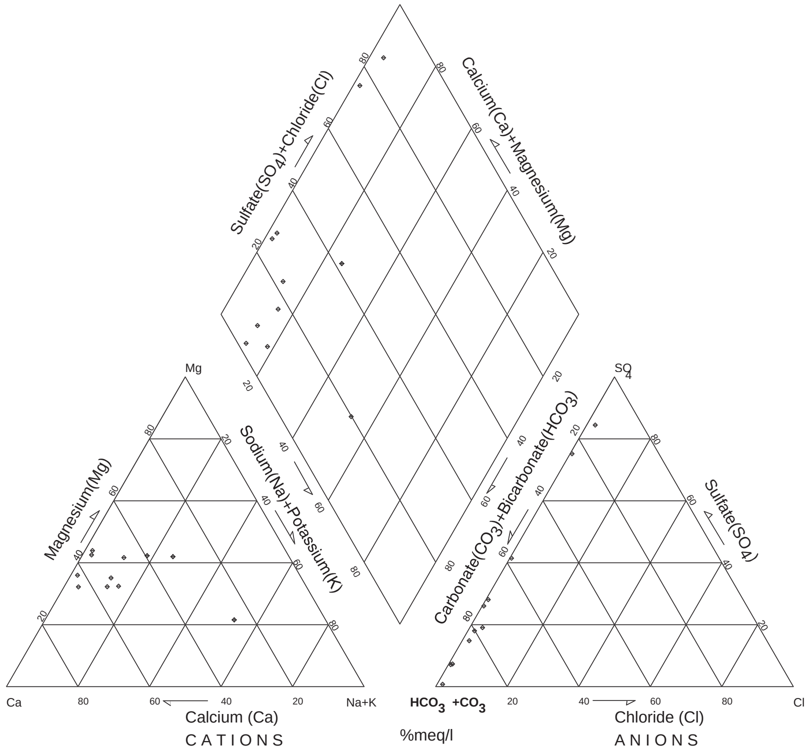
(5 Samples)



Appendix 3e. Piper trilinear diagrams of ground-water quality data for major unconsolidated aquifer systems

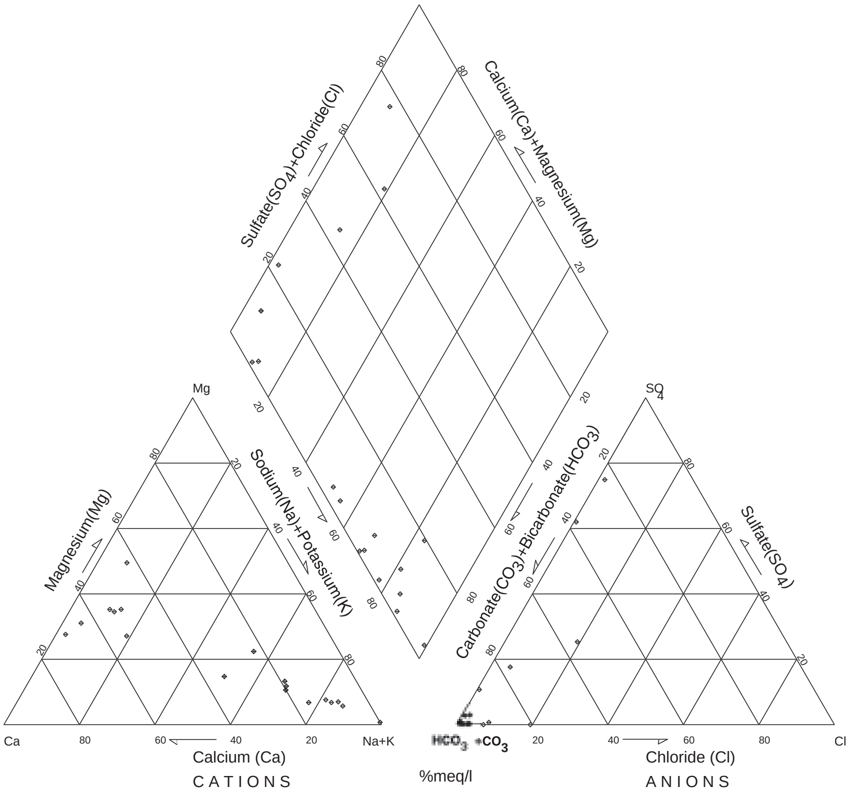
Mississippian--Buffalo Wallow, Stephensport, & W Baden Group Aquifer System

(11 Samples)



Pennsylvanian--Carbondale Group Aquifer System

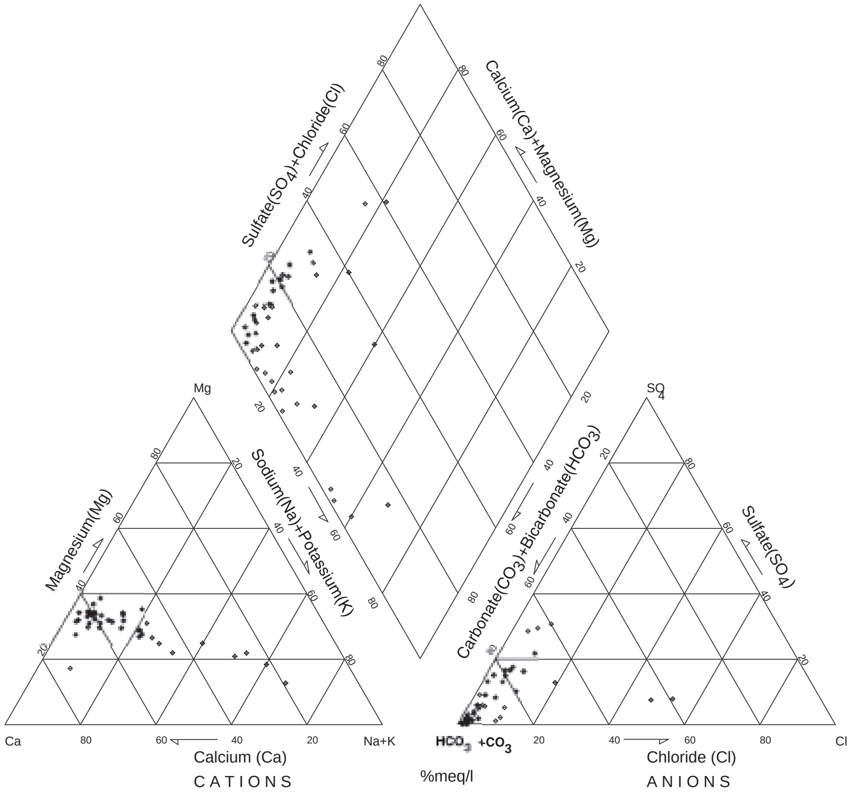
(18 Samples)



Appendix 3f. Piper trilinear diagrams of ground-water quality data for major unconsolidated aquifer systems

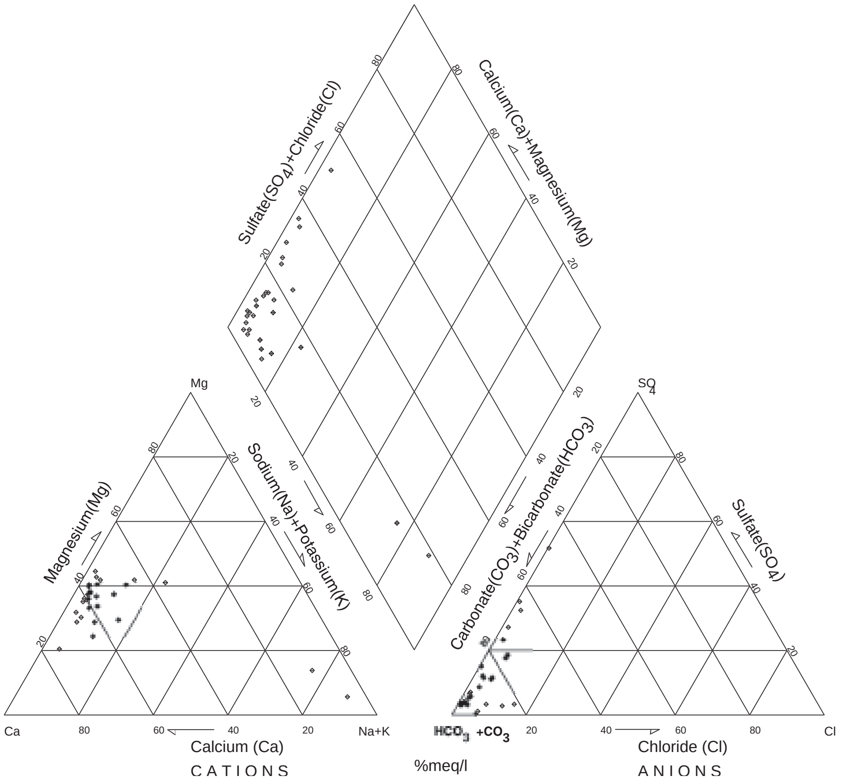
Mississippian--Borden Group Aquifer System

(44 Samples)

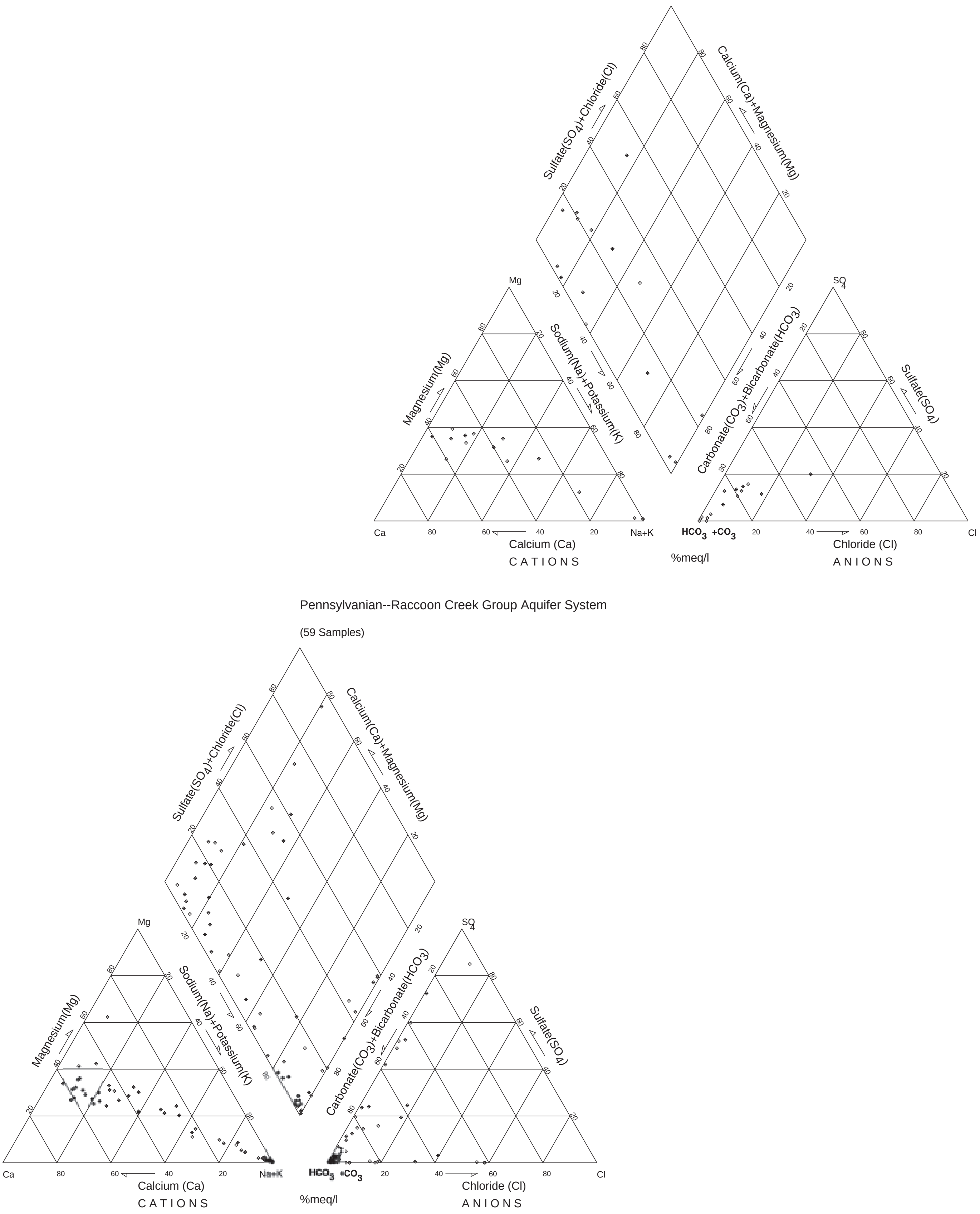


Mississippian--Blue River and Sanders Group Aquifer System

(29 Samples)



Appendix 3g. Piper trilinear diagrams of ground-water quality data for major unconsolidated aquifer systems

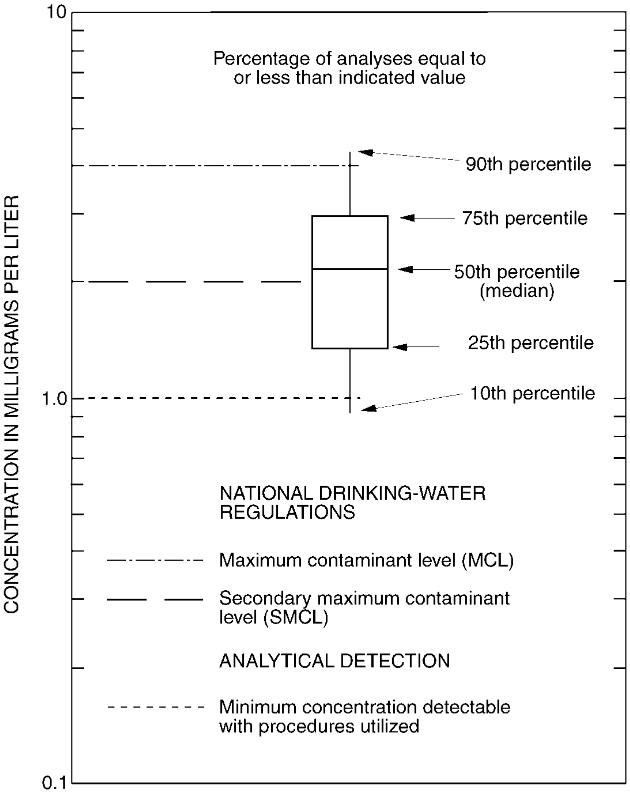

Pennsylvanian--McLeansboro Group Aquifer System

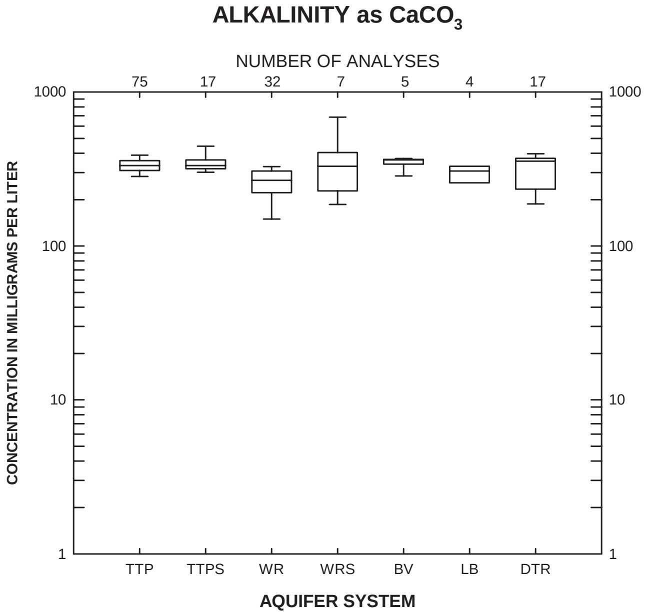
(15 Samples)

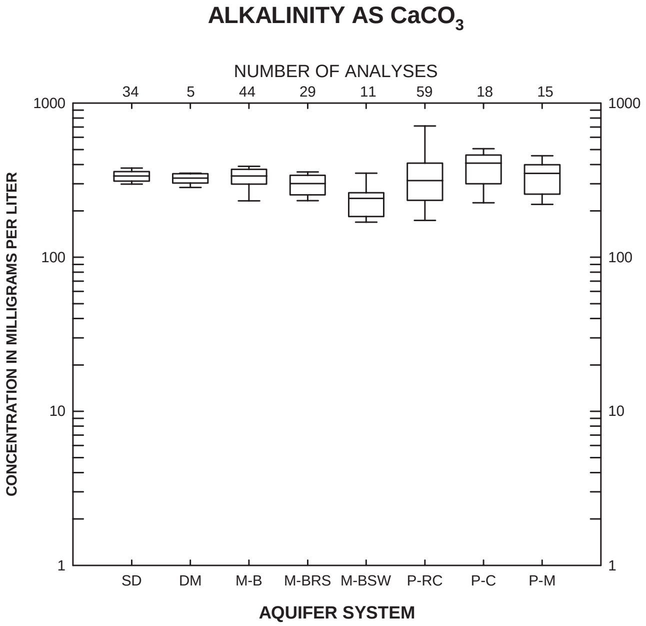
Pennsylvanian--Raccoon Creek Group Aquifer System

(59 Samples)

Appendix 3h. Piper trilinear diagrams of ground-water quality data for major unconsolidated aquifer systems



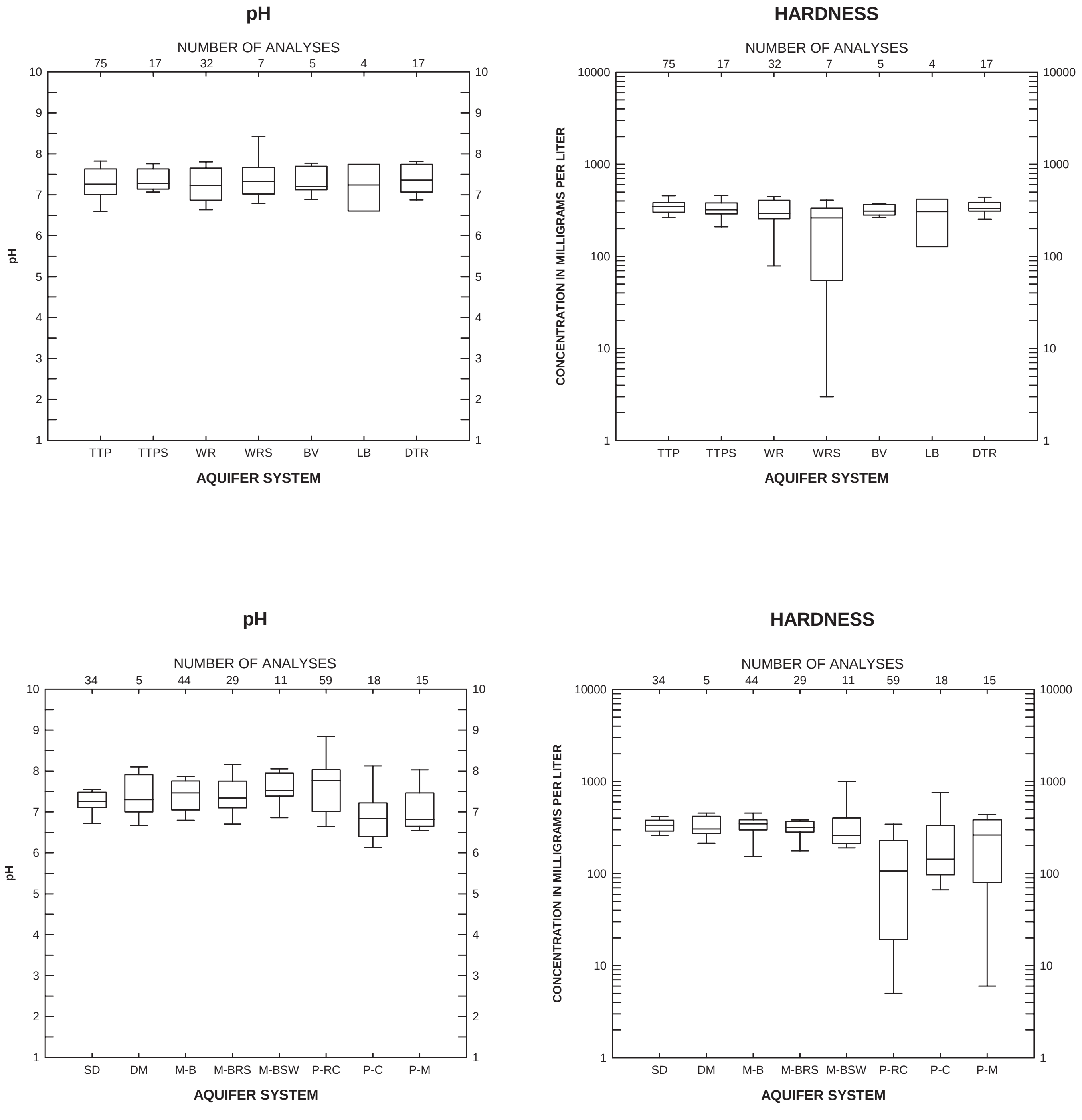

ALKALINITY as $CaCO_3$


ALKALINITY AS $CaCO_3$

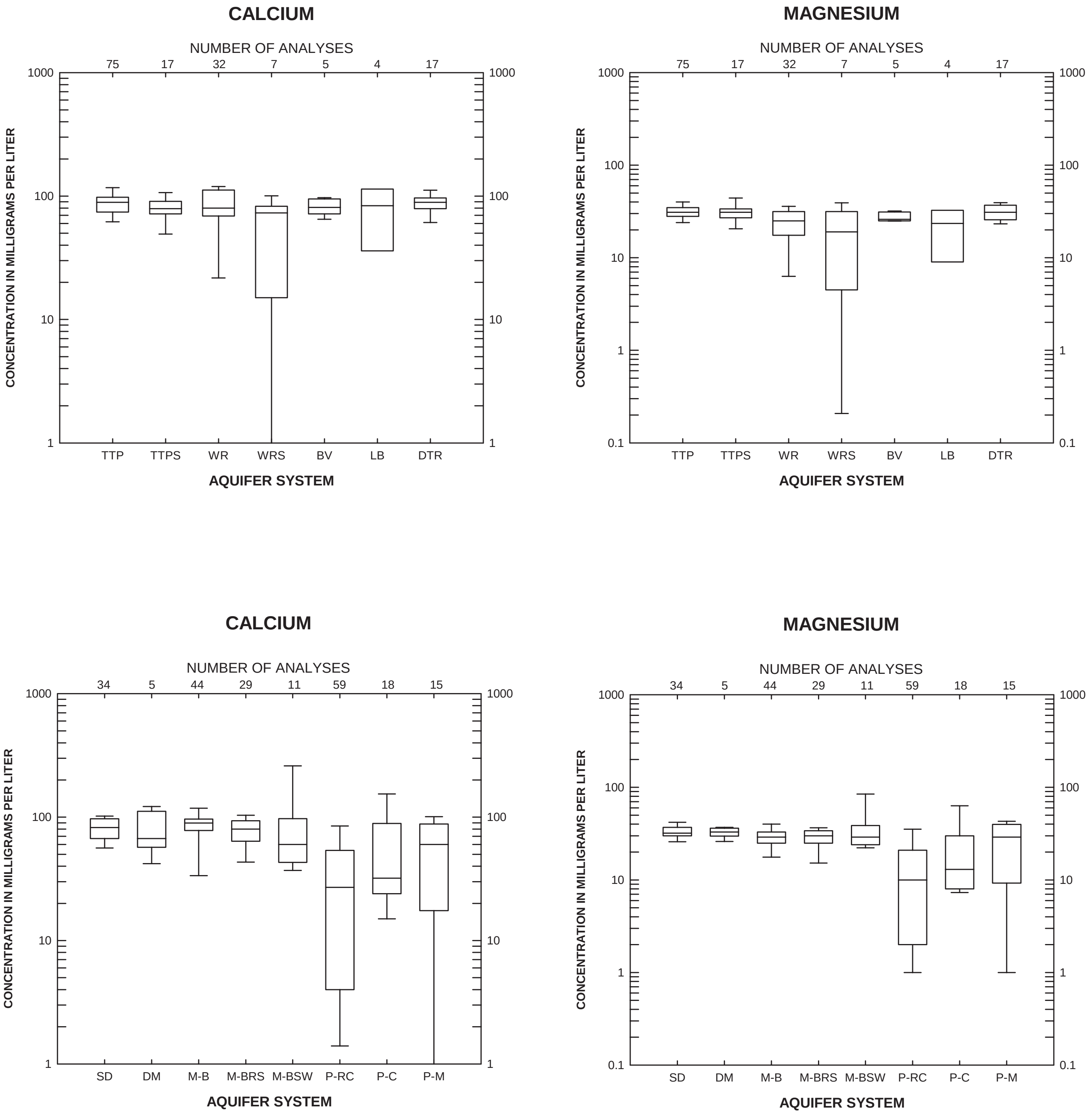
TTP	Tipton Till Plain
TTPS	Tipton Till Plain Subsystem
WR	White River Outwash
WRS	White River Subsystem
BV	Buried Valley
LB	Lacustrine and Backwater Deposits
DTR	Dissected Till and Residuum

SD	Silurian and Devonian Carbonates
DM	Devonian and Mississippian/New Albany Shale
M-B	Mississippian/Borden Group
M-BRS	Mississippian/Blue River and Sanders Groups
M-BSW	Mississippian/Buffalo Wallow, Stephensport, and West Baden Groups
P-RC	Pennsylvanian/Raccoon Creek Group
P-C	Pennsylvanian/Carbondale Group
P-M	Pennsylvanian/McLeansboro Group

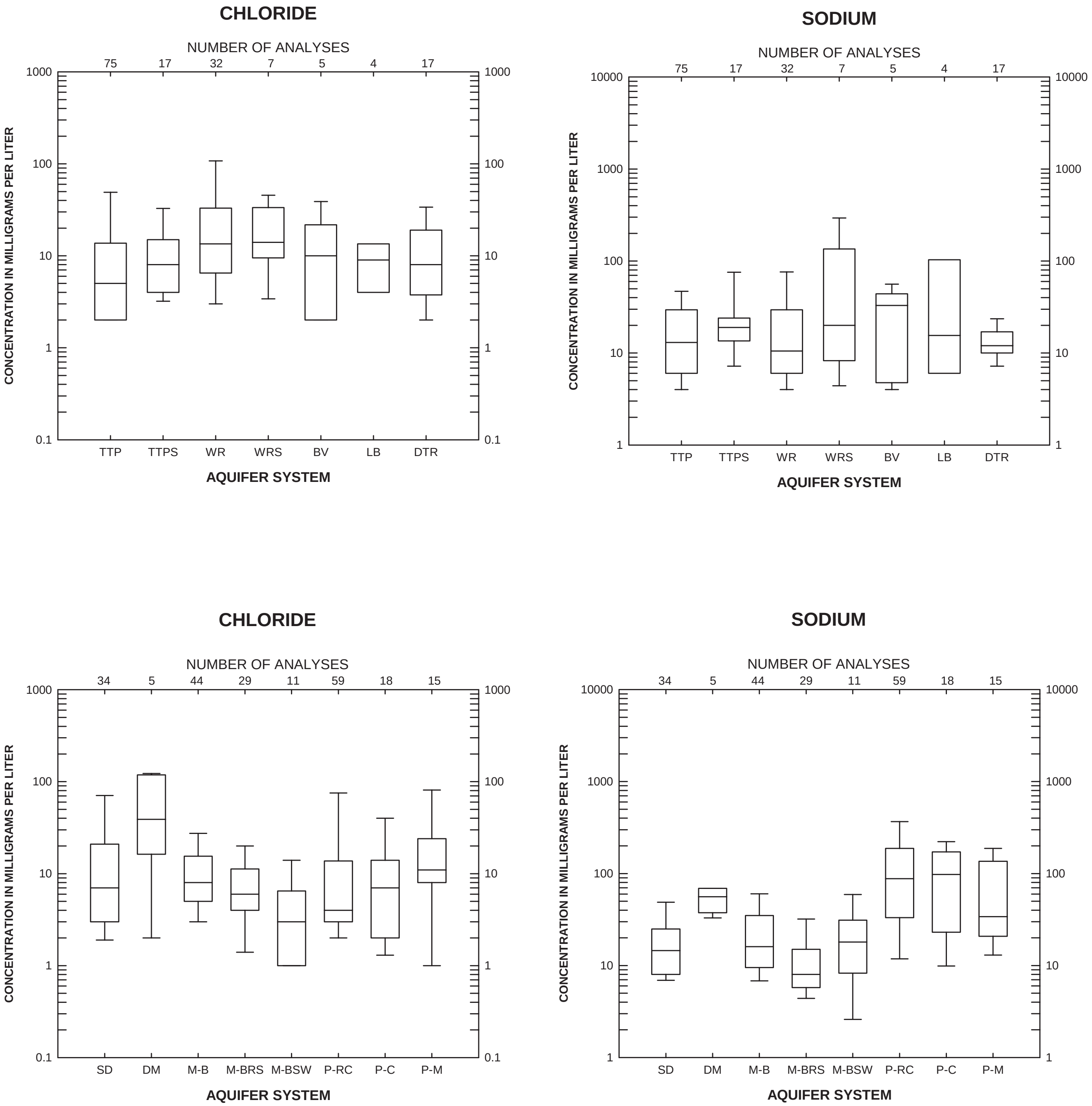
Appendix 4a. Statistical summary of selected water-quality constituents for aquifer systems



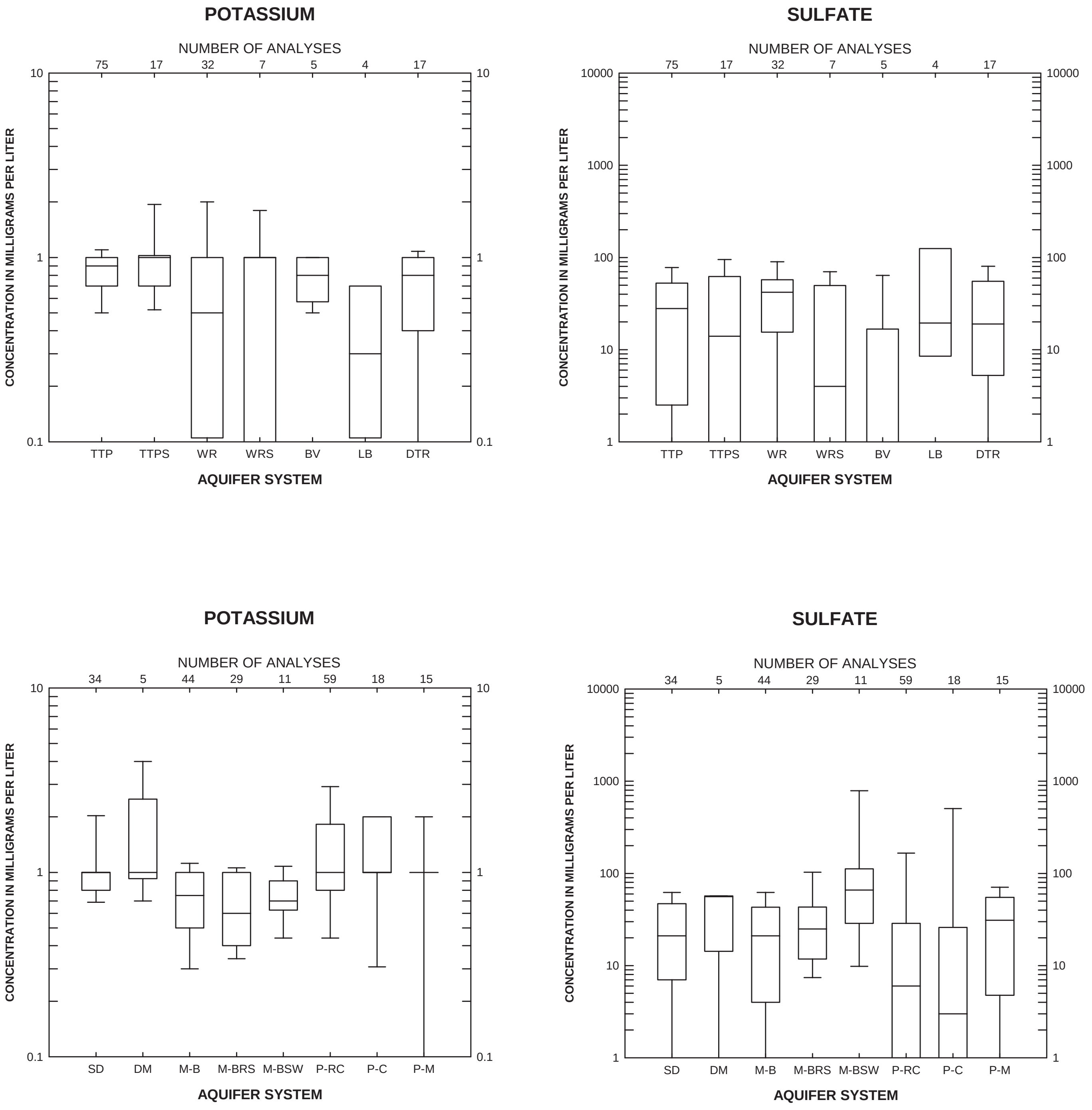
Appendix 4b. Statistical summary of selected water-quality constituents for aquifer systems



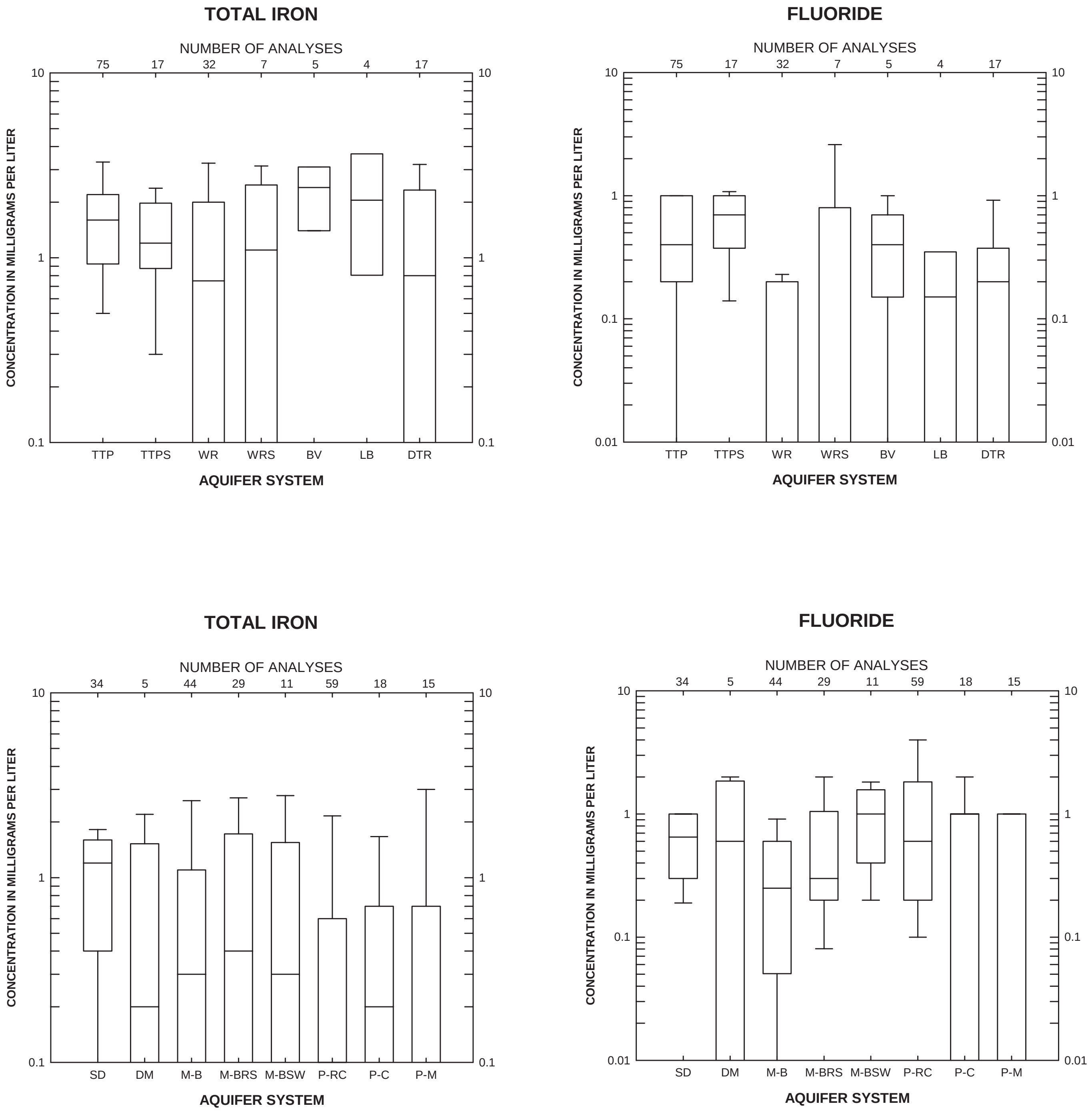
Appendix 4c. Statistical summary of selected water-quality constituents for aquifer systems



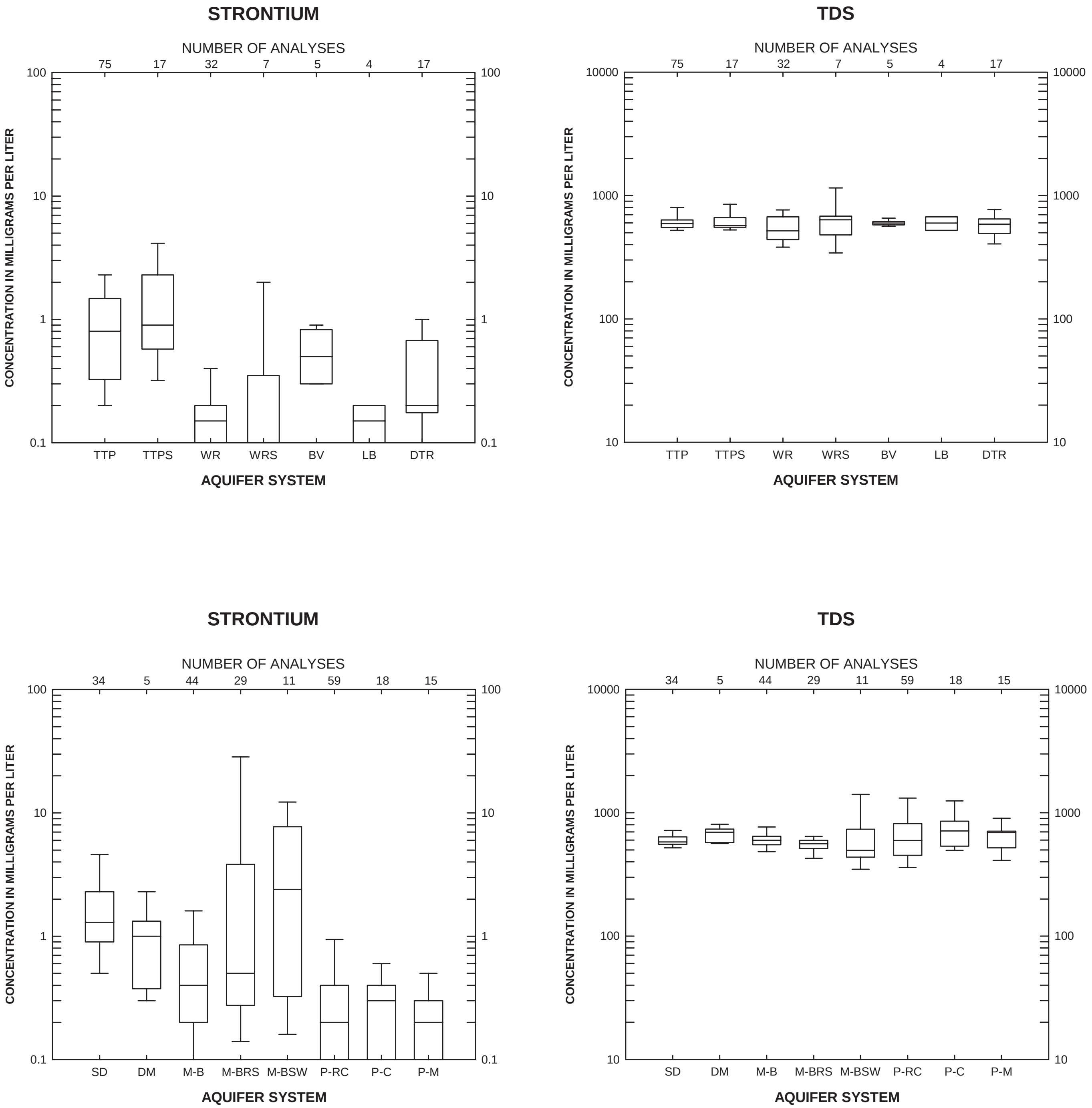
Appendix 4d. Statistical summary of selected water-quality constituents for aquifer systems



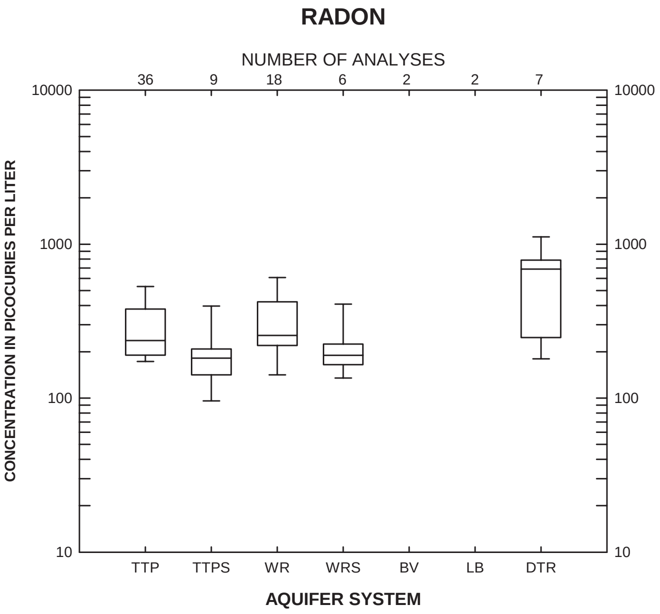
Appendix 4e. Statistical summary of selected water-quality constituents for aquifer systems

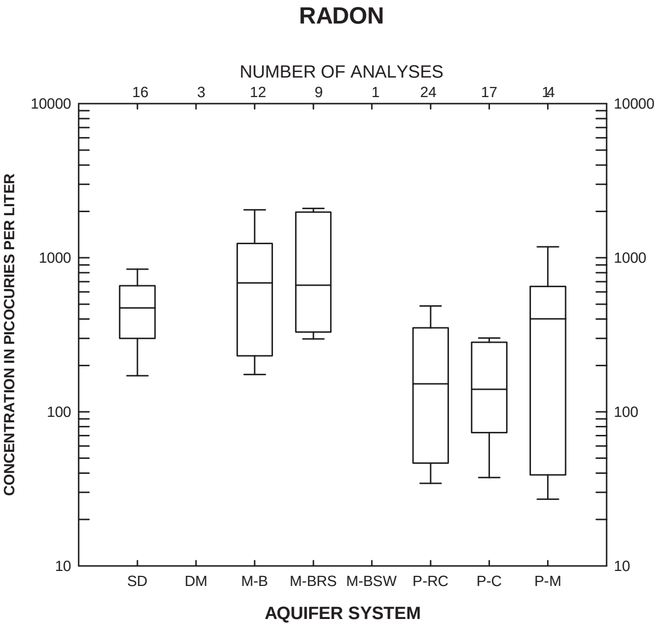


Appendix 4f. Statistical summary of selected water-quality constituents for aquifer systems



Appendix 4g. Statistical summary of selected water-quality constituents for aquifer systems





Appendix 4h. Statistical summary of selected water-quality constituents for aquifer systems

Appendix 5. Standards and suggested limits for selected inorganic constituents

(All values except pH and are in milligrams per liter. If multiple uses have been designated, the most protective standard applies. Dash indicates no available criterion).

Aquatic life: Values for all constituents except iron, pH, selenium, and silver are 4-day average concentrations; selenium value is the 24-hour average; silver criterion is not to be exceeded at any time. All values are chronic aquatic criteria which apply outside the mixing zone, except for silver which is the acute aquatic criterion. Where applicable, trace metal standards were calculated using a hardness value of 325 milligrams per liter. Except where indicated, all values are from the Indiana Water Pollution Control Board, 1992, IAC 327 2-1-6.

Public supply: Unless otherwise noted, values represent maximum permissible level of contaminant in water at the tap. National secondary regulations (denoted sec) are not enforceable. All values are from the U.S. Environmental Protection Agency, 2001.

Irrigation and livestock: All values are from the U.S. Environmental Protection Agency, 1973.

Constituent	Aquatic life	Public supply	Irrigation	Livestock
Arsenic (trivalent)	0.190	0.01	0.10	0.2
Barium	-	2.0	-	-
Cadmium	0.003	0.005	0.01	0.05
Chloride	230	250 sec	-	-
Chlorine	0.011	-	-	-
Chromium (total)	0.05[a]	0.1	0.1	1.0
Copper	0.032	1.0 sec	0.20	0.5
Cyanide	0.005	0.2	-	-
Fluoride	-	4.0	1.0	2.0
	-	2.0 sec		
Iron	1.00[b]	0.3 sec	5.0	-
Lead	0.014	0.015**	5.0	0.1
Manganese	-	0.05 sec	0.20	-
Mercury (inorganic)	0.012*	0.002	-	0.01
Nickel	0.427	-	0.20	-
Nitrate (asnitrogen)	-	10.0	-	-
pH (standard unit)	6.0-9.0	6.5-8.5 sec	4.5-9.0	-
Selenium	0.035	0.05	0.02	0.05
Silver	0.015	0.1 sec	-	-
Sulfate	-	250 sec	-	-
Total dissolved solids	-	500 sec	500-1000	3000
Zinc	0.288	5 sec	2.0	25.0

* Value is in micrograms per liter

[a] U.S. Environmental Protection Agency, 1973

[b] ______1976

** Action Level