

SAMPLING SITE SYMBOLS				
WELL TYPE	MAJOR DATA SOURCE ²			
	IGS	ISBH	USGS	PRIVATE LAB
MUNICIPAL ¹	◆	◇	◊	◈
PUBLIC SUPPLY	■	□	▣	▤
INDUSTRIAL OR COMMERCIAL	▲	△	▴	▵
LIVESTOCK	●	○	◐	◑
DOMESTIC	●	○	◐	◑
OBSERVATION AND TEST	▼	▽	▾	▿
15 - SAMPLING SITE AND DESIGNATION AQUIFER TYPE: UNCONSOLIDATED ■ BEDROCK ■				
¹ SOME SITES HAVE TWO OR MORE WELLS ² IGS - INDIANA GEOLOGICAL SURVEY; ISBH - INDIANA STATE BOARD OF HEALTH; USGS - UNITED STATES GEOLOGICAL SURVEY				

STATE OF INDIANA
 DEPARTMENT OF NATURAL RESOURCES
 DIVISION OF WATER

WHITWATER RIVER BASIN

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SCALE AS SHOWN

5 0 5 10 MILES

5 0 5 10 KILOMETERS

DRAFTED 1986

Figure 24. Ground-water quality sampling locations

degree to which these factors affect original aquifer water is unknown, the ground-water analyses used in this study generally typify the quality of ground water at the tap rather than the composition of in-situ aquifer water. Despite these potential sources of variability, results of the sample analyses can provide valuable information on ground-water quality characteristics of aquifer systems in the Whitewater River Basin.

National Interim Primary Drinking Water Regulations (U.S. Environmental Protection Agency, 1986a, 1986c) and National Secondary Drinking-Water Regulations (U.S. Environmental Protection Agency, 1979) were examined to determine the suitability of ground water in the Whitewater Basin for public supply

(app. 7; also see table 12). The primary regulations list *maximum contaminant levels* for inorganic constituents considered toxic. Although these concentration limits are enforceable only in public water supply systems, they can be used to assess ground-water quality for privately owned wells. The secondary regulations specify *contaminant levels* for inorganic constituents that are not known to be harmful to health but that have undesirable aesthetic effects (taste and odor). Secondary drinking-water standards are not mandatory and are commonly exceeded in ground-water supplies. General water quality criteria for irrigation and stock are also given in app. 7; however, they will not be discussed in detail.

Table 12. Significance of selected chemical constituents

Constituent	Remarks	Constituent	Remarks
Sulfate	Concentrations greater than 250 mg/l, the secondary maximum contaminant level, in combination with ions (especially sodium and magnesium) can impart odors and a medicinal or bitter taste to water. Amounts above 600 mg/l may have a laxative effect for people unaccustomed to sulfate-rich water.	Iron	Concentrations exceeding 0.3 mg/l, the secondary maximum contaminant level, cause staining of laundry, utensils and fixtures and may impart a metallic taste to water. Values above 0.5 mg/l may cause well screens to become encrusted. Large quantities stimulate the growth of iron bacteria.
Chloride	Concentrations in excess of 250 mg/l, the secondary contaminant level, in combination with high sodium may impart a salty taste. Amounts above 1000 mg/l may be physiologically unsafe. Large amounts may accelerate corrosion.	Manganese	Concentrations above 0.2 mg/l discolors food during cooking and stains laundry utensils and fixtures black. Food and water may have a metallic taste at amounts above 0.5 mg/l. Amounts as low as 0.1 mg/l stimulate growth of certain bacteria. Manganese tends to precipitate at concentrations above 0.05 mg/l, the secondary maximum contaminant level, and may form a filter clogging sludge or slime.
Fluoride	Fluoride concentrations ranging from 0.7 to 1.4 mg/l help prevent tooth decay. Amounts above 2 mg/l, the secondary maximum contaminant level, may cause mottled teeth. Crippling skeletal defects may occur with concentrations above 4 mg/l, the maximum contaminant level.	Total Dissolved Solids	Water with concentrations greater than 500 mg/l, the secondary maximum contaminant level, may have a disagreeable taste. Amounts greater than 1000 mg/l may accelerate corrosion of well screens, pumps and casings and cause foaming and scaling in boilers.
Nitrate as nitrogen	Concentrations above 20 mg/l impart a bitter taste to drinking water. Concentrations greater than 10 mg/l, the maximum contaminant level, may cause infant methemoglobinemia, a disease characterized by cyanosis or a bluish coloration of the skin.		

References: Hunn and Rosenshein, 1969; Governor's Water Resource Study Commission, 1980; Lehr and others, 1980; Todd, 1980; and U.S. Environmental Protection Agency, 1986a.

Factors Affecting Ground-Water Chemistry

The chemical composition of both recharge water infiltrating through the soil zone and ground water in an aquifer is the result of the interrelationship of many complex factors, including the composition and solubility of rock or rock materials in the soil or aquifer, water temperature, partial pressure of carbon dioxide gas, acid-base reactions, and oxidation-reduction reactions. Furthermore, mixing of ground water from adjacent strata, the loss or gain of constituents as water percolates through clay layers (adsorption-desorption), and the residence time of water are also important factors which affect the composition of aquifer water.

Rain and snow, the major sources of recharge to ground water, contain small amounts of dissolved solids and gases such as carbon dioxide, sulfur dioxide, oxygen, nitrogen, and argon. As the rain infiltrates through the soil, biologically-derived carbon dioxide reacts with the water, forming a weak solution of carbonic acid. The reaction of free oxygen with reduced iron minerals such as pyrite is an additional source of acidity. Concentrations of chemical constituents such as bicarbonate, sodium, calcium, magnesium, chloride, iron, and manganese are increased or added as the slightly acidic water dissolves soluble rock material. As ground water slowly moves along a flow path in the zone of saturation (aquifer), the composition of water continues to change, usually by the addition of dissolved constituents (Freeze and Cherry, 1979).

With longer residence time, concentrations of dissolved solids in ground water usually increase as reactions approach equilibrium. Ground water in recharge areas commonly contains lower concentrations of dissolved constituents than water occurring deeper in the same aquifer or in shallow discharge areas (Freeze and Cherry, 1979). Also, because recharge to intratill aquifers travels slowly through clay- and silt-rich materials of low permeability, these aquifers usually contain ground water with greater concentrations of dissolved solids than outwash aquifers, which are composed of more permeable sand and gravel deposits.

Elevated concentrations of natural inorganic components and of organic components may be induced by man. The susceptibility of an aquifer to contamination depends on the geologic setting. Contamination is less likely to occur in intratill aquifers because they are protected by layers of low-permeability clay which retard the vertical and horizontal migration of poten-

tial pollutants. In contrast, valley-train aquifers are highly susceptible to contamination because protecting clay layers are either discontinuous or absent. Protection of bedrock aquifers from contamination depends on the thickness of overlying outwash, till, or soil. Pl. 3 briefly summarizes the susceptibility to contamination of six aquifer systems identified within the Whitewater Basin.

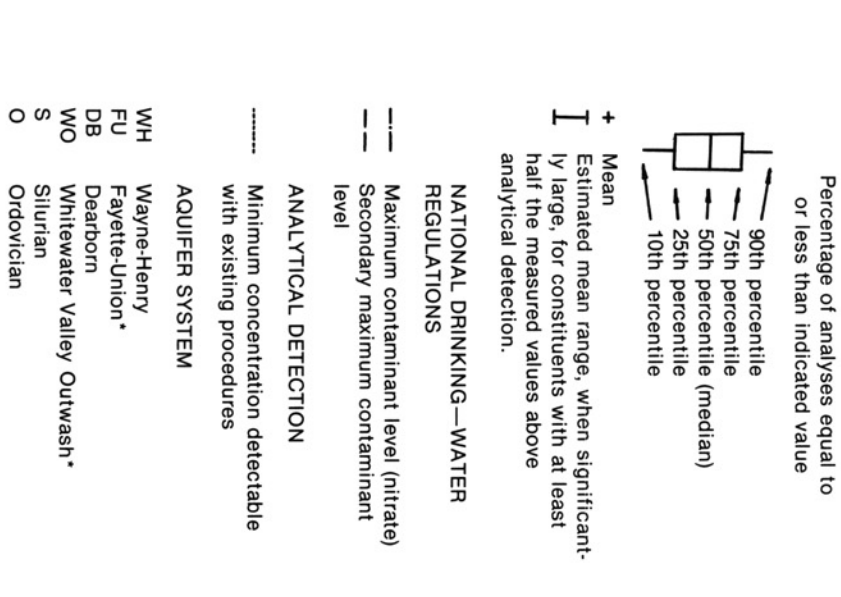
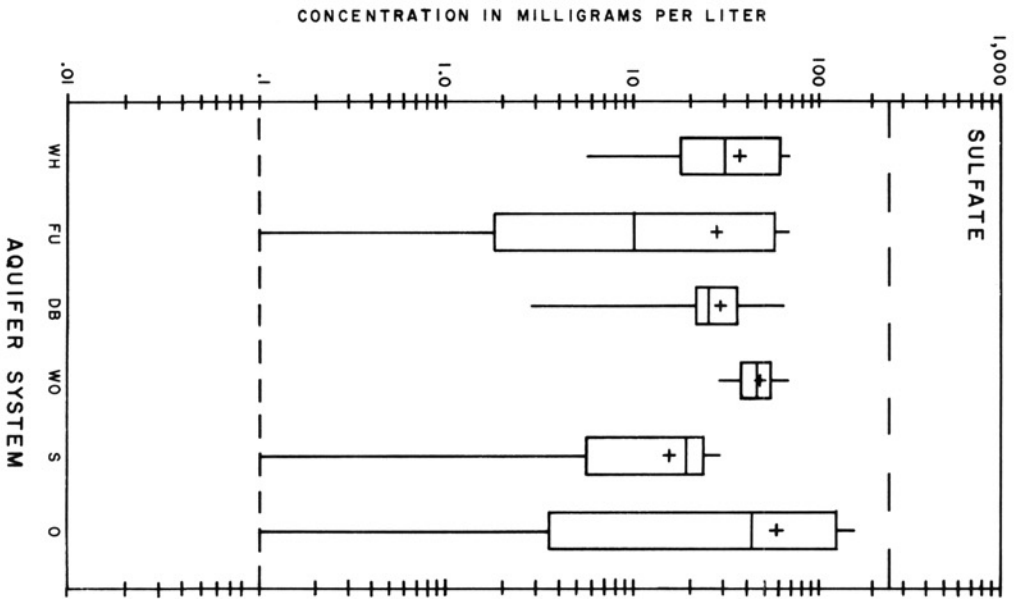
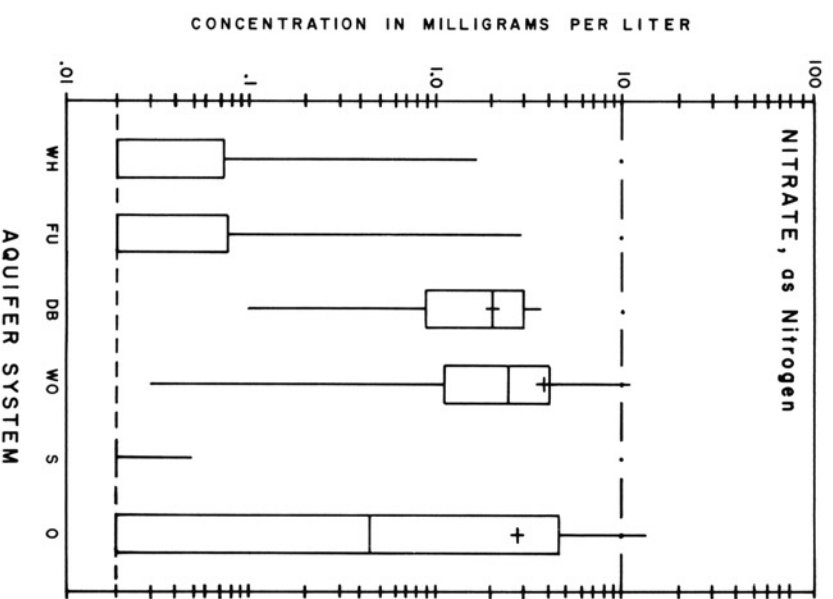
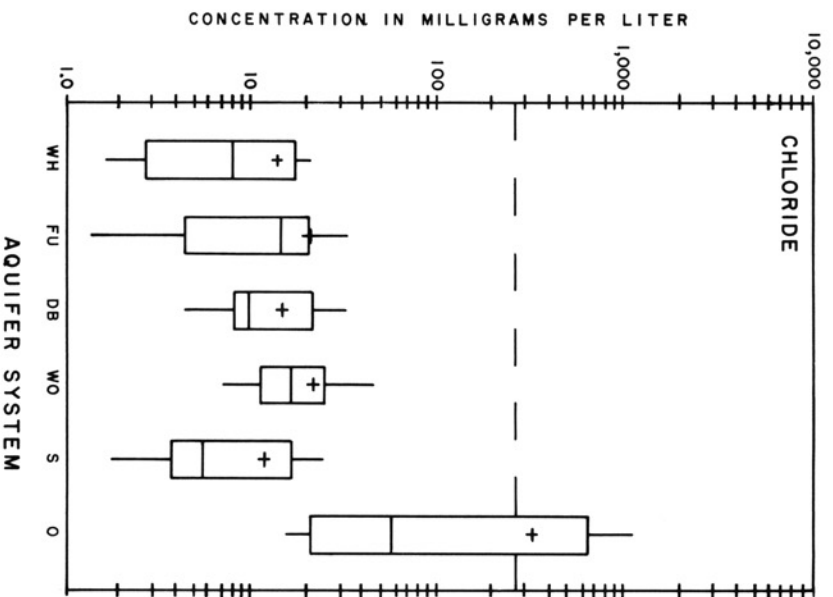
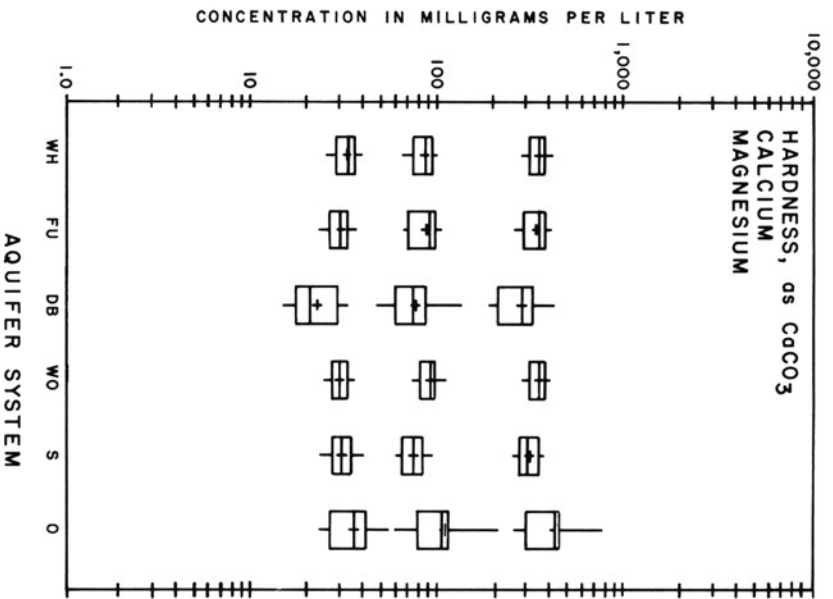
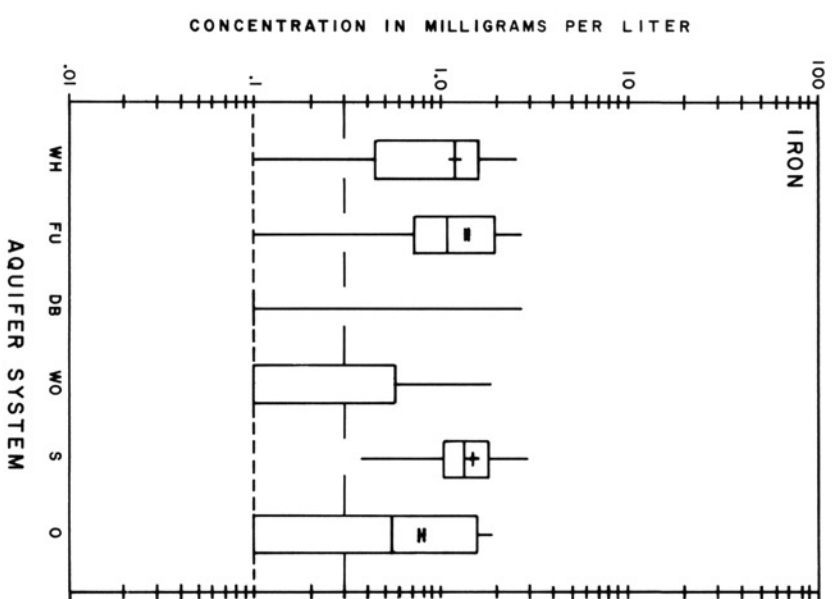
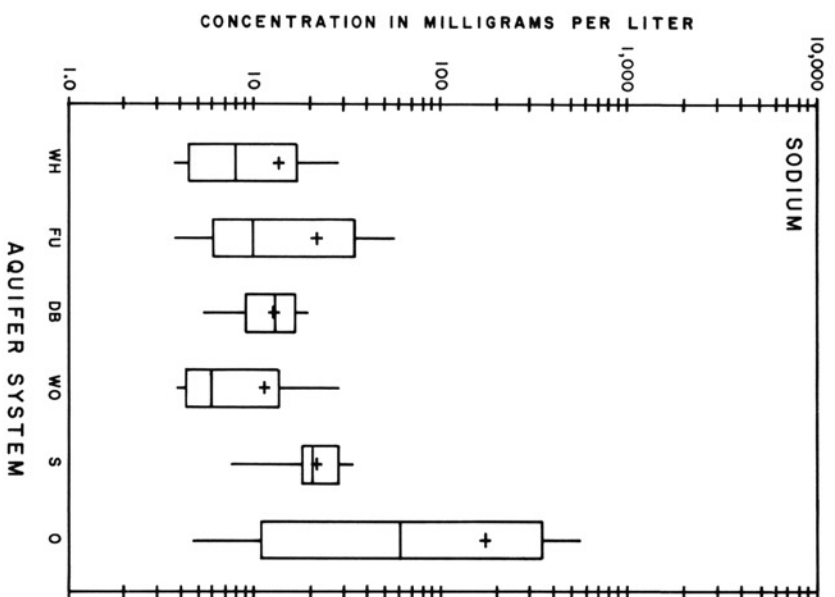
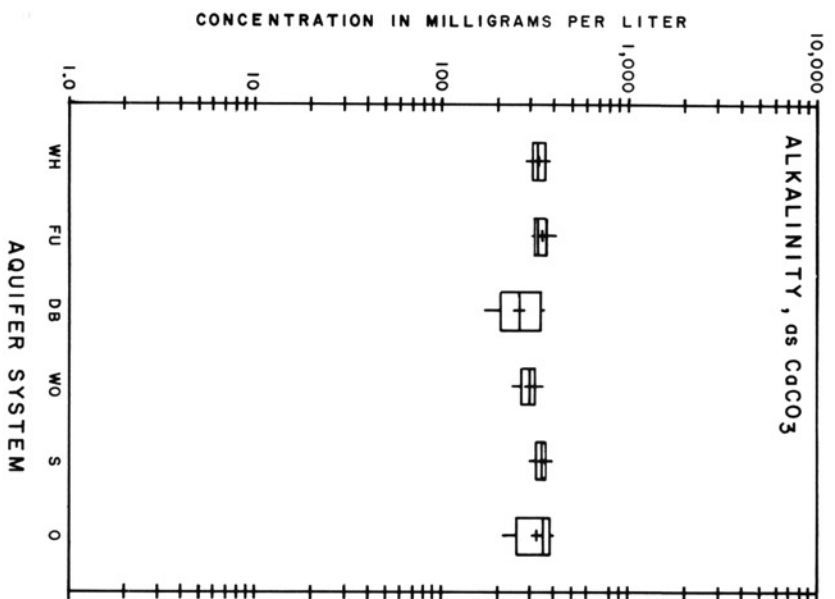
Basin Assessment

Ground water in the Whitewater River Basin is primarily of the calcium bicarbonate type, which is characterized by high alkalinities, high hardness, and mostly basic pH. Major chemical constituents include bicarbonate, calcium, magnesium, sodium, sulfate, and chloride. Less abundant components include iron, potassium, manganese, fluoride, and nitrate. Concentrations of these constituents, except bicarbonate, are given in app. 12 for each of the 153 selected wells. Additional information is on file at the Division of Water for bromide, phosphate, zinc, barium, strontium, and silica for most wells; however, such data are not presented in this report.

Alkalinity, the capacity of water to neutralize acid, can be produced by bicarbonate, carbonate, silicate, hydroxide, borates, and certain organic compounds. In ground water of the Whitewater Basin, alkalinity is predominantly produced by bicarbonate, which is mainly derived from 1) the atmosphere, 2) carbon dioxide produced in the soil zone, and 3) the solution of carbonate minerals (calcite and dolomite).

Median alkalinity values in the basin are high, and values range from 260.6 mg/l (milligrams per liter) as CaCO_3 (calcium carbonate) in the Dearborn Aquifer System to 355.2 mg/l as CaCO_3 in the Ordovician Aquifer System (fig. 25). The lowest concentrations of alkalinity (less than 300 mg/l as CaCO_3) occur primarily within the Dearborn Aquifer System and Whitewater Valley Aquifer System (fig. 26).

Lower alkalinity concentrations found in the Dearborn Aquifer System may be explained by two factors: 1) fewer carbonate minerals are available to produce alkalinity because these minerals have been leached from thick soils developed on the older pre-Wisconsinan till (Alfred and others, 1960); and 2) alkalinities are decreased as carbon dioxide is lost to the atmosphere from ground water stored in bucket-rig wells and carbonate minerals are precipitated (Gibb and others, 1981). The lower median alkalinity value in the Whitewater Valley Aquifer System may be explained by the shorter residence time of the ground water.



EXPLANATION

- Percentage of analyses equal to or less than indicated value
- 90th percentile
- 75th percentile
- 50th percentile (median)
- 25th percentile
- 10th percentile
- + Mean
- | Estimated mean range, when significantly large, for constituents with at least half the measured values above analytical detection.
- NATIONAL DRINKING—WATER REGULATIONS
- Maximum contaminant level (nitrate)
- Secondary maximum contaminant level
- ANALYTICAL DETECTION
- Minimum concentration detectable with existing procedures
- AQUIFER SYSTEM
- WH Wayne-Henry
- FU Fayette-Union*
- DB Dearborn
- WO Whitewater Valley Outwash*
- S Silurian
- O Ordovician

*Data from bucket-rig wells were omitted from the statistics

Figure 25. Statistical summary for selected ground-water quality constituents

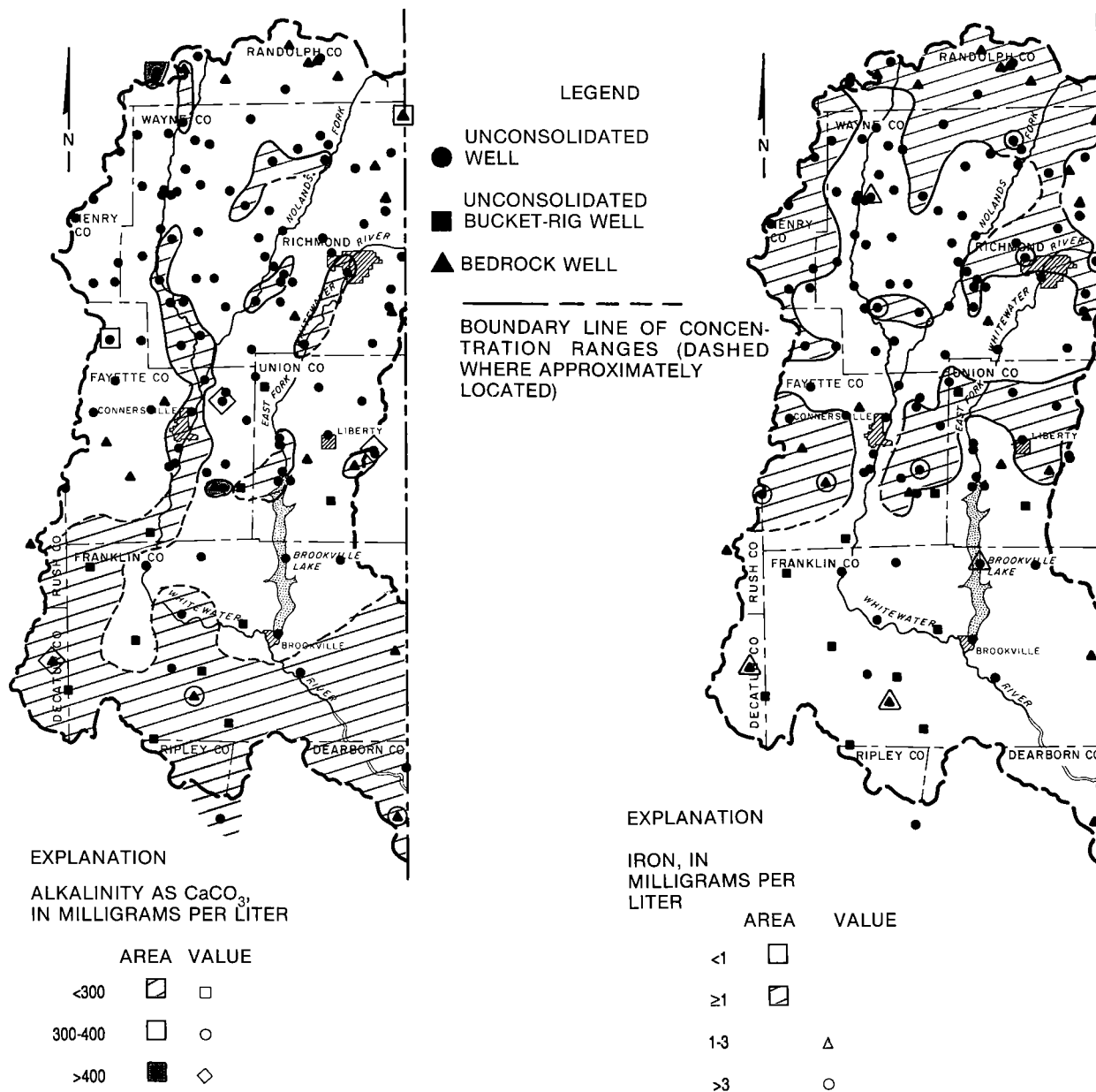


Figure 26. Generalized areal distribution of alkalinity and iron concentrations

Hard water and soft water are relative terms because water considered hard in one region might be considered soft by inhabitants of another region. For discussion purposes, however, the following scale can be used: soft water, 0–60 mg/l as CaCO₃; moderately hard water, 61–120 mg/l; hard water, 121–180 mg/l; and very hard water, more than 180 mg/l (Hem, 1985). Hardness is principally caused by calcium and magnesium. Hard water consumes excessive amounts of soap and detergents and forms an

insoluble scum. In addition, hard water causes scale to encrust water heaters, boilers, and pipes, thus decreasing their capacity and heat transfer properties.

Median hardness values for all aquifer systems in the basin are significantly greater than 180 mg/l (fig. 25); in other words, ground water is very hard. Median hardness values are nearly identical for the Wayne-Henry, Fayette-Union, and the Whitewater Valley Aquifer Systems.

Median hardness, calcium, and magnesium values

are lowest for the Dearborn Aquifer System and highest for the Ordovician Aquifer System (fig. 25). Lower calcium concentrations and hardness in the Dearborn Aquifer System may be caused by a lesser abundance of calcium minerals in the older leached pre-Wisconsinan till, and/or by precipitation of calcium carbonate in large-diameter bucket-rig wells as carbon dioxide is lost from stored water (Gibb and others, 1981). Higher concentrations in the Ordovician System may be explained by longer residence time of ground water in the aquifer.

The hydrogen ion activity in water (pH) is expressed on a scale of zero to 14. Water with a pH less than 7 is acidic, greater than 7 is basic, and equal to 7 is neutral. The pH of ground water in the basin is predominantly basic, but values range from 6.1 to 8.5 (slightly acidic to basic). Median values for all aquifer systems are similar and range from 7.0 to 7.3.

Sulfate, chloride, and sodium are major chemical constituents of ground water in the basin, although concentrations are usually less than bicarbonate and calcium. Sulfate concentrations did not exceed the secondary maximum contaminant level of 250 mg/l for drinking water in any of the wells sampled (fig. 25; table 12); however, values can be locally high. Three out of eight wells sampled in the Ordovician Aquifer System contained chloride concentrations which exceeded the recommended level of 250 mg/l (fig. 25; table 12). In addition, these three wells had sodium concentrations greater than 300 mg/l. A deep well completed in sediments overlying a buried bedrock valley in the Fayette-Union System and a shallow well in the Wayne-Henry System also contained elevated concentrations of chloride and sodium between 95 and 210 mg/l. A secondary maximum contaminant level has not been established for sodium; however, sodium in excess of 500 mg/l, when combined with chloride, produces a salty taste.

Median values of sulfate range from 10.2 mg/l in the Fayette-Union Aquifer System to 45.1 mg/l in the Whitewater Valley Aquifer System (fig. 25). In general, sulfate concentrations are greater for shallow wells where dissolved oxygen is present (oxidizing conditions) than deep wells where oxygen has been depleted (reducing conditions). Large percentile ranges of sulfate concentrations, characteristic of some aquifer systems (fig. 25), may be explained by the presence of variable concentrations of dissolved oxygen reacting with sulfide minerals. The high median sulfate value and small percentile range for the Whitewater Valley Aquifer System suggest the presence of a more consistent oxidizing environment and a source of sulfur

such as the minerals pyrite and gypsum.

The bedrock aquifer systems have median chloride values of 5.7 mg/l in the Silurian Aquifer System and 57.4 mg/l in the Ordovician Aquifer System (fig. 25). In unconsolidated systems, median chloride values range from 8.2 mg/l in the Wayne-Henry System to 16.8 mg/l in the Whitewater Valley System (fig. 25). The Silurian and Ordovician Systems have median sodium values of 20.7 mg/l and 61.5 mg/l, respectively, and median values range from 6.0 mg/l to 13.2 mg/l in the unconsolidated aquifer systems (fig. 25). High median values of sodium and chloride in the Ordovician System may be explained by two factors: 1) inclusion of ancient seawater in the fine-grained shale, or the presence of sodium chloride-cementing material in the rock; or 2) longer residence time of the ground water. Bedrock wells containing high chloride concentrations were 290, 208, and 100 feet deep.

The secondary maximum contaminant level of iron in drinking water (0.3 mg/l) was commonly exceeded in wells sampled in the Wayne-Henry, Fayette-Union, Silurian, and Ordovician Aquifer Systems, and less commonly exceeded in the Dearborn and Whitewater Valley Aquifer Systems (figs. 25, 27; also see table 12). Manganese exceeded the detection limit of 0.1 mg/l in all aquifer systems except the Dearborn System (fig. 27; table 12). However, because the detection limit was twice the secondary maximum contaminant level of 0.05 mg/l, the percent of wells exceeding the standard could not be determined.

Median iron values are highest for the Silurian, Wayne-Henry, and Fayette-Union Aquifer Systems and lowest for the Dearborn and Whitewater Valley Aquifer Systems (fig. 25). Median values in the latter two systems were both less than the 0.1 mg/l detection limit. Iron concentrations in the Silurian Aquifer System are similar to those in the overlying glacial till, its major source of recharge. Ground water in the Wayne-Henry Aquifer System, the Knightstown Moraine and underlying Silurian bedrock are characterized by high concentrations of iron greater than 1 mg/l (fig. 26).

Lower iron concentrations in the Dearborn Aquifer System may be explained by two factors: 1) the reduction and transfer of iron in the pre-Wisconsinan till may have decreased the iron minerals available for solution (Nickell, 1981); 2) the iron originally present may have been oxidized and precipitated out before sampling when ground water stored in bucket-rig wells was exposed to the atmosphere (Hem, 1985). Lower concentrations in the Whitewater Valley System may be explained by the oxidizing conditions in the aquifer and

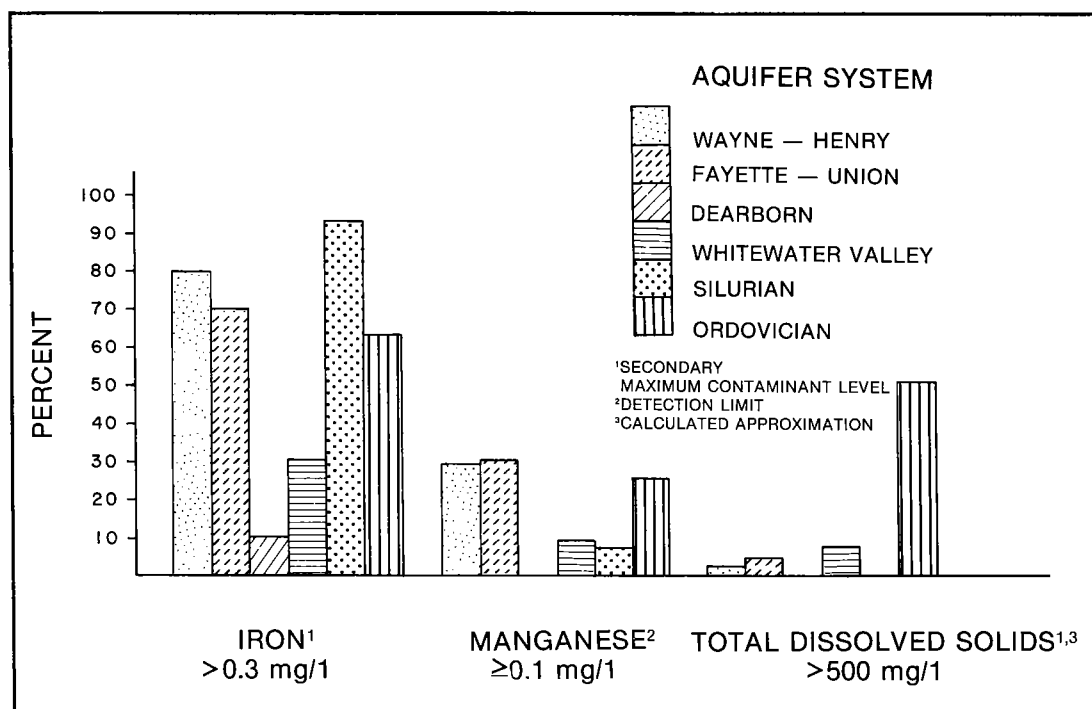


Figure 27. Percent of water samples exceeding selected concentration limits

the lower abundance of iron minerals in the sand and gravel. In general, average iron concentrations are greater in deep wells (greater than 100 feet deep) than in shallow wells (less than 60 feet deep).

Total dissolved solids (TDS) is a measure of the concentration of mineral constituents dissolved in water (table 12). TDS values used in this discussion and shown in app. 12 are the calculated sum of major constituents expected in an anhydrous residue of a groundwater sample. A good approximation of the determined residue on evaporation is calculated when 1) the concentrations of major ions are known, and 2) bicarbonate ions present in solution are converted to carbonate in the solid phase by a gravimetric factor, and the resulting carbonate value is used in the summation (Hem, 1985). App. 12 also includes values for total dissolved solids, "as reported," which is the sum of major constituents in which no adjustment of bicarbonate was made.

TDS values in the basin range from 224 to 2377 mg/l. In the wells sampled, concentrations of TDS did not exceed the secondary maximum contaminant level for drinking water of 500 mg/l in the Dearborn and Silurian Aquifer Systems. A small percentage of the wells sampled in the Wayne-Henry, Fayette-Union and Whitewater Valley Aquifer System contained concentrations of TDS above the standard. Concentrations of TDS in fifty percent of the wells sampled in the Ordovician Aquifer System exceeded the secondary maximum contaminant level (fig. 27).

Areas with higher concentrations of TDS (greater than 400 mg/l) occur primarily in the Wayne-Henry and Fayette-Union Aquifer Systems (fig. 28). Lower values of TDS (less than 300 mg/l) are found mainly in the Dearborn Aquifer System. The median TDS value is lowest for the Dearborn System, which has the lowest median values of alkalinity, calcium, and magnesium (fig. 25). The median TDS value is

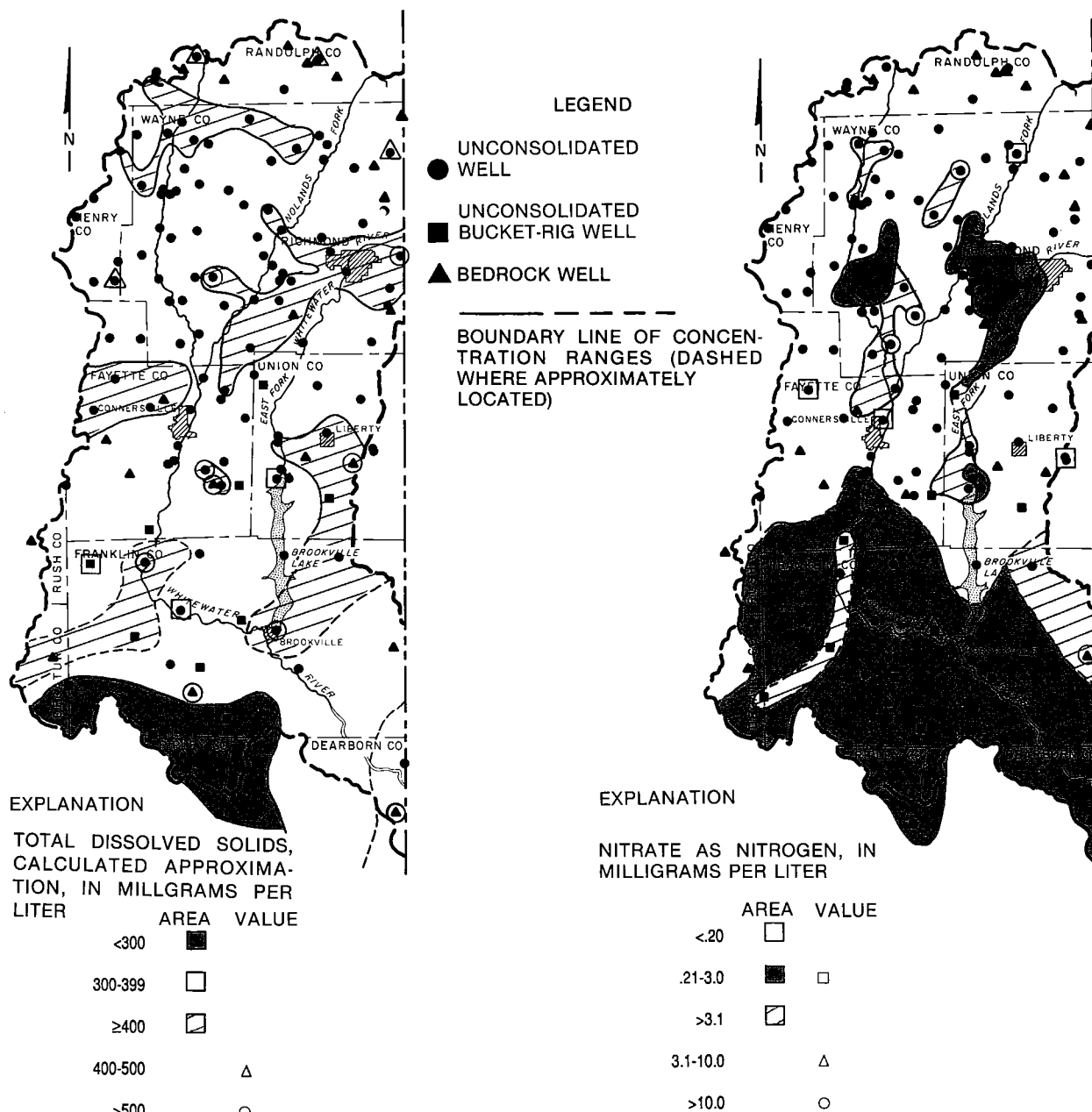


Figure 28. Generalized areal distribution of total dissolved solids and nitrate concentrations

highest for the Ordovician System, which has the highest median values of alkalinity, calcium, sodium, chloride, and magnesium. The remaining aquifers have median TDS values which range between 377 and 402 mg/l (fig. 25).

Natural concentrations of nitrate in ground water originate from the atmosphere and from living and decaying organisms. The majority of wells sampled in the Whitewater Basin contained concentrations of nitrate (as nitrogen) less than 0.20 mg/l (fig. 28). Con-

centrations less than this value are assumed by Madison and Brunett (1984) to represent natural background concentrations. Concentrations of nitrate (as nitrogen) between 0.21 and 3.0 mg/l that may or may not represent human influence are considered transitional (Madison and Brunett, 1984). Wells containing these concentrations are found primarily in the Dearborn and Whitewater Valley Aquifer Systems (fig. 28).

High levels of nitrates can result from leachates of industrial and agricultural chemicals or decaying

Ground-Water Contamination

organic matter such as animal waste or sewage. Concentrations of nitrate (as nitrogen) between 3.1 and 10 mg/l may indicate elevated concentrations of nitrate resulting from human activity (Madison and Brunett, 1984). Wells containing these levels are found mainly in the Whitewater Valley Aquifer System, which has been designated as highly susceptible to contamination (Indiana Department of Environmental Management, [1986]).

Four domestic wells sampled in the basin contained nitrate (as nitrogen) levels greater than 10 mg/l, the maximum contaminant level for public water supplies (app. 7; also see table 12). Three of the wells are located in the Whitewater Valley System and one well is located in the Ordovician Aquifer System (fig. 28). Insufficient grouting or infiltration of contaminated water through fractures in the 25-foot till cover may account for high nitrate (as nitrogen) concentrations in the Ordovician well.

Median concentration values of nitrate (as nitrogen) are greatest for ground water in the Whitewater Valley and Dearborn Aquifer Systems. Median values for the Wayne-Henry, Fayette-Union, and Silurian Systems are all less than the detection limit of 0.02 mg/l (fig. 25). In general, average nitrate (as nitrogen) concentrations are higher for shallow wells than deep wells, probably because deep ground water is protected from surface contamination by overlying materials.

Natural sources of fluoride in ground water include clay minerals, apatite, and fluorite. In the wells sampled, fluoride concentrations did not exceed the maximum contaminant level of 4 mg/l (table 12), except in one well in the Whitewater System which had an anomalously high concentration of 4.7 mg/l. Median values were highest in the Silurian (0.7 mg/l) and Wayne-Henry (0.6 mg/l) Aquifer Systems. The remaining aquifers had median values which range from 0.2 to 0.4 mg/l.

Natural sources of barium in ground water include the minerals barite and witherite. In wells sampled, barium concentrations did not exceed the maximum contaminant level of 1.0 mg/l except in one well in the Silurian Aquifer System which had a concentration of 1.6 mg/l. Median concentration values for barium for the Wayne-Henry, Fayette-Union, and Silurian Aquifer Systems are all 0.2 mg/l. The remaining systems have median values below the detection limit of 0.1 mg/l.

A ground-water supply that otherwise would be plentiful can be diminished by contamination from man's activities. As defined by the Indiana Department of Environmental Management [1986], contamination occurs when concentrations of chemicals exceed public drinking-water standards, proposed standards, or health protection guidance levels from the U.S. Environmental Protection Agency (USEPA). To protect Indiana's ground water resource, officials of the USEPA, IDEM, and Indiana State Board of Health are working in a cooperative effort for prevention, detection, and correction of ground-water problems in Indiana.

One important step in developing a ground-water management and protection program is identifying geographic areas most susceptible to ground-water contamination. The IDEM has designated 11 counties in Indiana, including Wayne County, as geographic areas where ground-water protection may be most needed. Screening criteria used to identify Wayne County include: 1) the susceptibility of the Whitewater Valley Aquifer System to contamination; 2) the presence of 11 public water wells and nearly 28,500 private wells; 3) the potential for significant increases in water use; 4) ground-water contamination sites; and 5) the presence of potential sources of contamination. Potential contamination sources identified by IDEM include 40 hazardous waste treatment, storage, and disposal facilities; two sanitary landfills; hazardous material spills (38 of which were documented by IDEM in 1985-86); and two abandoned hazardous waste disposal sites on the U.S. Environmental Protection Agency's Superfund Inventory list.

Since 1981, the USEPA has been conducting a survey of 26 volatile organic compounds in Indiana's public ground-water supplies serving more than 25 customers. Volatile organic compounds are a broad class of synthetic chemicals used commercially as degreasing agents, paint thinners, varnishes, glues, dyes, and pesticides which can contaminate ground water if improperly disposed. In the Whitewater River Basin, detectable levels of at least one VOC were found in six public water supplies in Wayne, Union, and Franklin Counties (Indiana Department of Environmental Management, [1986]). If the levels were a risk to public health, corrective action was taken; otherwise, levels are continuing to be monitored.