detect long-term water-level trends. Because most of the ground-water/lake wells have either served their intended purpose or have provided inconclusive data, two (Noble 10 and Kosciusko 8) were removed from the network in late 1986. The continuous recorder will be removed from Elkhart 6 and manual measurements will be made periodically. Funding for two of the remaining ground-water/lake wells (Kosciusko 6 and 7) has been assumed through 1987 by the City of Syracuse, after which the wells may also be discontinued. Elkhart 5 will remain in the network to monitor anticipated increases in high-capacity pumpage. Three nested wells are planned for construction near Kendallville in 1987. These wells will provide information about recharge to the deeper confined aquifer in the Kendallville area.

Piezometric Surface (Water Table)

The ground-water level within an aquifer constantly fluctuates in response to rainfall events, evapotranspiration, ground-water movement, and ground-water pumpage. Maximum fluctuations recorded at 14 in-basin observation wells average 5 feet. Because the natural fluctuations are small, static water levels can be used to approximate regional ground-water flow direction.

Static water levels used to develop the piezometric surface map for the St. Joseph River basin (Plate 2) include data for aquifers at various depths. The map represents a composite of water levels of the major aquifer systems, and it may or may not be a true representation of water levels in very shallow or very deep aquifers.

The piezometric surface map can be used to define the probable flow path of contaminants and to identify significant areas of ground-water recharge and discharge. The map can also be used to calculate expected depths to water in a well, but not to determine recommended depths of wells.

In a general way, ground-water flow approximates overlying topography and intersects the land surface at major streams. However, where thick deposits of sand and gravel occupy high topographic positions, as near Bristol (Plate 2), regional flow may not be controlled by topography.

In the St. Joseph River basin, ground-water levels range from an elevation of 1030 m.s.l. (mean sea level) in Steuben County to a low of about 670 m.s.l. along the St. Joseph River north of South Bend (Plate 2). Regional ground-water flow, which generally reflects regional topographic drainage, is toward the St. Joseph River. Ground water in southwest Steuben County, however, tends to flow out of the St. Joseph basin and into adjoining watersheds.

St. Joseph River Basin Aquifer Systems

The St. Joseph River basin presents one of the most complex geologic settings in Indiana for defining groundwater resources. The complexity is due to the impact of three major ice lobes, a thick mass of glacial drift and an irregular bedrock surface. Because of the complex glacial deposition, it is not possible in most cases to delineate discrete aquifers for any distance. Hence, seven regional aquifer systems were identified within the St. Joseph River basin (Plate 1) based on the similarities of geologic environments. These systems consist of aquifer complexes within outwash-plain, valley-train, till-plain, and intertill morainal glacial deposits. Table 11 summarizes selected hydrologic characteristics of the seven aquifer systems.

St. Joseph Aquifer System

The St. Joseph Aquifer System, an outwash plain extending from eastern Elkhart County to the basin divide in western St. Joseph County, is one of Indiana's major aquifer systems. It is composed primarily of fine to medium sand with local layers of coarse sand and gravel.

Although hundreds of well records are available to define aquifer conditions to a depth of 100 feet, little information describing greater depths is available. The St. Joseph Aquifer System is highly variable in thickness, ranging from less than 20 feet near its southern boundary to its greatest known thickness of approximately 400 feet over the buried bedrock valley at the west edge of Elkhart. Sand and gravel thicknesses of 40 to 120 feet are typical.

The main body of the outwash contains numerous interspersed thin (3 to 5 feet) layers of clay. Locally, clay deposits may extend to considerable depths, as in much of the area south of the St. Joseph River between Elkhart and South Bend. Clay deposits in an area southeast of Elkhart (Plate 1) essentially preclude significant occurrences of ground water and can make even domestic supplies difficult to obtain.

TABLE 11. Hydrologic Characteristics of Major Aquifer Systems

Aquifer System	Areal Extent (mi^2)	Range of Aquifer Thickness (ft)	Common Aquifer Thickness (ft)	Range of Pumping Rates (GPM)	Common Depth to Aquifer (ft)	Hydrostatic Condition
St. Joseph	381	20 - 400	40 - 120	100 - 1500	20 - 120	confined & unconfined
Hilltop	35	10 - 100	10 - 30	25 - 150	5 - 50	confined & unconfined
Nappanee	241	3 - 30	3 - 20	50 - 600	80-90	confined
Kendallville	327	3 - 20	3 - 5	25 - 600	15 - 100	confined
Howe Outwash	243	5 - 145	15 - 50	100 - 1000	25 - 180	confined
Natural Lakes and Moraines	450	4 - 35	5 - 20	25 - 80	20 - 100	confined
Topeka	23	5 - 126	30 - 50	100 - 600	25 - 50	confined & unconfined

In the South Bend-Mishawaka area, moderately thick deposits of clay/till separate an upper deposit of sand and gravel from a deeper productive sand and gravel aquifer. The clay unit separating the upper and lower sand and gravel has an irregularly sloping surface that trends generally to the northwest. The bottom elevation of this layer ranges from about 600 feet m.s.l. near the Michigan state line to 635 feet m.s.l. in the South Bend area. Similar conditions are present east and north of Mishawaka (Plate 1), where elevations of the bottom of the clay layer are about 630 to 675 feet m.s.l. Locally, irregular clay conditions are also present in some areas north of the St. Joseph River near Bristol.

St. Joseph Tributary Valley Aquifer System

The Tributary Valley portion of the St. Joseph System encompasses valleys of the Elkhart and Little Elkhart rivers and Turkey, Solomon and Pine Creeks. These valley-train outwash systems are similar to the principal St. Joseph Aquifer System except that they often contain coarser grained deposits.

In the Goshen area and in the Elkhart River valley northwestward toward Elkhart, a well-defined sequence of surficial sand and gravel overlies a clay/till unit, which in turn overlies a confined sand and gravel aquifer. The surficial sand and gravel ranges up to 60 feet in thickness. The lower confined aquifer of this sequence ranges up to 50 feet in thickness.

South of Goshen, outwash materials of the Elkhart River and Turkey Creek-Rock Run valleys coalesce. Here the clay/till confining bed is generally absent, and thicknesses of sand and gravel exceeding 150 feet may be found.

(Turkey Creek)

The reappearance of an intermediate confining clay is noted along the Turkey Creek valley south of New Paris. The Turkey Creek Aquifer System is typified by the hydrogeology of the Milford area, where characteristic surficial sand and gravel overlie localized clay/till lenses and a lower confined sand and gravel aquifer.

Thicknesses of surficial sand and gravel units commonly average 40 feet, but may range from 10 to 100 feet. Outwash sands and gravels are thicker in the Turkey Creek System than in areas to the north, and in broader portions of the valley commonly range from 50 to 100 feet in thickness. A subsurface clay/till zone is frequently encountered at an elevation ranging from 750 to 820 feet m.s.l. While the approximate thickness of the clay/till zone is variable, it apparently thickens toward the edges of the Turkey Creek System. Although localized clay/till lenses contained within the outwash are normally thin, thicknesses of 25 to 50 feet have been reported.

A deeper 5- to 75- foot thick sand and gravel aquifer complex is frequently encountered at an elevation of 740 to 770 feet m.s.l. This aquifer complex is locally confined beneath the clay/till zone, and is probably interconnected with thick sequences of surficial sand and gravel. The deeper sand and gravel unit extends laterally to the west into the Nappannee Aquifer System and to the east into the transitional portion of the Natural Lakes and Moraines Aquifer System.

A few water wells have penetrated a third deep sand and gravel zone at elevations between 690 to 720 feet m.s.l. This zone is confined by a lenticular clay/till layer. Only the thickest sequences of surficial sand and gravel may intersect this deeper aquifer locally. The lateral extent of the deepest aquifer complex is not known; however, a few wells in the transitional and main parts of the Lake and Moraine System encounter aquifer material at the same elevation range as the deepest Turkey Creek aquifer complex.

Ground-water levels in the surficial outwash sand and gravel deposits are normally shallow, and static water levels are less than 10 feet below ground surface. Near the boundaries of the aquifer system, static water levels deepen to nearly 40 feet.

Thicker deposits of this aquifer system can be expected to yield 500 to 1000 gpm per well. A few scattered high-capacity wells south of Milford along Coppes Ditch have reportedly produced 750 to 1350 gpm during brief pumping tests.

(Solomon Creek)

The Solomon Creek Tributary Valley Aquifer System is composed of thick layers of outwash sand and gravel with interbedded clay layers. Data for this system are sparse, but the aquifer appears to be less complex than the Turkey Creek System. From its junction with the Elkhart River, the Solomon Creek System trends in a southeasterly direction. Thicknesses of sand and gravel units average 60 to 70 feet but vary from 20 to 160 feet. Greatest thicknesses occur southeastward of the Elkhart-Kosciusko County line where up to 104 feet of saturated sand and gravel deposits have been found. Sand and gravel thins in the southeastern portion of the system.

In the area of Wolf Lake, clay layers become more common in the system and increase in thickness. Whereas the sand and gravel occurs as one thick unit to the northwest, in the Wolf Lake area several sand and gravel layers generally are separated by clay zones of variable thickness.

Generally the Solomon Creek Aquifer System is capable of yielding 300 to 1000 gpm from individual wells; however, some wells near the Noble-Elkhart County line have yields of over 1200 gpm. High-capacity yields may not be possible in areas within the aquifer where localized thick clay deposits are present, such as in some areas between Benton and the Elkhart-Kosciusko county line. Well depths generally average 50 feet, but may range up to 250 feet.

(Pine Creek)

Although little is known about the Pine Creek-Rock Run Aquifer System, this tributary valley outwash system is potentially the most complex. Morainal deposits have blocked the lower reaches of this valley where it merges with the St. Joseph Aquifer System, and have substantially modified the surface appearance of the Pine Creek valley. Where data are available, sand and gravel is a major component of the materials contained within the valley. Deeper sand and gravel is expected to underlie a clay layer which in turn underlies the surficial sand and gravel. The outwash contained within the Pine Creek valley may be related to the materials deposited in the Turkey Creek valley. It is expected that moderately high producing (300 to 600 gpm) wells could be developed in the Pine Creek Aquifer System.

(Little Elkhart River)

The Little Elkhart Aquifer System originates northwest of Topeka in LaGrange County, where outwash deposits of surficial sand and gravel are found in the valleys of Little Elkhart River and Rowe-Eden Ditch. The sand and gravel deposits, which range up to 50 feet in thickness, overlie a thick clay sequence which may, in turn, overlie a deeper sand and gravel aquifer sequence. Data in the southeastern part of the valley system are quite limited.

Southeast of Middlebury, the valley system becomes more defined and outwash sand and gravel deposits up to 60 feet in thickness can be found. At Middlebury the surficial sand and gravel is underlain by a 50- to 60- foot clay/till layer that separates the upper aquifer from a deeper sand and gravel deposit that locally exceeds 60 feet in thickness. The elevation at the bottom of the confining clay unit is about 730 to 740 feet m.s.l. at Middlebury, and probably declines to the northwest.

Wells completed in the Little Elkhart System typically can be expected to yield 500 to 1000 gpm to properly constructed, large-diameter wells.

Topeka Aquifer System

The Topeka Aquifer System, characterized by thick surficial deposits of outwash sands and gravels, is bounded on all sides by the Natural Lakes and Moraines Aquifer System. Along the gradational system boundaries, surficial sands and gravels thin and interfinger with clays of the Natural Lakes and Moraines System.

The Topeka Aquifer System consists of two separate areas that are geologically similar. The main (western) portion, located near the town of Topeka, is composed of surficial sand and gravel deposits up to 126 feet in thickness, but having common thicknesses of 30 to 50 feet. Interbedded clay layers up to 10 feet in thickness, occasionally found in the main system, become thicker and more common near the aquifer system boundaries. Static water levels in the unconfined surficial sand and gravel deposits are generally 25 to 50 feet. Yields from shallow unconfined wells are unknown due to limited data.

A deeper confined aquifer underlies the main Topeka system, commonly at an elevation of about 850 feet m.s.l. This deeper system may be related to the Natural Lakes and Moraines Aquifer System. A primary sand and gravel deposit comprising the deeper Topeka aquifer is up to 20 feet in thickness and seems to be continuous throughout the Topeka system. Other minor sand and gravel layers are locally present in clays underlying the surficial outwash deposits, but do not appear to be laterally extensive or continuous.

The main Topeka Aquifer System is used by several high-capacity irrigation wells. These wells are usually from 120 to 160 feet deep and produce water from confined or semi-confined sand and gravel aquifers beneath clay layers. Reported well yields range from 1000 to 2000 gpm. Although these yields are greater than can normally be expected, properly constructed, large diameter wells can produce yields in the range of 300 to 1000 gpm.

The eastern portion of the Topeka Aquifer System is a surficial outwash deposit that averages 40 feet in thickness, but may be as much as 80 feet. Static water levels in the unconfined outwash are about 30 feet. Deeper confined aquifers underlie the outwash at elevations of about 725 to 850 m.s.l. and are 5 to 20 feet thick. As with the main Topeka system, the deeper aquifers are probably related to the adjacent Natural Lakes and Moraines Aquifer System.

The eastern section of the Topeka Aquifer System is similar to the main system but exhibits more discontinuous outwash deposits and is not as productive. Shallow wells (40 to 60 feet) reportedly produce 10 to 45 gpm. Some deeper wells in the eastern system can produce from 90 to 205 gpm and create only slight (about 10 feet) drawdown. Although few high-capacity wells are present to test the aquifer's adequacy, yields from 150 to 500 gpm are anticipated from properly constructed, largediameter wells.

Natural Lakes and Moraines Aquifer System

The Natural Lakes and Moraines Aquifer System, one of the largest in the St. Joseph basin, is a complex intertill aquifer system covering large areas in Noble, LaGrange, Elkhart and Kosciusko Counties. At ground surface, this system is essentially a till plain. Most aquifer materials occur below the surficial till. Although the topographic drainage divide of the St. Joseph River basin defines the southern boundary of the aquifer system, it is presumed that the aquifer system continues further south.

The Natural Lakes and Moraines Aquifer System can be subdivided into two parts on the basis of surficial deposits. Most of the system is characterized by surficial clays of varying thickness having only scattered, localized areas of surficial sand and gravel. Surficial clay thickness is generally from 20 to 100 feet. The surficial clays are underlain by multiple intertill sand and gravel lenses. As many as five distinct layers of sand and gravel may be present in any area, although two or three are more common. Typically the upper sand and gravel layers, if present, are non-productive. Thickness of these upper layers ranges from 4 to 35 feet and averages 10 to 20 feet. The deepest layers are generally thinner (5 to 10 feet) than the upper units, but are productive.

Significant areas of surficial sand and gravel zones are present within the Lakes and Moraines Aquifer System, but layers are generally thin (less than 20 feet) and lack continuity. Three localized areas northeast of Topeka, east of Emma, and at LaGrange, however, appear to have continuity of surficial sand and gravel deposits.

Most of the Lakes and Moraines Aquifer System (except where it borders the Kendallville) has water-bearing sand and gravel zones which occur at fairly consistent elevations. There appears to be good elevation correlation of these water-bearing zones with the deeper confined aquifers of the Topeka Aquifer System and even with aquifers on either side of the Solomon Creek Aquifer System. Elevations of the Lakes and Moraines water-bearing sands and gravels decrease to the west and northwest (from 840 to 880 feet m.s.l. in southwest and central to 800 to 850 feet m.s.l. in northwest, north, and west). Domestic well yields for the west, southwest, north and central areas of the system range from 15 to 30 gpm. One highcapacity well in the southwest has a reported yield of 800 gpm and one in the central region a reported yield of 1200 gpm.

To the east and northeast, aquifers of the Lakes and Moraines System appear to lose continuity and to become more scattered and variable. Well yields generally decrease for these two regions (6 to 20 gpm) as opposed to the remainder of the aquifer system. Aquifer elevations in the east and northeast are closely related to elevations of aquifers in the bordering Kendallville and Howe Aquifer Systems.

Near Dallas Lake, Oliver Lake and Atwood Lake, very thick clay sequences are uninterrupted by sand and gravel lenses. Clay layers near these lakes reach up to 200 feet in thickness. The sands and gravels when encountered at depth may be exceptionally thick. Locally, there are saturated thicknesses of granular deposits up to 160 feet near this group of lakes.

In the extreme southern portion of the Lakes and Moraines System, aquifer conditions change abruptly. Wells in this area are often very deep (200 to 360 feet), but produce adequate water for domestic purposes. Yields of 10 to 20 gpm are reported for most wells. Aquifer elevations become highly variable (600 to 850 feet m.s.l.) and exhibit little correlation. Sand and gravel layers may be quite thick (up to 55 feet), but are usually fairly thin (5 to 10 feet), especially in deeper zones. Surficial clays over 100 feet thick are common.

The northwestern portion of the Lakes and Moraines Aquifer System has diverse and irregular terrain due to glacial processes associated with the Saginaw Lobe (fig. 10 and table 2) and to subsequent dissection by major drainage systems. Aquifers of some apparent continuity are present at elevations of 710 to 760 feet m.s.l. Shallower sand and gravel units are present locally at an elevation of about 800 to 825 feet m.s.l. Water levels are quite deep in some areas and depths to water greater than 100 feet have been reported. Surficial sands and gravels are sometimes present, but typically do not contain water because of deep static water levels. Locally, where the deeper sand and gravel aquifer (710 to 750 feet m.s.l.) is from 20 to 40 feet thick, high yields of water can be expected from large-diameter, properly constructed wells.

The Natural Lakes and Moraines Subsystem occurs adjacent to the Solomon Creek and Turkey Creek Aquifer Systems (see cross-hatched area, Plate 1). The subsystem is characterized by a somewhat continuous surficial deposit of sand and gravel. Thicknesses range from 8 to 90 feet but 20 to 30 feet are common. The sand and gravel units thin to the east and northeast towards the main part of the Natural Lakes and Moraines System. Few if any wells are developed in this surficial layer. Deeper sand and gravel layers present within the clays under the surficial deposit are tapped for water supplies. Two aquifers are commonly found at elevations of about 770 and 870 feet and are approximately 4 and 25 feet thick, respectively. Other aquifer layers are sporadically encountered from 730 to 900 feet m.s.l. These layers vary from 8 to 33 feet thick but do not seem to be continuous, nor is their occurrence predictable.

Wells in the Natural Lakes and Moraine Subsystem are typically 80 to 120 feet deep. Average well depths and primary aquifer elevations correlate with the adjacent part of the Natural Lakes and Moraines System to the north and east. Wells in the subsystem have reported yields from 30 to 375 gpm. The more productive wells tend to be in areas closer to the Solomon Creek outwash.

Kendallville Aquifer System

The Kendallville Aquifer System is a highly variable intertill complex. It is characterized by a lack of surficial sand and gravel and the presence of variable, but often thick clays and clay-rich zones that have multiple discontinuous sand and gravel lenses at varying depths.

The Kendallville System as mapped is bounded on the west by indistinct, gradational boundaries with the Natural Lakes and Moraines and the Howe Aquifer systems, and on the south and east by the topographic drainage divide of the St. Joseph River basin. The aquifer system is expected to extend eastward beyond the topographic divide.

Surficial sand and gravel deposits, when present, are merely a thin veneer which overlie the clay/till sequence. Exceptions are present as narrow, thick outwash bands trending northwestward along valleys of present drainageways.

The surficial clay/till layer varies from 5 feet in thickness to more than 100 feet, generally thickening to the south and east.

The Kendallville System and the Natural Lakes and Moraines System to the west are similar except for the ratio of clay to sand and gravel. The Kendallville System is more clay-rich and has less surficial sand and gravel. In addition, sand and gravel zones within the Kendallville are generally thinner and less continuous than those of the Lakes and Moraines System.

Intertill sands and gravels occur within zones in the Kendallville system, but rarely occur at consistent elevations. In the northwestern portion, however, aquifer materials consistently occur from 800 to 850 feet m.s.l. The aquifer materials in this range closely correspond to similar materials in the Lakes and wells. An area of exceptionally low capability exists in southwest Steuben County where one dry hole has been reported. Even here, dry holes are uncommon, however, and domestic yields of 8 to 15 gpm are more typical. Larger diameter wells in southwest Steuben occasionally yield 50 to 70 gpm, and 150 gpm capacities have been reported.

Well yields of at least 10 gpm for domestic supplies are expected for most regions within the Kendallville System, and yields of 15 to 30 gpm are typical. The most productive regions within the Kendallville System are in the northeast and west where respective yields of 1000 gpm and 1400 gpm are reported for larger diameter wells. An area of exceptionally low capability exists in southwest Steuben County where one dry hole has been reported. Even here, dry holes are uncommon, however, and domestic yields of 8 to 15 gpm are more typical. Larger diameter wells in southwest Steuben occasionally yield 50 to 70 gpm, and 150 gpm capacities have been reported.

The northernmost intertill aquifers seem to be hydrologically connected, as reflected in the interrelationship of water levels (Plate 2). Static water levels in the Kendallville System are usually shallow (40 feet or less), but have occurrences from above the surface (flowing wells) to more than 100 feet below.

Howe Aquifer System

The Howe Aquifer System occurs primarily in LaGrange County, but extends eastward into Steuben County. A narrow "leg" of outwash included as part of the Howe system trends northwest-southeast, cutting the adjacent Kendallville Aquifer System in Steuben County into two parts.

The Howe Aquifer System may be described as variable glacial deposits in a predominently clay-rich environment. It is characterized by surficial outwash sand and gravel deposits of variable thickness overlying an altered till plain which includes thinner zones of sand and gravel in a clay-rich intertill deposit. The surficial sand and gravel deposits have been identified by Johnson and Keller (1972) as outwash deposits to the west and ice-contact kame and kame moraine deposits to the system's eastern edge. The outwash sand and gravel is continuous except for minor "windows" where the system is till capped.

Thicknesses of the Howe surficial sand and gravel may reach 145 feet, but thicknesses of 15 to 50 feet are much more common. Although these unconfined deposits have abundant granular material, they are only rarely utilized for water supplies. Most wells are completed in deeper confined sand and gravel layers that alternate with clays in an underlying till sequence.

The intertill system consists of moderately thick clay and clay-rich sequences alternating with lenses of sand, gravel, or a combination of sand and gravel. These lenses, locally continuous at best, average 5 to 25 feet thick, but may reach 100 feet. The tops of sand and gravel lenses characteristically occur between 780 to 805 feet m.s.l. in western portions of the Howe system, and from 800 to 850 feet m.s.l. further east. At least one confined, unconsolidated aquifer is present at depth throughout the Howe system. In some areas, as many as four confined sand and gravel lenses occur above bedrock.

An unexpectedly large clay constituent occurs around Pigeon, North and South Twin and Still lakes. Clay sequences ranging from 25 to 180 feet in thickness (considerably thicker than the clays in the remainder of the Howe Aquifer System) underlie up to 30 feet of surficial sand and gravel. Sand and gravel lenses underlying this clay, however, closely resemble the intertill sequences found throughout the Howe System.

Ground-water availability within the Howe system is excellent. Most domestic wells produce at least 10 to 20 gpm, though rates up to 60 gpm are common. High-capacity wells within the system can produce as much as 2600 gpm.

Well depths vary from 30 to as much as 200 feet, but are generally from 50 to 150 feet. Most wells penetrate lower confined intertill aquifers.

Static water levels throughout the Howe system are at fairly shallow depths, but have occurrences from above the surface (flowing wells) to more than 50 feet below.

Nappanee Aquifer System

This glacial till plain aquifer system consists of a series of zones of interbedded medium to coarse sand and fine gravel separated by thin clay layers within a thick till sequence. The Nappanee Aquifer System is almost uniformly characterized by surficial clay/till, often 80 to 90 feet in thickness, overlying a persistent 3- to 20- foot thick sand and gravel aquifer complex. Typically, the individual aquifers are clustered in a 25- to 30-foot vertical section within the till sequence. This clustering of aquifers is common to this aquifer system which underlies extensive areas in western Elkhart and eastern St. Joseph counties.

Individual aquifers, which locally thicken to 30 feet or more, seldom are found under more than 1 to 2 square miles in a given area. Near Nappanee System boundary edges, the aquifers commonly thicken, and an abrupt change in both the surface topography and aquifer character becomes apparent. In areas adjacent to major streams and river valleys, it is possible that the Nappanee System blends into the outwash deposits contained in the Tributary Valley and St. Joseph Aquifer System.

It is common to have two or more sand and gravel aquifers within a given elevational range (zone), such as near Nappanee, where several discontinuous aquifers are found from about 750 to 800 feet m.s.l. This zone of aquifers does not always appear to be thick enough to be used for well supplies.

At Nappanee, city wells ranging from 150 to 164 feet in depth receive water from the aquifer occurring at elevation 750 feet m.s.l. These wells produce about 1000 gpm each and are completed in about 35 to 40 feet of sand and gravel. A thick sand and gravel aquifer loosely associated with the Nappanee Aquifer System appears to be present in some areas below a depth of 150 to 175 feet.

South of Nappanee in Kosciusko County, a persistent 5- to 20- foot thick sand and gravel complex is frequently encountered below the glacial clay/till at an elevation of about 740 to 770 feet m.s.l. Some wells are completed at a shallower depth. Wells are occasionally completed below the 740- to 770- foot clustering of individual aquifers.

Near Foraker and Wakarusa, the aquifer cluster is found at about 770 to 780 feet m.s.l. Further north toward Dunlap, aquifers within the Nappanee system occur at a lower elevation, typically from about 735 to 770 feet m.s.l.

In the Millersburg area of eastern Elkhart County the cluster of individual aquifers comprising the Nappanee System is at a generally higher elevation (800 to 850 feet m.s.l.) than to the west. Individual water-bearing sand and gravel units are more erratic than those to the west, and well depths and aquifer elevations are more variable. Locally, zones of sand and gravel exceeding 30 feet in thickness can occur, although most units range from 3 to 10 feet. The production potential for high-capacity wells is expected to be less near Millersburg than in other areas of the aquifer system.

Hilltop Aquifer System

The Hilltop Aquifer System is located at the south edge of South Bend. The north boundary of the Hilltop System abuts the St. Joseph Aquifer System while all other boundaries merge into the Nappanee Aquifer System. The St. Joseph—Hilltop contact is marked by a sharp topographic rise from the low, flat St. Joseph outwash valley to the higher and more rugged topography where the Hilltop System is present. There is no noticeable topographic contrast along the gradational Hilltop System Nappanee System contact.

Records for water wells completed in the Hilltop system normally indicate significant thicknesses of sand and fine gravel and few interbedded clay/till lenses. The Hilltop Aquifer System differs from the St. Joseph Aquifer System by virtue of its higher elevation. In contrast to the clay/till dominated Nappanee Aquifer System, the Hilltop Aquifer is typically comprised of 60 to 100 percent sand and gravel.

A variable, but mostly thin, 5- to 50- foot thick clay/till unit is found at the surface throughout much of the Hilltop System. A 4- to 5- mile wide section of thick surficial or nearsurface sand and gravel, locally approaching 100 feet in thickness, extends north-south throughout the central portion of the system. Below, a lenticular 5-to 20- foot thick, clay/till unit overlies a partially confined sand and gravel aquifer unit having a top elevation ranging from 740 to 760 feet m.s.l. Where the lenticular clay/till unit is absent, upper and lower sand and gravel units coalesce. Static water levels for most wells range from approximately 100 feet near the northern edge of the system, to 40 to 60 feet southward.

Continuity of the sand and gravel aquifer units decreases from north to south. Near the contact with the St. Joseph Aquifer System, a persistent 10- to 30-foot thick confined sand and gravel unit is frequently encountered at an elevation of 720 to 690 feet m.s.l. This elevation range nearly matches that of the surficial sand and gravel unit found in the nearby St. Joseph outwash valley, thus suggesting some degree of depositional interconnection between the two systems.

Various aquifers are tapped in the southern portion of the system where a number of wells are finished in the thick sand and gravel sequences. Nearby wells are completed in confined or partially confined aquifer units at elevations of approximately 740 to 780 feet m.s.l. A few wells in the south half of the system have total depth elevations either slightly greater or less than 700 feet m.s.l.

Major residential development overlies much of the west and north portions of the Hilltop Aquifer System, where domestic wells commonly yield 10 to 60 gpm. The City of South Bend Rum Village well No. 2, located at the extreme northwest edge of the Hilltop Aquifer System, pumped 1450 gpm with 31 feet of drawdown during an 8-hour test. In much of the area underlain by the Hilltop Aquifer System, high-capacity wells can be expected to yield from 50 to 250 gpm.

Ground-Water Development Potential

Transmissivity Values

Transmissivity is a measure of the water-transmitting capability of an aquifer. Expressed as the rate at which water flows through a unit width of an aquifer, transmissivity is obtained by multiplying the aquifer's hydraulic conductivity by its saturated thickness.

Fig. 21 shows transmissivity values at various locations throughout the St. Joseph River basin. The wide range of values is due partly to variations in geologic materials and partly to the method used to estimate transmissivity.

The most accurate method of estimating transmissivity utilizes aquifer test data. The next most accurate method utilizes specific capacity data (pumping rate divided by drawdown) which has been adjusted for the effects of dewatering and/or partial penetration of the aquifer. The least accurate method utilizes specific capacity data with unadjusted drawdowns. If the total thickness of the aquifer utilized was unknown, drawdowns could not be adjusted for the effects of dewatering and partial penetration. Fig. 21 is color-coded to show which method was used to estimate each transmissivity value.

For comparative purposes, it is best to examine transmissivity values of the same color, thus eliminating one of the sources of variation. The resulting comparison is based solely on differences in the thickness and permeability of the water-bearing formation.

Interpretation of a given transmissivity value is complicated by the fact that transmissivity is the product of hydraulic conductivity and saturated thickness. Therefore, a given transmissivity value could result from a thick sequence of relatively lowpermeability materials or from a thin sequence of relatively high-permeability materials.

Despite the limitations, fig. 21 is useful in making generalizations on a regional scale. Transmissivities are higher in areas having thick sequences of high-permeability materials (such as in the South Bend area), and lower in areas having thinner sequences of low-permeability materials (such as in northeastern Steuben County).

Recharge

The potential amount of ground water available for development in the St. Joseph River basin is a combination of natural recharge (derived chiefly from precipitation), recharge which can be induced to infiltrate from existing streams, and water in storage.

Natural recharge rates have been estimated based on the prevailing geologic and hydrologic conditions (tables 12 and 13). Applying these rates across an aquifer system yields total system recharge. Summing the totals for each system gives an estimate of the recharge rate to the entire basin. Using this method, the St. Joseph River basin total recharge is estimated to be in excess of 500,000,000 gallons per day.

''Safe yield'' is a term frequently used to describe the amount of ground water which can be withdrawn without exceeding a given criteria. For example, safe yield is often defined as an amount not exceeding average annual natural recharge. However, safe yield estimates based solely on natural recharge are conservative because they ignore the effects that ground-water development may have on the recharge capability of an aquifer. For example, pumping ground water from an aquifer which is hydraulically connected to a river may induce recharge to the aquifer through the streambed. If the hydraulic connection is good, the pumped water will eventually be derived from stream flow reduction, in which case safe yield is limited by an allowable reduction in stream flow.

Safe yield is also defined in terms of the maximum pumpage which will avoid lowering water levels below some predetermined level. For example, it may be decided that for an unconfined aquifer, the maximum allowable reduction in saturated thickness is 50 percent. Analytical and numerical models can then be used to estimate the amounts of water which can be pumped at given locations without exceeding the 50 percent reduction criterion.

Minimum ground-water levels may be legally established by the Natural Resources Commission (IC 13-2-6.1). If established, the minimum level criteria may govern the safe yield of a given ground-water withdrawal facility.

Ground-Water Quality

Rain and snow, the major sources of recharge to ground water, contain small amounts of dissolved substances. However, the natural chemistry of ground water depends primarily on the composition and solubility of rock materials, as well as on the water's temperature and residence time in the materials. As rain infiltrates through the soil, biologically-derived carbon dioxide reacts with the water, forming a weak solution of carbonic acid. Concentrations of chemical constituents such as bicarbonate, sodium, calcium, magnesium, chloride, iron and manganese are increased or added as the slightly acidic water dissolves rock material. These dissolved constituents are increased further as the ground water slowly moves along a flow path to deeper parts of the zone of saturation (aquifer). The chemical composition of ground water may also change by loss or gain of some constituents as the water percolates through layers or materials of varying composition (such as interbedded sand or clay).

With longer residence time, concentrations of dissolved solids in ground water usually increase. Ground water in recharge areas commonly contains lower concentrations of dissolved constituents than water occurring deeper in the same aquifer. Because recharge to intertill aquifers must travel through low permeability till, these aquifers generally contain water which has greater concentrations of dissolved solids

TABLE 12. Aquifer System Recharge

Aquifer System	System Rate	St. Joseph	Elkhart	Kosciusko	LaGrange	Noble	Steuben	Dekalb	System Total
	GPD/Mi.²	MGD	MGD	MGD	MGD	MGD	MGD	MGD	MGD
St. Joseph	500,000	70.9	54.8	-	4.5	-	-	-	130.2
Tributaries	500,000	-	34.3	17.3	-	8.8	-	-	60.4
(Sub-Total)		(70.9)	(89.1)	(17.3)	(4.5)	(8.8)	-	-	(190.6)
Nat. Lakes & Mor.	250,000	-	24.1	11.0	31.9	36.8	-	-	103.8
Transition	300,000	-	-	5.1	-	5.1	-	-	10.2
(Sub-Total)		-	(24.1)	(16.1)	(31.9)	(41.9)	-	-	(114.0)
Nappanee	175,000	8.8	28.3	2.8	2.2	-	-	-	42.1
Howe	500,000	-	1.1	-	76.2	-	44.5	-	121.8
Kendallville	200,000	-	-	-	14.7	19.8	29.1	1.8	65.4
Topeka	300,000	-	-	-	1.2	5.7	-	-	6.9
Hilltop	300,000	10.4	-	-	-	-	-	-	10.4
County Total (MGD)		90.1	142.6	36.2	130.7	76.2	73.6	1.8	551.2

GPD = Gallons per day System Recharge Rate (per square mile); GPD/Mi² x 0.0575 x 10^{-6} = inches/day.
MGD = Millions of Gallons per day Recharge (for total area).

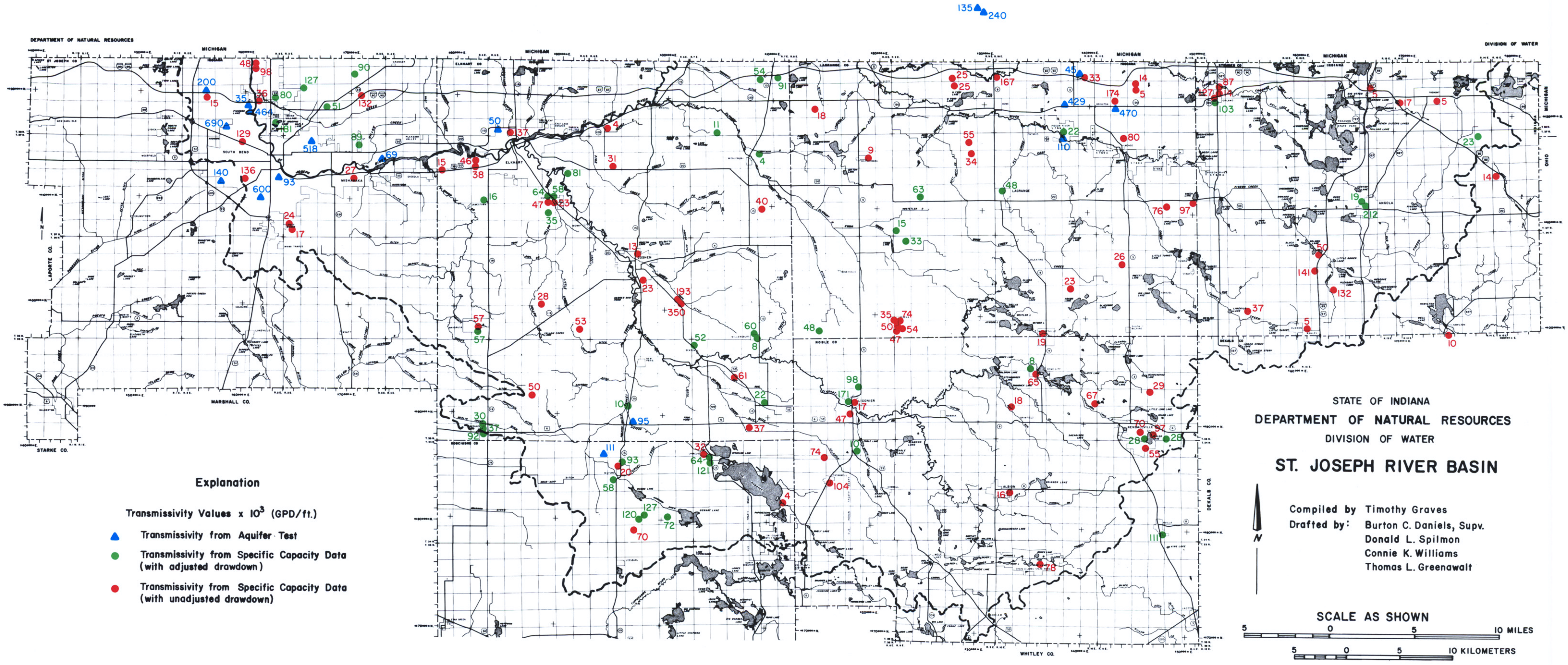

Figure 21. Transmissivity Values

TABLE 13. Aquifer System Area

Aquifer System	COUNTY St. Joseph	Elkhart	Koscuisko	LaGrange	Noble	Steuben	Dekalb	Total System Acres	Total System Sq. Miles
St. Joseph	90,759	70,105	-	5,761	-	-	-	166,625	260
Outwash Tributaries	-	43,902	22,087	-	11,319	-	-	773,308	121
(Sub-Total)	(90,759)	(114,007)	(22,087)	(5,761)	(11,319)	-	-	(243,933)	(381)
Nat. Lakes & Moraines	-	61,727	28,174	81,725	94,322	-	-	265,948	416
Nat. Lakes & Mor. -transition-	-	-	10,796	-	10,961	-	-	21,757	34
(Sub-Total)	-	(61,727)	(38,970)	(81,725)	(105,283)	-	-	(287,705)	(450)
Nappanee	32,288	103,598	10,220	7,949	-	-	-	154,055	241
Howe	-	1,363	-	97,511	-	56,897	-	155,771	243
Kendallville	-	-	-	46,938	63,377	93,008	5,888	209,211	327
Topeka	-	-	-	2,509	12,129	-	-	14,638	23
Hilltop	22,275	-	-	-	-	-	-	22,275	35
Total County Acres (in basin)	145,322	280,695	71,277	242,393	192,108	149,905	5,888	1,087,588	-
Sq. Mi. (in basin)	226.7	438.9	110.8	379	300.6	233.8	9.2		1,699

Miscellaneous-
- •Clay Layer 10,112 (St. Joseph Aquifer System)
- •Thick Clay 1,490 (St. Joseph Aquifer System)
- •Lake Area 883 (Howe Aquifer System)

than outwash aquifers.

Elevated concentrations of natural inorganic components (such as nitrate, chloride and sodium) and of organic components may be induced by man. The susceptibility of an aquifer system to contamination depends on the geologic setting. Contamination is less likely to occur in intertill aquifers because they are protected by layers of semipermeable clay which retard the vertical and horizontal migration of potential pollutants. Outwash and valley-train aquifers, however, are highly susceptible to contamination because protecting clay layers are either discontinuous or absent. Plate 1 briefly summarizes the susceptibility to contamination of seven aquifer systems identified within the St. Joseph basin.

Basin Assessment

Chemical data on samples from a total of 410 water and test wells were used to characterize the ground-water quality in the St. Joseph River basin. Major sources of information included: (1) analyses of 200 water samples collected in a cooperative effort between the Division of Water and the Indiana Geological Survey (summer 1985); (2) Indiana State Board of Health analyses of municipal, public supply, fish hatchery, and test wells; and (3) U.S. Geological Survey data from studies of St. Joseph County (Rosenshein and Hunn, 1962) and northwest Elkhart County (Imbrigiotta and Martin, 1981). Additional data on nitrate contamination were provided by the Indiana Department of Environmental Management (IDEM). Most data summarized in this report were collected between 1975 and 1985; however, older data were occasionally utilized. The water quality analyses used in this study generally typify the composition of water consumed by users rather than the composition of in-situ aquifer water. A number of factors may cause alteration of original aquifer water (for example, contact with plumbing, residence time in a pressure tank, and time elapsed between sampling and lab analysis).

Ground water in the St. Joseph River basin, primarily of the calcium bicarbonate type, is characterized by high alkalinities, high hardness, and mostly basic pH. Major chemical constituents include calcium, magnesium, sodium, bicarbonate, sulfate, and chloride. Less abundant components include potassium, iron, manganese, fluoride, and nitrate. Ranges of selected physical and chemical parameters are summarized in table 14 for the seven aquifer systems within the St. Joseph basin. (See Plate 1 for locations and descriptions of these systems.) Individual data for each of the 410 selected wells are presented in app. 14. Well locations are shown in Plate 3.

Alkalinity, the capacity of water to neutralize acid, is produced by bicarbonate, carbonate, and hydroxide. In the St. Joseph River basin, alkalinity is mainly produced by bicarbonate and ranges from 37 to 456 mg/l (milligrams per liter) as calcium carbonate ($CaCO_3$). Higher concentrations of alkalinity (greater) than 300 mg/l as $CaCO_3$) are found primarily in areas of Nappanee, Natural Lakes and Moraines, and Kendallville Aquifer Systems (Plate 1).

Hardness is principally caused by calcium and magnesium, and is commonly associated with water's effect on soap. Ground water in the basin contains large amounts of calcium and magnesium, and is considered hard to very hard. Hardness ranges from 73 to 580 mg/l as $CaCO_3$ (table 14). Of all wells sampled, 97 percent contain very hard water (hardness greater than 180 mg/l as $CaCO_3$). Although not included in this report, mapped trends of hardness distribution show that ground water in at least half of the basin (mostly within the intertill Nappanee, Kendallville, and Natural Lakes and Moraines Aquifer Systems) has a hardness of greater than 300 mg/l.

The hydrogen ion activity in water (pH) is expressed on a scale of zero to 14. Water with a pH of less than 7 is acidic, greater than 7 is basic, and equal to 7 is neutral. The pH of ground water in the St. Joseph River basin is predominantly basic, but ranges from 6.0 (slightly acidic) to 8.9 (basic), as table 14 shows.

National Interim Primary Drinking Water Regulations (USEPA, 1979a) and National Secondary Drinking Water Regulations (USEPA, 1979b) were examined to determine the suitability of ground water in the St. Joseph River basin for public supply (app. 15; also see app. 10 and table 14). The primary regulations list maximum concentration limits for inorganic constituents considered toxic or harmful to human health. These concentration limits are not to be exceeded in public water supplies. The secondary regulations list recommended concentration limits for inorganic constituents that are not known to be harmful to health but have undesirable aesthetic effects (taste and odor). Secondary drinking water standards are not mandatory and are commonly exceeded in ground-water supplies.

In general, the natural ground-water quality in the basin is within regulation for public supply. However, recommended (secondary) concentration limits for iron and manganese are commonly exceeded in wells throughout the basin. Although iron and manganese are not known to be harmful to human health, they

TABLE 14. Ranges of Chemical Constituents [a]

Constituent	U.S. EPA Drinking Water Standard	St. Joseph River Basin Aquifer System[b]					
		St. Joseph and Tributary Valley	Howe	Hilltop	Nappanee	Natural Lakes and Moraines	Kendallville
Alkalinity (as $CaCO_3$)	-	37.0-376.0	160.0-333.3	187.0-456.0	221.8-402.5	209.3-374.3	262.8-398.3
Hardness (as $CaCO_3$)	-	118-580	174-463	216-364	73-393	217-513	180-576
pH	5.0-9.0[c]	6.0-8.8	6.1-7.9	7.2-7.9	6.9-8.6	6.1-8.0	6.8-8.9
Calcium (Ca)	-	35.0-164.0	67.1-133.0	57.0-94.0	17.0-98.8	59.0-141.7	42.9-158.0
Magnesium (Mg)	-	10.0-41.0	1.0-30.5	19.0-30.0	7.4-36.4	15.0-36.6	17.0-42.4
Sodium (Na)	-	1.5-170.0	1.7-19.4	1.6-21.0	3.4-91.1	2.0-18.0	1.4-88.0
Sulfate (SO_4)	250[c]	1.0-250.0	1.2-144.0	14.0-50.0	0-116.0	0-148.0	<.1-134.0
Chloride (Cl)	250[c]	0-180.0	1.6-35.2	1.8-61.0	1.1-106.0	<.1-43.5	0.7-194.0
Potassium (K)	-	0.4-6.8	0.4-2.2	0.5-2.0	0.5-1.6	0.4-3.0	0.5-6.0
Iron (Fe)	0.3[c]	0-8.9	<.1-3.2	0.01-0.5	<.1-6.4	0-8.8	0.07-8.5
Manganese (Mn)	0.05[c]	0-1.3	0.02-0.4	0-0.2	0.02-0.5	0-0.5	0-0.5
Fluoride (F)	2.4[d]	0-2.7	<.1-1.2	0-0.2	0.2-1.4	0-1.1	0-1.7
Nitrate (NO_3 as N)	10[d]	0-16.0	<.02-15.1	<.02-5.2	<.02-13.6	<.02-20.3	0-7.2
Total Dissolved Solid (TDS)	500[c]	88-773	190-755	245-585	246-655	274-784	331-899
Number of selected wells		167	39	10	43	83	66

[a]Except for pH, all values are in milligrams per liter.
[b]The Topeka Aquifer System was not included because data on only two wells was available.
[c]U.S. EPA National Secondary Drinking Water Regulations.
[d]U.S. EPA National Interim Primary Drinking Water Regulations.

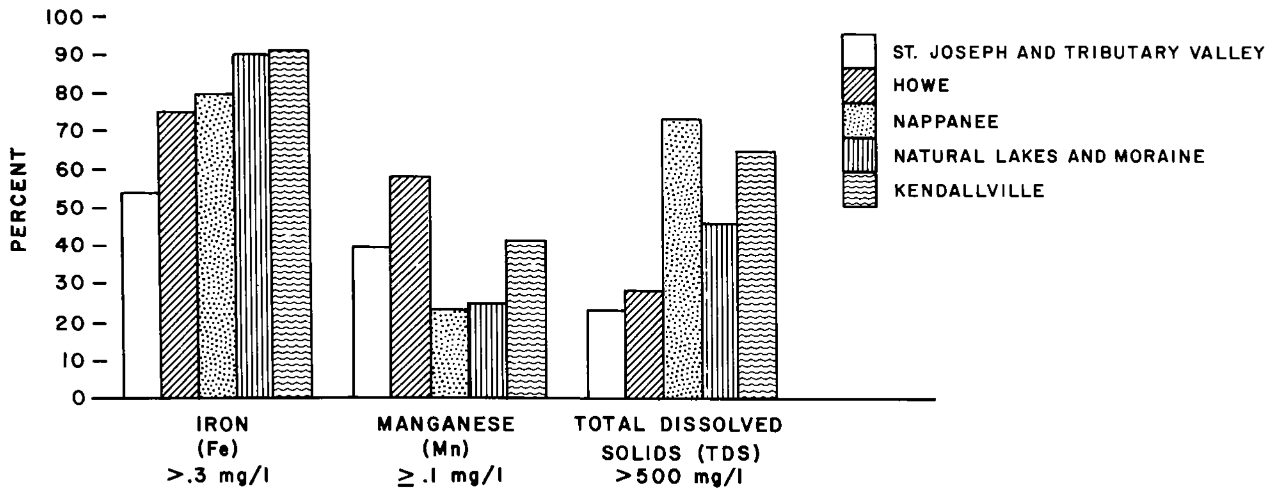

Figure 22. Percentage of Water Samples from Major Aquifer Systems Exceeding Recommended Limits for Iron and Total Dissolved Solids and a Selected Concentration of Manganese

cause taste problems, staining of utensils and laundry, and may clog well screens (app. 15). Concentrations of iron exceeding recommended limits are found in all aquifer systems, as are concentrations of manganese equal to or exceeding .1 mg/l, a selected concentration (fig. 22). Iron concentrations are generally higher (greater than 1 mg/l) in the eastern half of the basin, primarily within the Natural Lakes and Moraines, Kendalville, and (eastern) Howe Aquifer Systems. Lower concentrations (less than 1 mg/l) are commonly found in the St. Joseph, (western) Howe, and Nappanee Aquifer Systems, although some localized areas have values greater than 1 mg/l.

Total dissolved solids (TDS) is a measure of the concentration of mineral constituents dissolved in water. TDS values in the basin (the calculated sum of major constituents expected in an anhydrous residue of a ground-water sample) range from 88 mg/l to 899 mg/1 (table 14). The recommended concentration limit for TDS (500 mg/1) is not exceeded for most wells in the main St. Joseph Aquifer System and Howe System (fig. 22). However, the limit is exceeded in areas of the Natural Lakes and Moraines, Nappanee, and Kendallville Aquifer Systems, as well as the tributary valley portion of the St. Joseph Aquifer System. Sulfate, chloride, and sodium concentrates also do not exceed USEPA's recommended concentration limit; however, values can be locally high (100-250 mg/l).

Fluoride concentrations are less than the maximum (primary) concentration limit of 2.4 mg/l throughout the basin. However, concentrations greater than or equal to 1 mg/l are found in several localized areas, as well as in 15 wells which trend northeast-southwest on the eastern basin edge (fig. 23). The wells in this trend are completed in sediments of the Mississinewa Moraine (deposited by the Erie Lobe) where ground water is known for having elevated concentrations of fluoride (W.J. Steen, IDNR Division of Water, personal communication, 1986).

Natural concentrations of nitrate in ground water originate from the atmosphere in addition to living and decaying organisms. High levels of nitrates can result from leachates of industrial and agricultural chemicals or decaying organic matter such as animal waste or sewage. In the St. Joseph basin, nitrate concentrations greater than the maximum (primary) concentrations limit of 10 mg/l have been found in 13 of the 410 selected wells (nine sampled in summer 1985). These 13 wells (nine of which are less than 60 feet deep) are located mainly in the St. Joseph, Tributary Valley, and Howe Aquifer Systems and sandier areas of the Natural Lakes and Moraines Aquifer System (fig. 23). Forty-six sites (58 wells, primarily shallow), contain lesser concentrations of nitrate between 1 mg/l and 10 mg/l. Twenty-nine of these 46 sites are located in the St. Joseph and Tributary Valley Aquifer System (fig. 23). In general, wells with concentrations of nitrates above 1 mg/l are associated with shallow and/or deep outwash sand and gravel aquifers designated by IDEM as easily susceptible to contamination.

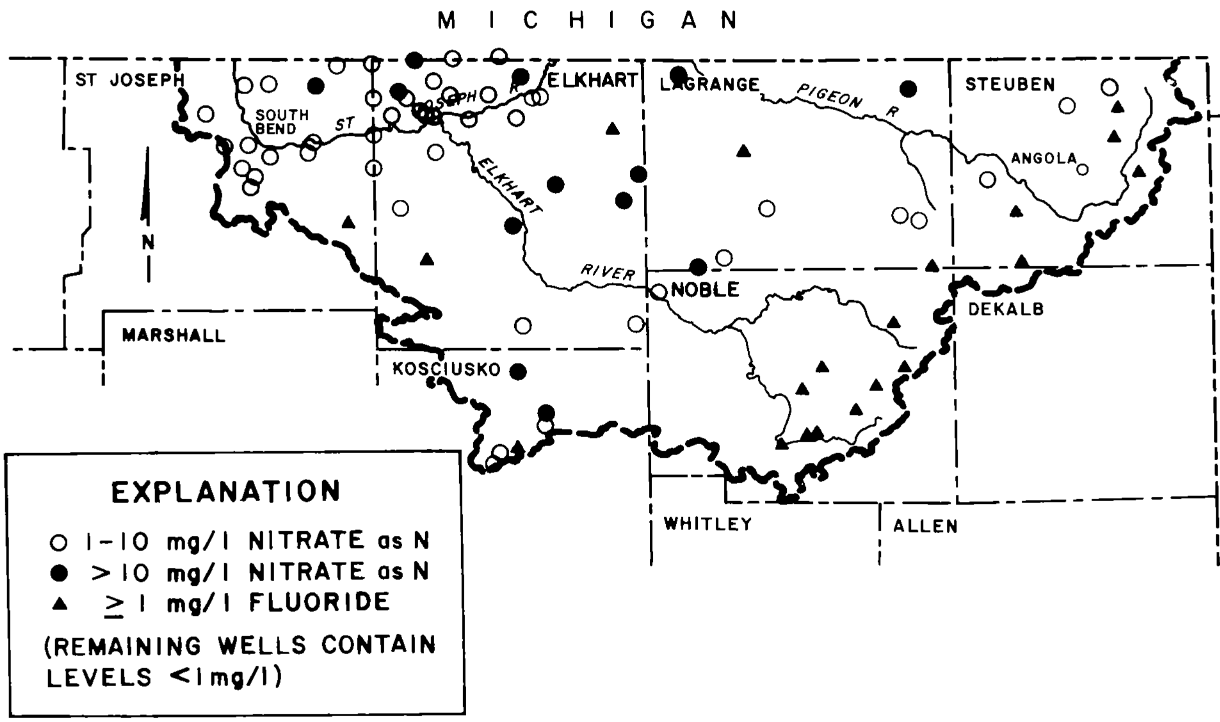

Figure 23. Concentration Ranges of Nitrate and Fluoride

Ground-Water Contamination[14]

A ground-water supply that otherwise would be plentiful can be diminished by contamination from man's activities. Contamination, as defined by IDEM [1986], occurs when concentrations of chemicals are in excess of public drinking water standards, proposed standards, or health protection guidance levels from the U.S. Environmental Protection Agency. To protect Indiana's ground-water resource, officials on state (IDEM and ISBH) and federal (USEPA) levels 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 more susceptible to ground-water contamination than others. The IDEM has designated 11 counties in Indiana— three in the St. Joseph River Basin (St. Joseph, Elkhart and Kosciusko)— as geographic areas where ground-water protection may be most needed. Screening criteria used to identify these areas include: (1) the susceptibility of an area to contamination; (2) the magnitude of current and potential water use; (3) the location of known sites of contamination; and (4) the presence of potential sources of contamination. In general, geographic areas of concern are located near major rivers and highly productive ground-water resources where there is an association among the prevalence of industry, spills, and ground-water or water-well contamination.

In 1986, the Indiana Department of Environmental Management summarized organic and inorganic contamination sites documented in Indiana. In general, substances contaminating ground water in Indiana include volatile organic chemicals, petroleum and petroleum products, metals and heavy metals, chlorides and salts, and nitrates.

Within the St. Joseph River basin, 33 sites of ground-water contamination have been documented by the IDEM. Three sites of contamination have been identified in Steuben County: two in the Howe Aquifer System and one in the Kendallville Aquifer System.

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14 Information in the following paragraphs was summarized from IDEM [1986].

Two sites have been documented in Kosciusko County; five in St. Joseph County; and 23 in Elkhart County. These 30 sites, which occur in counties of major concern, are primarily within the St. Joseph and Tributary Valley Aquifer Systems. In St. Joseph and Elkhart Counties, sites occur predominately in the industrial areas of South Bend and Elkhart. The need for ground-water protection in Elkhart County is being addressed by the Elkhart County Health Department which is implementing an aggressive ground-water protection program.

Nitrates were the contaminating substance at four of the documented contamination sites, according to County Health Department data supplied by the IDEM. Nitrates above recommended limits were found in 23 wells at the following sites: Orland (11) in Steuben County; Leesburg (2) and Milford (2) in Kosciusko County; and south of Middlebury (8) in Elkhart County.

Since 1981, the USEPA has been conducting a survey of 26 volatile organic chemicals (VOCs) in Indiana's public ground-water supplies serving more than 25 customers. These chemicals include both chlorinated VOCs which are associated with hazardous waste disposal and hazardous material spills and aromatic VOCs which are associated with fuel and solvent spills and leaking underground storage tanks. Detectable levels of at least one VOC were found in seven public water supplies in in-basin portions of St. Joseph, Elkhart, LaGrange, Steuben and Dekalb counties. If levels were a risk to public health, corrective action was taken; otherwise, levels are continuing to be monitored. (Contamination of Elkhart's Main Street well field is discussed later in this report.)