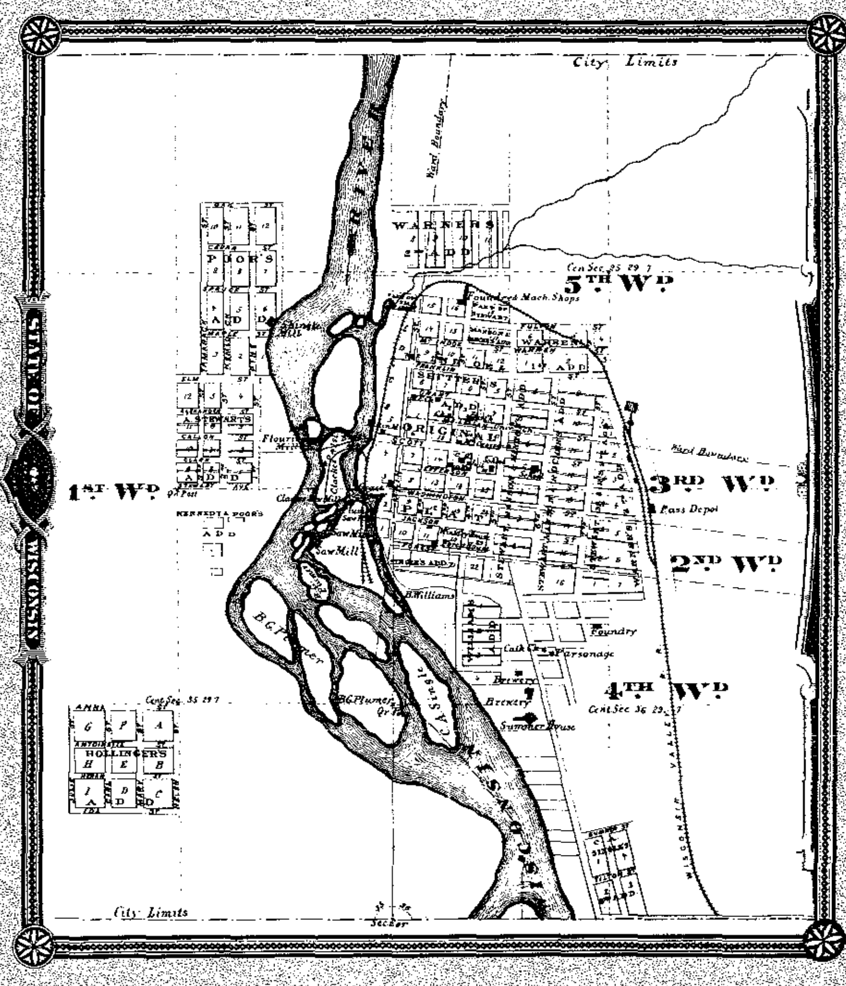
Hydrogeology of the Wisconsin River Valley in Marathon County, Wisconsin

Eloise Kendy and Kenneth R. Bradbury



Wisconsin Geological and Natural History Survey
Information Circular 64
1988

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A description and discussion of the hydrogeologic framework, history, groundwater movement, and potential for groundwater contamination in the Wisconsin River valley in Marathon County, Wisconsin

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Finally, we thank the generous residents of Marathon County who allowed us to install piezometers on their property.

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ABSTRACT

The sand-and-gravel deposits that fill the lower part of the Wisconsin River valley form the most important aquifer in Marathon County, called the Wausau aquifer in this report. This unconfined aquifer is the source of nearly all drinking, irrigation, and industrial water supplied to residents and industries in the valley near the Wisconsin River. Responsible management of the aquifer is therefore critical. Proper management requires a thorough understanding of aquifer characteristics and the groundwater flow system.

In this report we define the basic hydrogeology of the aquifer. Basic resource data have been collected and generated to apply to immediate management problems and future system modeling. These data include summary compilations of historical pumpage and other water-resource developments, hydrogeologic properties of the aquifer, and records of wells constructed in the area. We constructed maps of the water-table elevation, elevation of the base of the aquifer, and attenuation potential of soil. A steady-state model calibration verified that the data presented in this report are sufficient to construct a two-dimensional groundwater flow model at a regional scale.

The Wausau aquifer is bounded by hilly crystalline bedrock and irregularly distributed clay deposits. Pumping tests, piezometer tests, grain-size analyses, and well constructor's reports demonstrate that the aquifer is extremely heterogeneous. Aquifer thickness ranges from about 160 ft in the north to 40 ft in the south, and hydraulic conductivity exhibits a trend ranging from about 10^{-3}ft/s (10^{-1}cm/s) in the north to 10^{-5}ft/s (10^{-3}cm/s) in the south.

Groundwater flow is generally southward and toward the Wisconsin River and its tributaries. Local exceptions that result from groundwater pumping can induce aquifer recharge from the river.

Because the soils overlying the Wausau aquifer provide little attenuation of contaminants, and because the sand-and-gravel deposits that compose the aquifer are extremely permeable, the Wausau aquifer is susceptible to contamination from surface sources. The heterogeneity of the aquifer material and the irregularity of its boundaries make site-specific investigations particularly difficult.

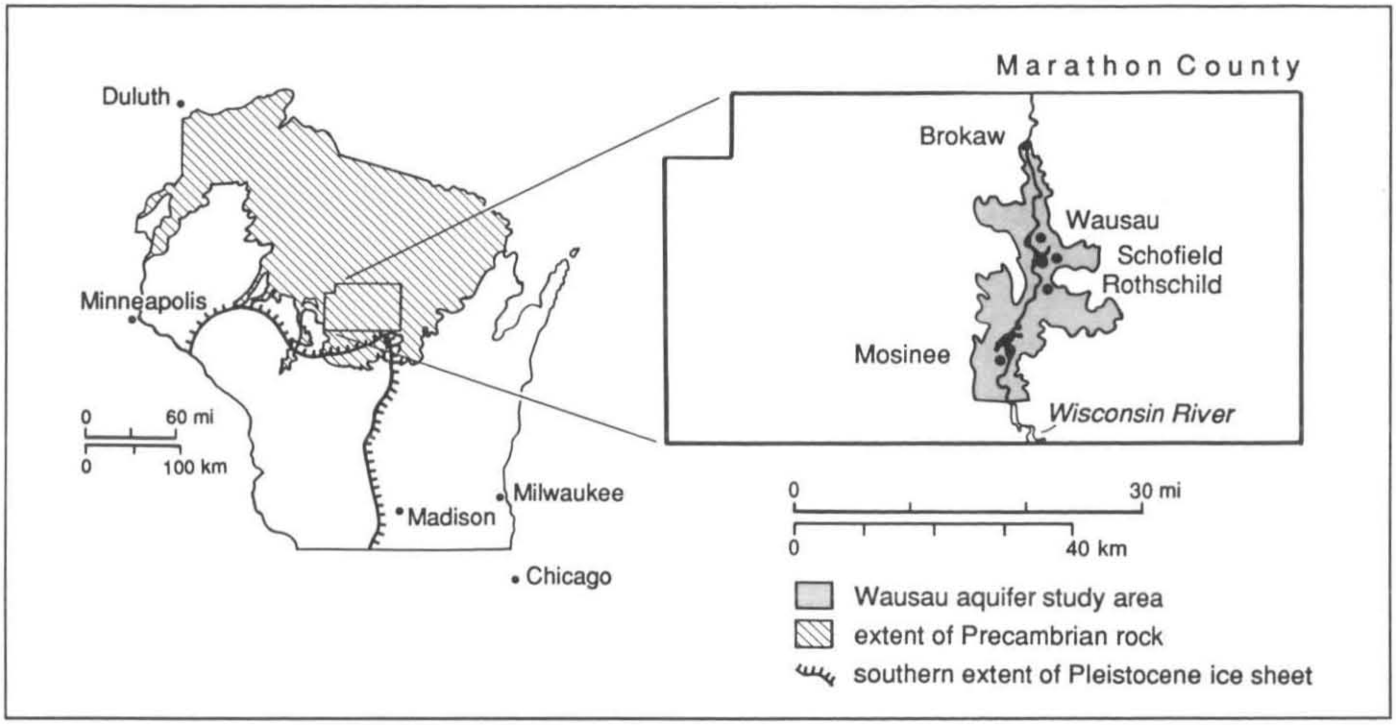

Figure 1. *Location of Wausau aquifer study area in relation to regional geology.*

INTRODUCTION

Background

The sediment that fills the Wisconsin River valley in Marathon County, Wisconsin, constitutes a significant *aquifer* (a saturated permeable geologic formation that will yield significant quantities of water) in north-central Wisconsin, an area of crystalline rocks and clayey glacial deposits of low permeability. In this report, the *unconfined aquifer* (aquifer whose upper surface is the water table) will be referred to as the Wausau aquifer. Plates 1 and 2 delineate the aquifer's horizontal boundaries.

Because of the favorable combination of plentiful surface water from the Wisconsin River and groundwater from the Wausau aquifer, several industries and their associated industrial towns have prospered in the valley for more than 100 years. The aquifer provided the sole source of drinking water to the more than 60,000 people living in the valley in 1986.

In recent years a variety of contaminants, including nitrates, pesticides, and other organic chemicals, has been detected in the groundwater of the Wausau aquifer. Certain contaminant levels have been high enough to force closure of some municipal wells. Several site-specific studies have been conducted to determine the extent and rate of movement of individual contaminant plumes, but until this study there had been no attempt to define aquifer characteristics, delineate groundwater flow paths, quantify groundwater flow rates, and delineate groundwater recharge and discharge areas for the entire aquifer. The results of this study can be used by resource managers to prevent further contamination and ensure the availability of sufficient water to meet public needs; this report can also provide the background information needed to implement site-specific studies and clean-up operations more easily and effectively.

Purpose and scope

The primary purpose of this study was to provide the basic geologic and water-resource data needed to protect and use the Wausau aquifer. These data include lateral and basal aquifer boundaries, hydraulic characteristics of the aquifer, the rate and direction of groundwater flow, and historical land-use and water-use practices. Although chemical data are as important as physical data, chemical analyses were beyond the scope of this report. The information presented here has been interpreted in the context of the entire Wausau aquifer to provide a regional framework that will enhance local investigations as well as regional planning.

Physical setting

Location

Marathon County is located in north-central Wisconsin between 44° and 46° N latitude, and 89° and 90.5° W longitude. The Wisconsin River flows from north to south through the center of the county. This study covered a 20-mile segment of the Wisconsin River valley, which includes the villages of Brokaw, Mosinee, and Rothschild, and the cities of Wausau (county seat) and Schofield. In this area, the valley varies from 0.25 to 10 miles in width (fig. 1).

Climate

A humid, temperate, continental climate characterizes the area: average annual temperatures range from about 10°F in January to 65°F in July. Extreme temperatures have ranged from -40°F in February 1899, to 101°F in July 1921. The area normally receives 32 inches of precipitation annually. One-third of this falls as snow from October to April, and most of the rest occurs during late spring and summer thunderstorms (Wisconsin Public Service Corporation, 1975).

Topography and vegetation

Although most of Marathon County consists of low rolling hills, the topography bordering the study area is more pronounced because of erosion by the Wisconsin River. In fact, the largest relief in the state borders the study area on the west, where Rib Mountain rises 740 ft from its base to a total elevation of 1,942 ft above mean sea level. Rib Mountain is the highest of several bedrock hills that protrude from the relatively featureless valley fill, forming the valley walls that define the borders of the study area. The alluvial valley fill slopes gently southward from an elevation of 1,220 ft at Brokaw to 1,140 ft at Mosinee.

Natural vegetation in the area consisted of dense forests of maple, hemlock, birch, white pine, and red pine (Wisconsin Geological and Natural History Survey, 1965), but these native forests have been logged. Some stands of secondary growth remain on public and paper company land, but much of the area is now covered with shrubs and grasses.

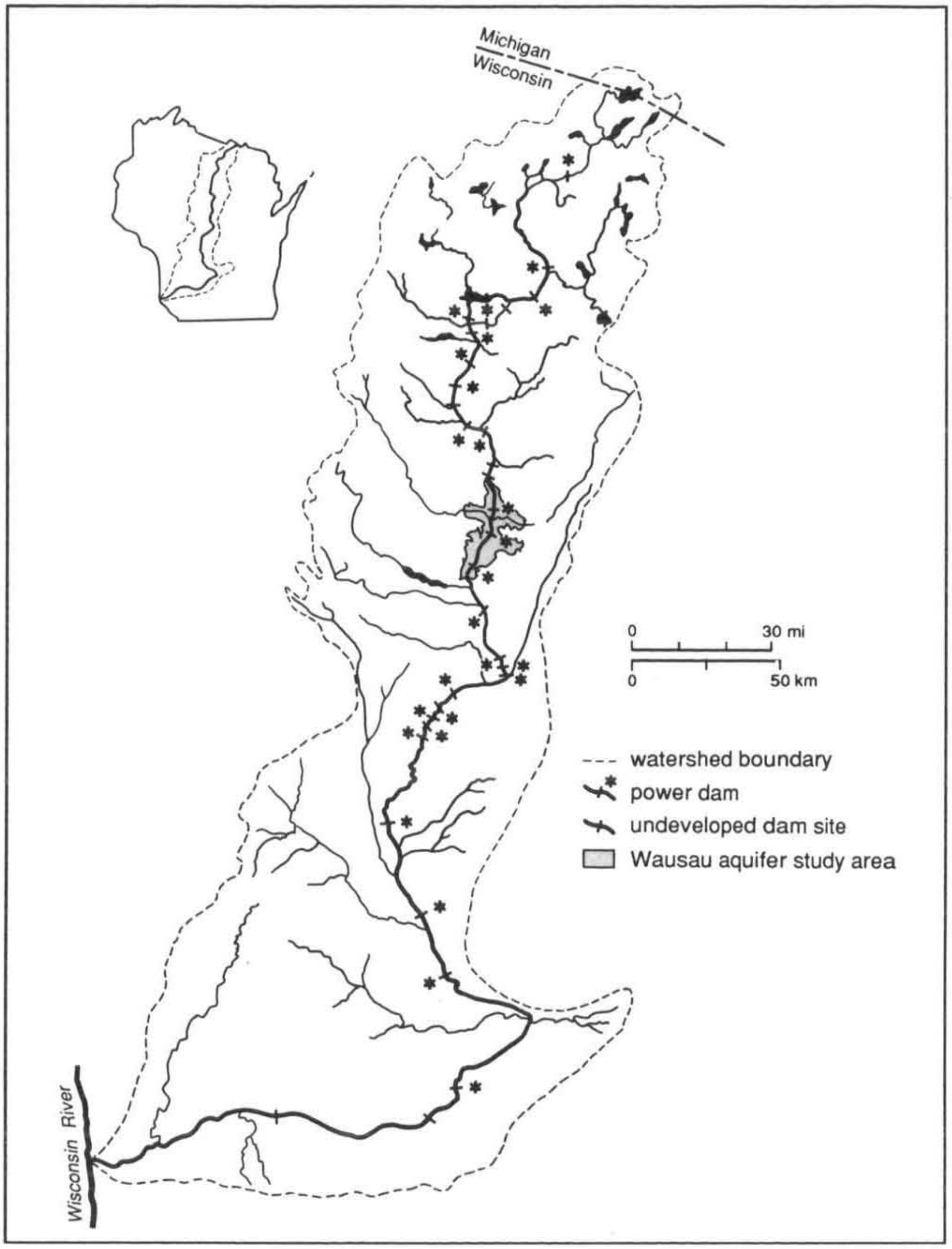

Figure 2. *Map of Wisconsin River basin, showing location of Wausau aquifer study area in relation to entire watershed (after Wisconsin Public Service Co., 1975).*

Hydrology

The Wisconsin River descends 1,071 ft over the 430 miles from its headwaters in Lac Vieux Desert at the Wisconsin-Michigan border to its confluence with the Mississippi River in southwestern Wisconsin (fig. 2). It drains an area of about 12,280 square miles (Wisconsin Public Service Corporation, 1975), making it a major surface-water basin. The Rib, Eau Claire, and Eau Pleine Rivers, as well as numerous minor tributaries, flow into the Wisconsin River in the study area. The average gradient is about 2.5 ft per mile over the entire length of the Wisconsin River, but it is 4.2 ft per mile in the study area. Flow through the U.S. Geological Survey's (USGS) gauging station in Rothschild averages 3,456 cubic ft per second (cfs). The maximum and minimum instantaneous discharges of 75,000 cfs and 678 cfs were recorded on September 1, 1941, and July 27, 1963, respectively (Wisconsin Public Service Corporation, 1975). The Wisconsin has been called the hardest working river in the country; its flow is regulated by 26 power dams that use 640 ft of fall to produce an annual average of 1 billion kilowatt-hours of electrical energy. Twenty-one additional tributary reservoir dams in the upper valley store water during high flow periods for use in the downstream power dams during periods of low flow. In addition to enhancing power production, these reservoirs diminish flood damage and increase recreation potential.

The river is also a major line of groundwater discharge, with groundwater entering from both sides. In Marathon County, groundwater flow is generally from the northwest and northeast toward the north-to-south flowing river (Lippelt and Hennings, 1981). Horizontal hydraulic groundwater gradients in the clayey till are typically about 30 to 70 ft per mile in the county, although gradients are higher near river valleys. The highest horizontal groundwater gradients in the county are found along the Wisconsin River, where the topography is relatively steep and the sediments are permeable. In the valley near Brokaw, the horizontal gradient is more than 200 ft per mile.

Previous work

Several hydrogeologic investigations have included all or parts of the Wausau aquifer. Weidman (1907) prepared cross sections through Wausau and Mosinee to illustrate his discussion of the alluvial deposits along the Wisconsin River. Weidman and Schultz (1915) described municipal wells in Wausau and Mosinee, including analyses for inorganic constituents in seven groundwater samples.

Most of the information in this report is also contained in a thesis by Kendy (1986), along with additional details of computer modeling and data analyses. In addition, Muldoon (1987) and Attig and Muldoon (in press) presented information about the hydrogeology, hydrostratigraphy, and Pleistocene geology of Marathon County outside of the Wisconsin River valley.

Other recent attempts to characterize the hydrogeology of central Wisconsin include Bell and Sherrill (1974) and Devaul and Green (1971). Lippelt and Hennings (1981) used data from well constructor's reports to produce water-table and probable-yield maps of Marathon County. The yield map in particular distinguishes the Wausau aquifer as a discrete hydrostratigraphic unit, physically separated from all other high water-yielding geologic material.

Some site-specific or special-purpose research has also included parts of the study area. Weeks (1969) used pumping tests to determine an anisotropy ratio of horizontal to vertical hydraulic conductivity of 2:1 in Mosinee. Summers (1972) delineated the bedrock surface, water-table configuration, Pleistocene geology, and saturated thickness of the Wausau aquifer in Rothschild as part of a study of the specific capacity of crystalline rocks. Socha (1983) used satellite imagery to identify a large lineament running along the east side of the Wisconsin River in Marathon County.

Several investigations have focused on site-specific hydrogeologic problems. Wisconsin Public Service Corporation (1975) compiled an exhaustive environmental impact report prior to the construction of the Weston power generating station 8 miles south of Wausau. Other investigations include studies of the groundwater supply serving Rothschild Village (Becher-Hoppe Engineers, Inc., 1962) and Brokaw Village (Layne-Northwest, 1970), leakage from the Wausau Dump (MacDonald, 1974) and from an abandoned city of Wausau landfill

(CH2M Hill, 1986), groundwater flow near the Wausau Paper Mill in Brokaw (Camp, Dresser & McKee, 1982; Ashco, Inc., 1985; Geraghty and Miller, 1986) and near the Marathon Paper Mill in Rothschild (Wright, 1985), and groundwater contamination in Wausau municipal well fields (Weston, Inc., 1985; STS Consultants, Ltd., 1985).

HISTORICAL USE OF THE WISCONSIN RIVER AND WAUSAU AQUIFER

Cause and effect relationships

The effects of civilization on groundwater flow in the Wausau aquifer have never been systematically documented. However, we determined that the Wausau aquifer has experienced three somewhat overlapping phases of human impact. In the first phase, dams were constructed, which caused large-scale alterations in groundwater flow patterns. In the second phase, groundwater pumping altered local flow. In the third phase, groundwater-quality degradation resulted from industrialization. The example in figure 3 illustrates some of these changes.

The turn-of-the-century configuration of the Wisconsin River near Rothschild and probable water-table contours are shown in figure 3A. The water-table configuration is hypothetical; the river configuration was surveyed by Smith (1906). The river represents base level, the lowest level of the water table on either side of the river. The river elevation therefore determines the gross shape and position of the water-table contour lines.

In the first phase of development, construction of the Wausau Dam significantly changed the river configuration (fig. 3B). Above the dam, the river was widened and its *hydraulic gradient* (ratio between the difference of elevation and the horizontal distance between two points) decreased substantially. As a result, groundwater levels rose, as shown by the position of the 1,170-foot contour line. Groundwater that previously discharged to the river instead discharged along the edges of the lake at a higher elevation than before. Below the dam, the sudden water-level drop created an extremely steep water-table gradient, resulting in concentrated groundwater flow toward the base of the dam. Downstream, flow remained unchanged. The water-table contours in figure 3b are hypothetical.

In the next phase of development, groundwater pumping wells created local cones of depression. In some areas, such as Wausau and Schofield, pumpage has been so extensive that the cones appear as closed contours on the water-table map. West of southern Lake Wausau, pumping has altered groundwater flow to a lesser degree, as shown in figure 3c. Much of the groundwater that discharged to the river prior to pumping now discharges to wells. In addition, the hydraulic gradient near the river has been reversed in some places, and water flows from the river into the aquifer. In general, well pumping altered groundwater flow on a more local scale than dam construction. However, only pumping actually reversed the flow, significantly reducing groundwater discharge to the Wisconsin River, and in some places inducing recharge from the river.

Historical summary

It is important to document historical changes in groundwater flow patterns to construct a pre-development water-table map. A groundwater modeler could

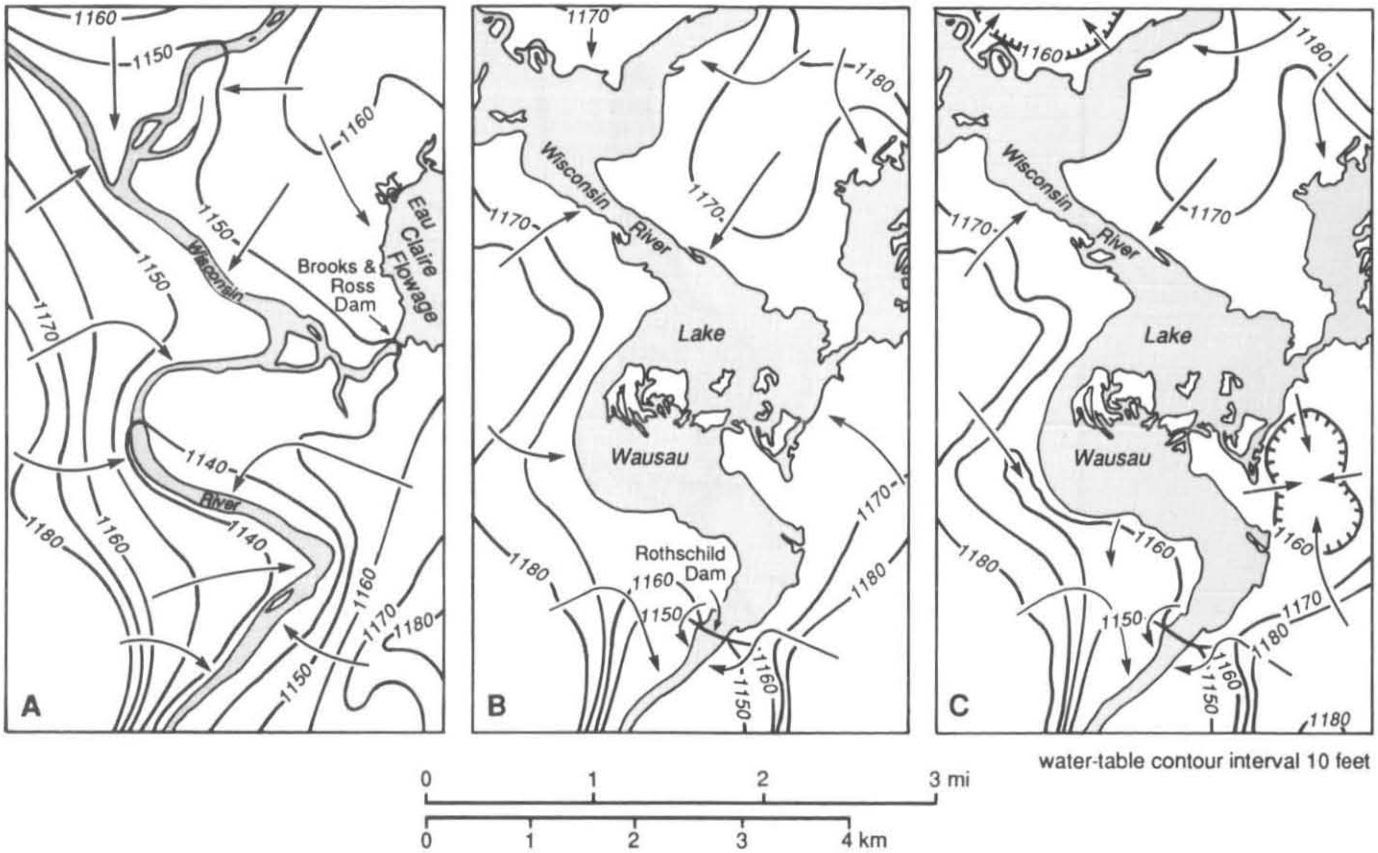

Figure 3. *Probable effects of dam construction and well pumping on groundwater flow regime near Rothschild. Arrows indicate general groundwater flow directions.*

A. River configuration (Smith, 1906) and probable water table before development of Rothschild area, between 1860 and 1909.

B. Construction of the Rothschild Dam in 1909 widened the Wisconsin River and significantly decreased the hydraulic gradient above the dam and increased the gradient directly below the dam. Regional changes in the groundwater flow pattern resulted.

C. From 1885 to the present, pumping wells have created drawdown in the water table, resulting in the present groundwater flow pattern.

then calibrate the aquifer's response to future stresses on the basis of its historical responses to past stresses. Unfortunately, no historical water-table data exist for the Wausau aquifer. Past water tables must be inferred from available data pertaining to possible causes of change, such as dam construction or well pumping.

The land overlying and surrounding the Wausau aquifer was included in an 1836 treaty with the Chippewa Indians. The treaty ceded a strip of land 6 miles wide and 40 long miles along the Wisconsin River to the U.S. government (Ladu, 1907; Snyder, Van Vechten & Co., 1878). Almost immediately thereafter, non-Indians began to settle the land and alter its resources for their use. By 1850 dams were built across the two largest falls (B. Sturtevant, Wisconsin Department of Natural Resources, verbal communication, 1986).

At that time, Marathon County's population of about 500 was almost entirely sustained by the growing timber industry (Fenhaus, 1985). By 1909 all the falls

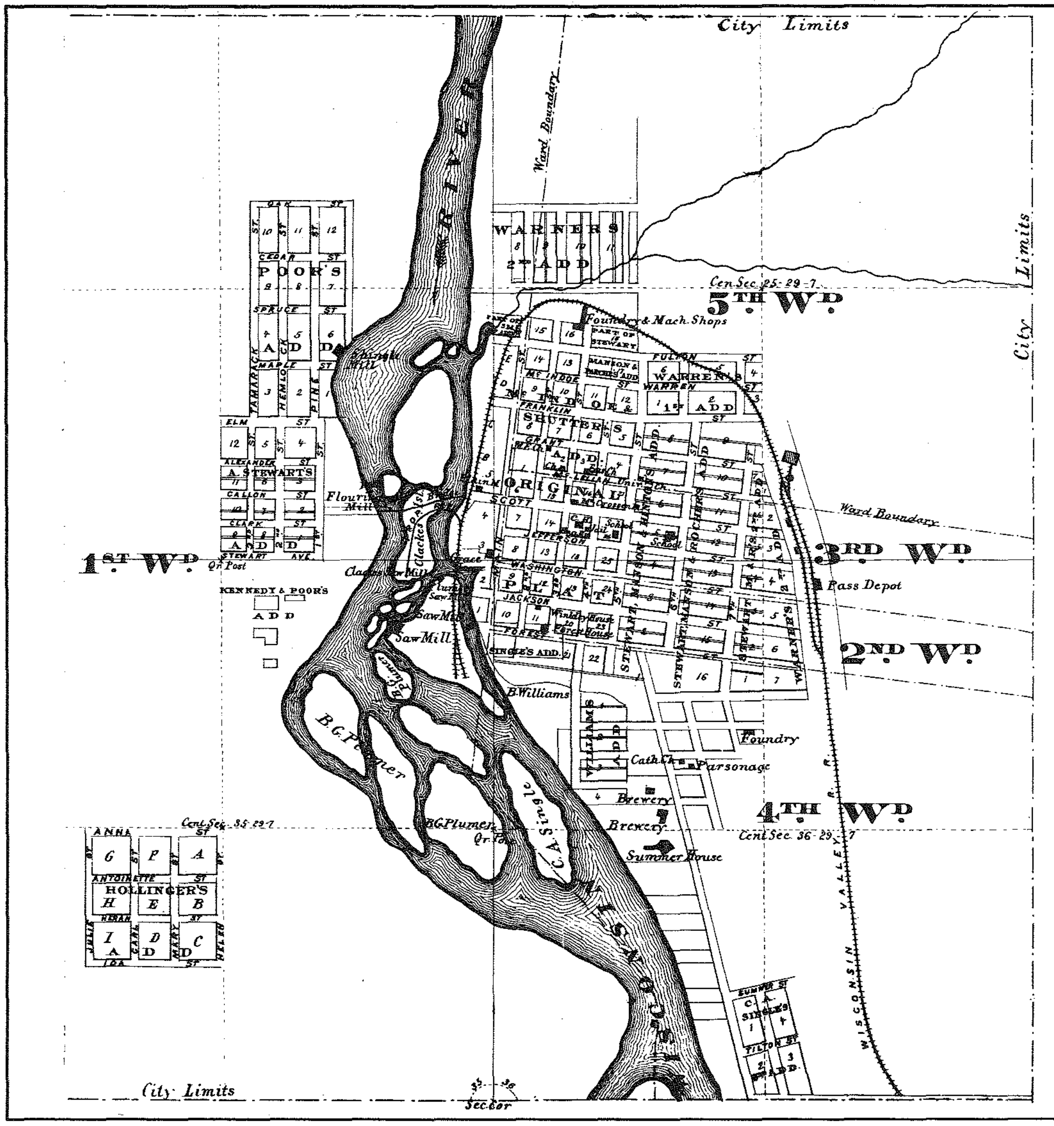

Figure 4. *Map of Wausau in 1877. Reduced from original in Snyder, Van Vechten & Co. (1878).*

documented by Smith (1907) had been dammed (B. Sturtevant, Wisconsin Department of Natural Resources, verbal communication, 1986). This completed the first phase of change in the groundwater flow regime (fig. 3b).

Lumber and farming continued to be the county's mainstay until the 1870s, when the rate of immigration suddenly began to increase (Snyder, Van Vechten & Co., 1878). The sudden growth, which encompassed all of Wisconsin (Zaporozec, 1979), was probably the motivation for the *Historical Atlas of Wisconsin* (Snyder, Van Vechten & Co., 1878). The atlas contains a map of Marathon County, in addition to a more detailed map of the Wausau area (fig. 4). Unfortunately, the 1878 maps do not include topographic contours. However, the heights of the falls were documented in 1899 (Renshaw, 1902; *The Central Wisconsin*, 1900; table A-1), and the Wisconsin River was carefully profiled in 1906 (Smith, 1907; Weidman, 1907; table 1). In addition, L.S. Smith estimated the power potential of each fall in 1906-7 (Weidman, 1907; table A-2).

Table 1. Profile of Wisconsin River in Marathon County, 1907 (From Weidman, 1907)

Station	Distance between stations (ft)	Elevation (ft)	Total descent between stations (ft)	Gradient between stations (ft per mile)
Line between R6E & R7E	--	1106.0	--	--
Mosinee Highway bridge	2.2	1114.0	8.0	3.7
Mosinee dam, foot	0.2	1122.0	8.0	40.0
Mosinee dam, crest	--	1127.7	5.7	--
Black Creek, mouth	3.4	1129.3	1.6	0.5
Cedar Creek, mouth	3.5	1133.5	4.2	1.2
Eau Claire R., mouth	5.3	1142.0	8.5	1.6
Big Rib River, mouth	1.3	1145.8	3.8	3.0
Wausau lower bridge	2.1	1153.5	7.7	3.7
Wausau dam, foot	1.0	1174.0	20.5	20.5
Wausau dam, crest	--	1180.0	6.0	--
Brokaw, below	5.3	1185.7	5.7	1.1
Brokaw, above	--	1201.2	15.5	--

Groundwater pumping also influences the water table, as illustrated in figure 3c. In other parts of the aquifer, pumping creates cones of depression that are too small to appear on figure 3c or plate 2. When Wausau Water Works began pumping its first well at 2,100 gpm in 1885, the second phase of water-resource development--which continues to the present--began. The establishment of the Water Works probably resulted from a sudden population expansion (Zaporozec, 1979) as well as the increased fire hazard and dry private wells caused by low precipitation in 1881. Kendy (1986) compiled all available pumping records for Brokaw, Wausau, Schofield, Rothschild, and Mosinee public water supplies. Pumpage is invariably highest during the summer and lowest in the winter. This seasonal effect is more evident than the long-term increase. The increased demand due to population growth partly accounts for increasing pumping rates.

The rate of development steadily increased as farmland was gradually converted to residential and industrial tracts. The local industry diversified to include paper and food packaging, building materials, dairy products, electric motors, boxes, road-building and industrial machinery, veneers, and red granite monuments and materials in addition to three of the nation's most important paper mills (Fenhaus, 1985). Consequently, recent history of the Wausau aquifer is dominated by accounts of groundwater contamination, marking the third phase of human impact on the Wausau aquifer. Contamination by volatile organic compounds (VOCs) and their derivatives, salt, pesticides, and landfill leachate have affected about 45,000 residents of the Wausau area (about 60% of the population) in the 1980s (Wisconsin Department of Natural Resources, 1986). The typical approach to solving these problems has been to install treatment facilities. Schofield, Rothschild, and Wausau treat their public water supplies with expensive air-stripping systems to remove VOCs.

Prompted by reports of nearby contamination, the town of Rib Mountain has taken the creative approach of delineating the recharge area for its newly installed wells and educating the public and using local land-use controls in an attempt to protect its water supply (Hennings and others, 1985). Thus, the Rib Mountain Sanitary District has set a precedent for the fourth phase: groundwater protection prompted by public awareness of its necessity.

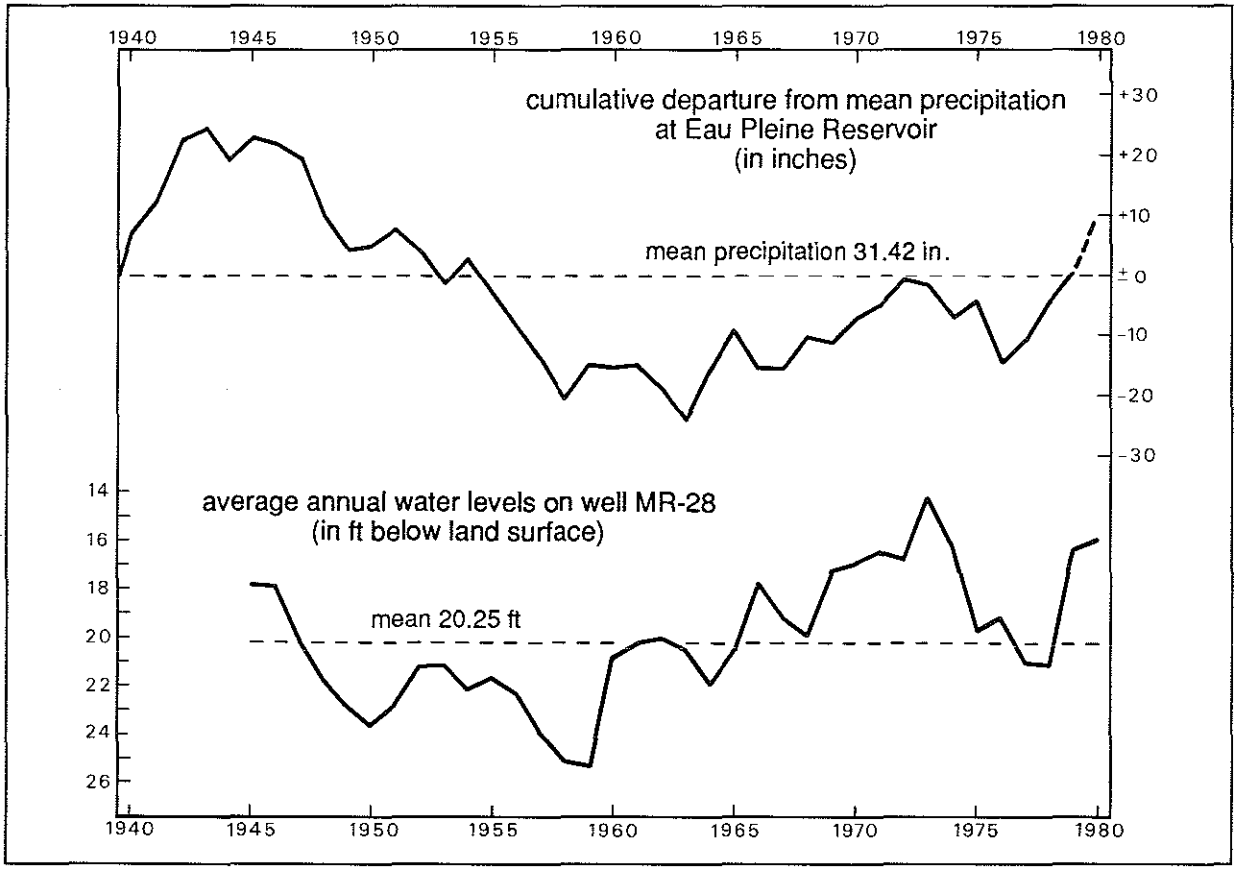

Figure 5. *Correlation between precipitation and water level in well MR-28. Water level responds slowly to precipitation because well is located in an upland area.*

Appendix A contains a detailed chronology of historical actions that have affected groundwater resources along the Wisconsin River in the study area.

Sources of additional historical water-level data

Although continuous records of water-table levels (since 1968) exist for only one well in the Wausau aquifer (Zaporozec, 1980), it may be possible to reconstruct approximate historical water levels for other parts of the aquifer. Figure 5 shows the relationship between precipitation and water-table levels in a well in outwash near the Wausau aquifer study area (fig. A-1, site 6). Because this well is in an upland area, it responds sluggishly to precipitation. Water levels in low-lying areas respond more rapidly.

Climatological data have been recorded for Wausau since 1894 (U.S. National Weather Service, 1980-86). The temperature, precipitation, and snowmelt information contained in these records could all be used to estimate historical groundwater elevations. In addition, the USGS operated river stage gauges on the Little Rib River from 1914-16 (fig. A-1, site 7; Railroad Commission of Wisconsin, 1924), Bull Creek from 1944-51 (fig. A-1, site 22; supplement to Smith, 1908), and the Wisconsin River at Rothschild from 1944 to the present (fig. A-1, site 18; supplement to Smith, 1908). The Wisconsin Valley Improvement Corporation independently gauges river levels at the dams in Wausau, Rothschild, and Mosinee.

HYDROGEOLOGY OF THE WAUSAU AQUIFER

Sources of data

Existing records

Much of the data used for the tables, figures, and plates in this report and its associated appendices have been compiled from the following sources:

- Logs of high-capacity wells published by the Wisconsin Geological and Natural History Survey (WGNHS) Subsurface Laboratory. Typical uses of these wells include irrigation, municipal water supply, and industrial use. Data used from these logs are compiled in appendix B under the well numbers assigned by WGNHS that begin with the county code, **MR**.
- Well constructor's reports filed with the Wisconsin Department of Natural Resources (WDNR) by area well drillers. The water from these wells is typically used in homes, farms, and small businesses. About 5,000 well constructor's reports were used for this project; data from a representative part of these are compiled in appendix B under arbitrarily assigned well numbers beginning with the prefix, **WC**.
- Reports of soil and rock borings by the Wisconsin Department of Transportation (WDOT).
- Conversations with Wausau area well drillers.
- Data on water levels and subsurface material from ongoing projects of the WDNR.
- Topographic maps published in 1982 by the USGS in cooperation with the Wisconsin Division of Highways and WGNHS at a scale of 1:24,000 (7.5-minute series).
- Reports prepared by consultants concerning various aspects of the Wausau aquifer (Ashco, Inc., 1985; Becher-Hoppe Engineers, Inc., 1962; Donohue and Associates, 1984; Geraghty and Miller, Inc., 1986; Layne-Northwest, 1970; MacDonald, 1974; STS Consultants Ltd., 1984 and 1985; Weston, Inc., 1985; Wisconsin Public Service Corporation, 1975).

Drilling and piezometer installation

To supplement the data in areas where existing wells were sparse, the WGNHS installed 17 piezometers for this study. These piezometers were installed using either solid-stem augers or mud-rotary equipment. Geologic samples obtained during drilling were carefully logged and studied by the staff of the WGNHS Subsurface Laboratory. Appendix C, part 1, contains logs of these piezometers. Water levels in the piezometers were monitored for up to one year. Appendix C, part 2, contains these water-level data.

Geophysical survey

To obtain data on the thickness of the Wausau aquifer beneath the Wisconsin River and Lake Wausau, the WGNHS and USGS carried out a geophysical survey in October 1986. This survey used marine seismic reflection equipment mounted in a boat to profile unlithified materials beneath the river. The survey successfully identified the bedrock surface at 50 locations between Brokaw and Mosinee. Appendix D contains a compilation of the data obtained during this survey.

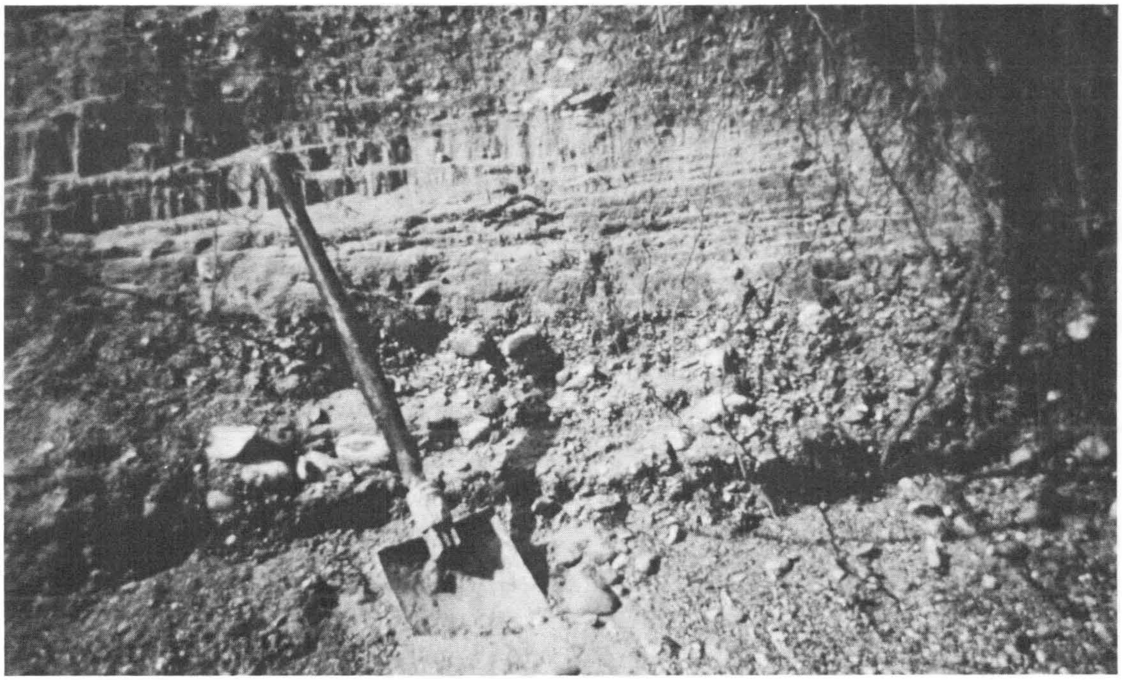

Figure 6. *Outcrop of material similar to that making up the Wausau aquifer, illustrating heterogeneity of the deposits. Note large variety of grain sizes present.*

Morphology

Geologic origin and stratigraphy of deposits

In Marathon County, the Precambrian consists of Early Proterozoic metavolcanic and granitic rock that was intruded by Middle Proterozoic syenite and associated granitic bodies (LaBerge and Myers, 1983). These younger bodies include the Wausau and Stettin syenite and the Ninemile granite. The Wausau syenite crops out extensively west of the Wisconsin River. The Ninemile granite forms most of Rib Mountain; the tops of Rib Mountain and Mosinee and Harwood Hills are large quartzite inclusions.

The Wisconsin River runs along the eastern margin of the Wausau and Ninemile bodies and may occupy a regional Precambrian fracture zone. Some of the tributaries of the Wisconsin River, including the Eau Claire, Eau Pleine, and Rib Rivers, occupy valleys defined by Precambrian fault zones.

In many places, beneath and surrounding the Wausau aquifer, the Ninemile granite has weathered to a poorly sorted, clayey residuum called grus; local drillers commonly report this material as rotten or decomposed granite. The residuum is recognizable by its high silt and clay content and low sand content, and by its stratigraphic position directly over unweathered bedrock. Angular granitic rock fragments are often present, including angular feldspar fragments that rarely occur in the outwash. Because the residuum is several orders of magnitude less permeable than the sand and gravel, it acts as a boundary to groundwater flow.

An eroded upland, partly covered by Pleistocene glacial sediment derived from late Wisconsin terminal moraines of three separate glacial lobes, surrounds the study area. Attig and Muldoon (in press) described the stratigraphy and glacial history of this area; Muldoon (1987) and Muldoon and others (1988) discussed the hydrogeologic properties of Pleistocene sediment outside the

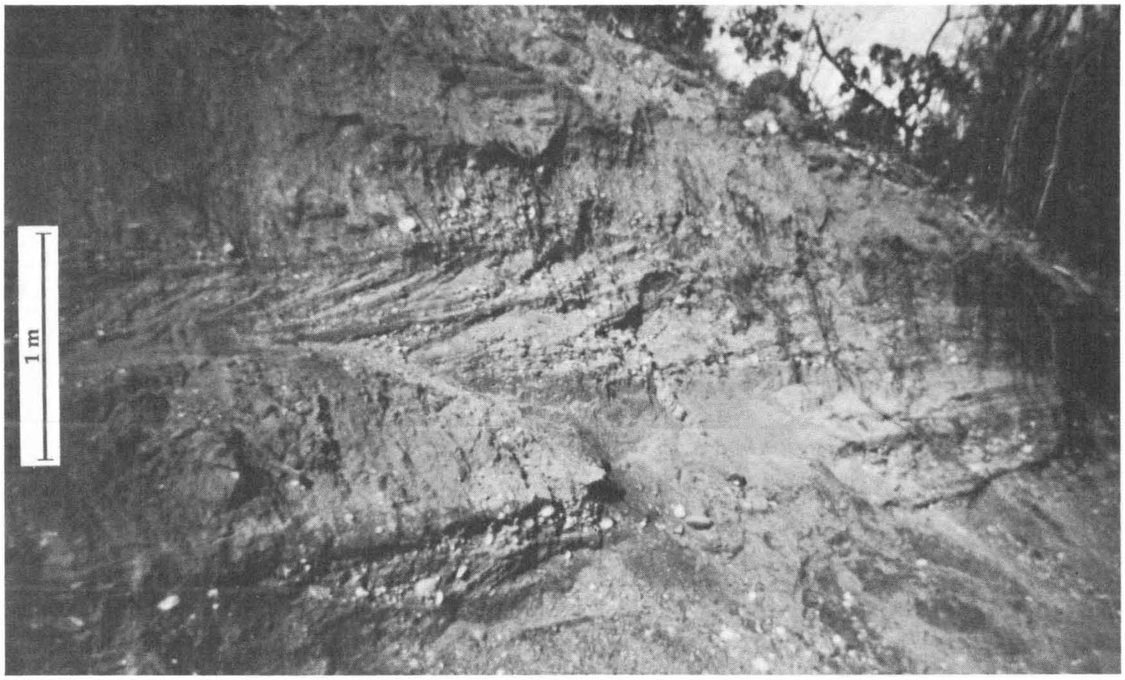

Figure 7. *Outcrop of material similar to that making up the Wausau aquifer, illustrating anisotropy of the deposits. Stratification and cross-bedding were created by changing flow velocities during deposition and rapid aggradation of stream channels.*

Wisconsin River valley. The glaciers that contributed outwash to the study area traversed a complex of Precambrian rocks, as shown by the large variation in lithologies of pebbles in the glacial sediment. The Green Bay Lobe deposits also contain dolomitic pebbles from the east (Mickelson and others, 1974). Although no till has been found in the Wisconsin River valley itself, a variety of lithologies occurs in the moraines surrounding the Wausau aquifer.

When the last continental glaciers reached their maximum extent, the Wisconsin River and its tributaries carried huge amounts of outwash away from the ice margin. These major drainage outlets had highly variable discharges and large debris loads that resulted in braided-stream channel deposits filling the valleys. These deposits typically consist of stratified, often cross-bedded, well rounded to angular sand and gravel (figs. 6 and 7).

Figure 8 shows the results of standard mechanical sieve analyses of several samples of meltwater stream sediment from the Wausau aquifer. These curves were used to determine the coefficient of uniformity, C_u,

$$C_u = R_{40}/R_{90} \qquad (1)$$

where R_{40} and R_{90} are the grain diameters that correspond to 40 and 90 percent retained on a grain-size curve (fig. 8). A sample having a uniformity coefficient of less than 4 is generally considered to be a uniform, or well sorted, material (Dunn and others, 1980, p. 27), which means that all the grains in the sample are of about equal size. Three of the samples shown in figure 8 have coefficients of less than 4 (table 2) and are therefore of uniform grain size, as is typical of stream deposits (Friedman and Sanders, 1978). The test well, which was installed at the site from which these samples were taken, produced enough water to warrant the installation of a high-capacity municipal well.

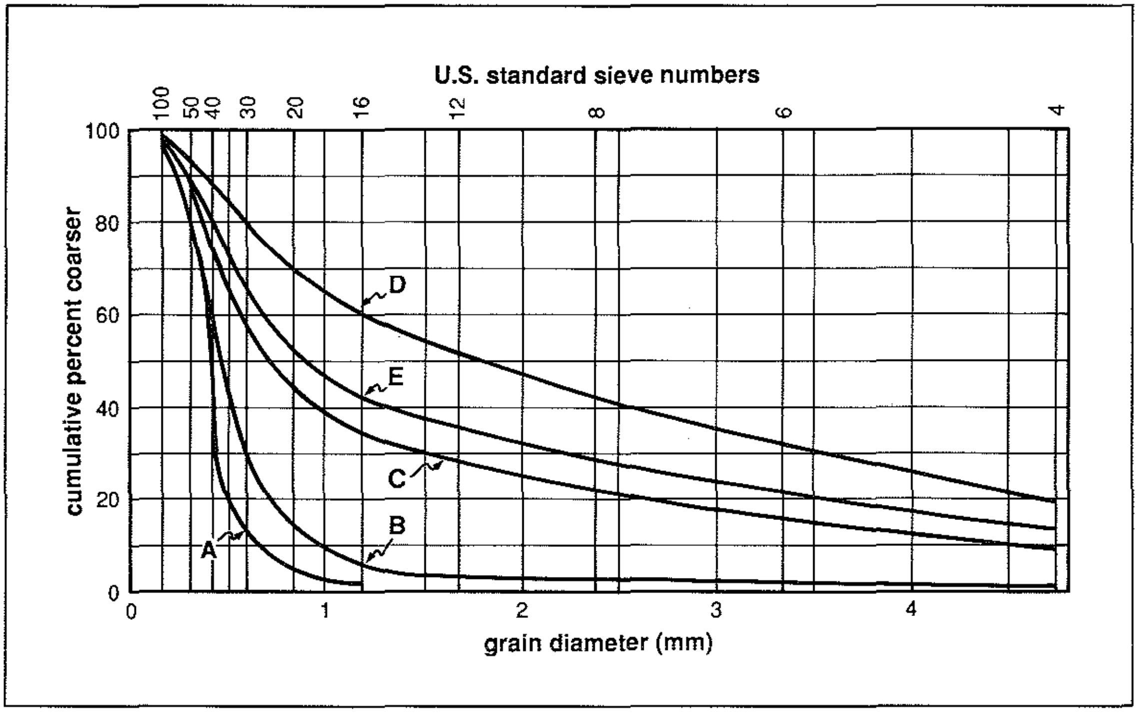

Figure 8. *Graphs of grain-size analyses for five samples from the same borehole in the Wausau aquifer. The depths from which samples are recovered are 100 to 115 ft (A), 115 to 125 ft (B), 125 to 130 ft (C), 130 to 135 ft (D), and 135 to 150 ft (E). Source: Sand analysis report to city of Wausau for test well at Bugbee and Tienery Streets.*

Table 2. Coefficients of uniformity for aquifer samples plotted in figure 8.

Sample	Depth (ft)	R_{90} (mm)	R_{40} (mm)	$Cu = \frac{R_{40}}{R_{90}}$
A	100-115	0.22	0.42	1.9
B	115-125	0.22	0.53	2.4
C	125-130	0.28	1.00	3.6
D	130-135	0.39	2.70	6.9
E	135-150	0.29	1.40	4.8

*By linear extrapolation

The outwash deposits are extremely heterogeneous at the scale of depositional bedding (fig. 9). Stratigraphic units within the outwash are virtually impossible to correlate laterally, especially perpendicular to the depositional flow direction. For example, two test holes drilled by the city of Wausau within 500 ft of one another contain no identical sand or gravel units from the same elevation (fig. 10). The inability to correlate sand and gravel beds is further complicated by the presence of at least three river terraces that formed in response to repeated degradation and aggradation of the outwash valleys as environmental conditions changed.

Sand-and-gravel beds exert strong control over the groundwater flow direction. In the saturated zone, water preferentially flows through well sorted, coarse-grained material; less permeable material inhibits groundwater flow. However, because beds usually cannot be horizontally correlated in the Wausau

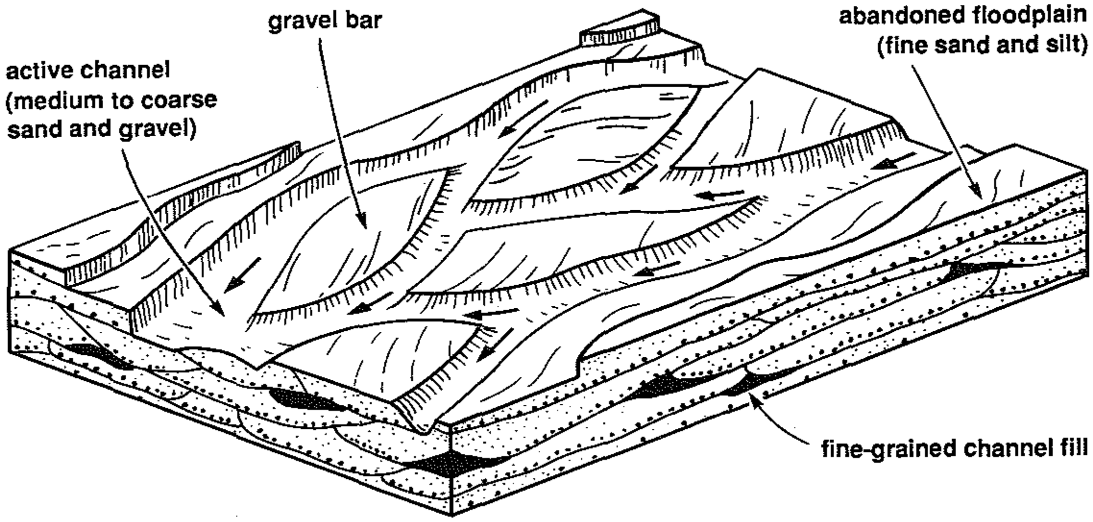

Figure 9. *Surficial and subsurface features of braided stream deposits. Lateral channel migration during vertical aggradation results in heterogeneous deposits on all scales. Stratification caused by changing velocities during channel migration results in directional anisotrophy. (After Freeze and Cherry, 1979.)*

aquifer, the presence or absence of a particular type of sediment cannot be predicted at any given location.

It is possible, however, to make some generalizations regarding the deposits. Along the Wisconsin River, the dominant grain size decreases from gravel in the north to fine- to medium-grained sand in the south. The deposits in the Eau Claire River valley are also sandy, as are deposits in the other tributaries east of the Wisconsin River. In contrast, the Rib River valley contains large amounts of silt and clay deposited when the Wisconsin River valley aggraded high enough to dam the Rib River, allowing fine material to fall out of suspension (fig. 11). This fine material is several orders of magnitude less permeable than the surrounding sand. The irregular silt and clay boundaries complicate groundwater flow near the Rib River.

The hydrologic response of the Rib River to precipitation also differs greatly from that of the Eau Claire River. Precipitation readily infiltrates the sand and gravel of the Eau Claire River valley, providing recharge to the Wausau aquifer. Groundwater then gradually discharges to the Eau Claire and Wisconsin Rivers. On the other hand, the fine material in the Rib River valley prevents infiltration and promotes overland flow. Thus, rainwater is rapidly channeled directly into the Rib River, causing large peaks in its hydrograph (fig. 12).

Aquifer boundaries

Base of the aquifer. The Wausau aquifer is bounded on the bottom and sides by relatively impermeable clay and crystalline bedrock (plate 1) and on top by the water table (plate 2). In areal view, the lateral boundaries are formed by the intersection of the water table and the aquifer base.

In most places, outwash directly overlies Precambrian bedrock, so the base of the aquifer is the bedrock surface. Near the lateral boundaries, however, clayey

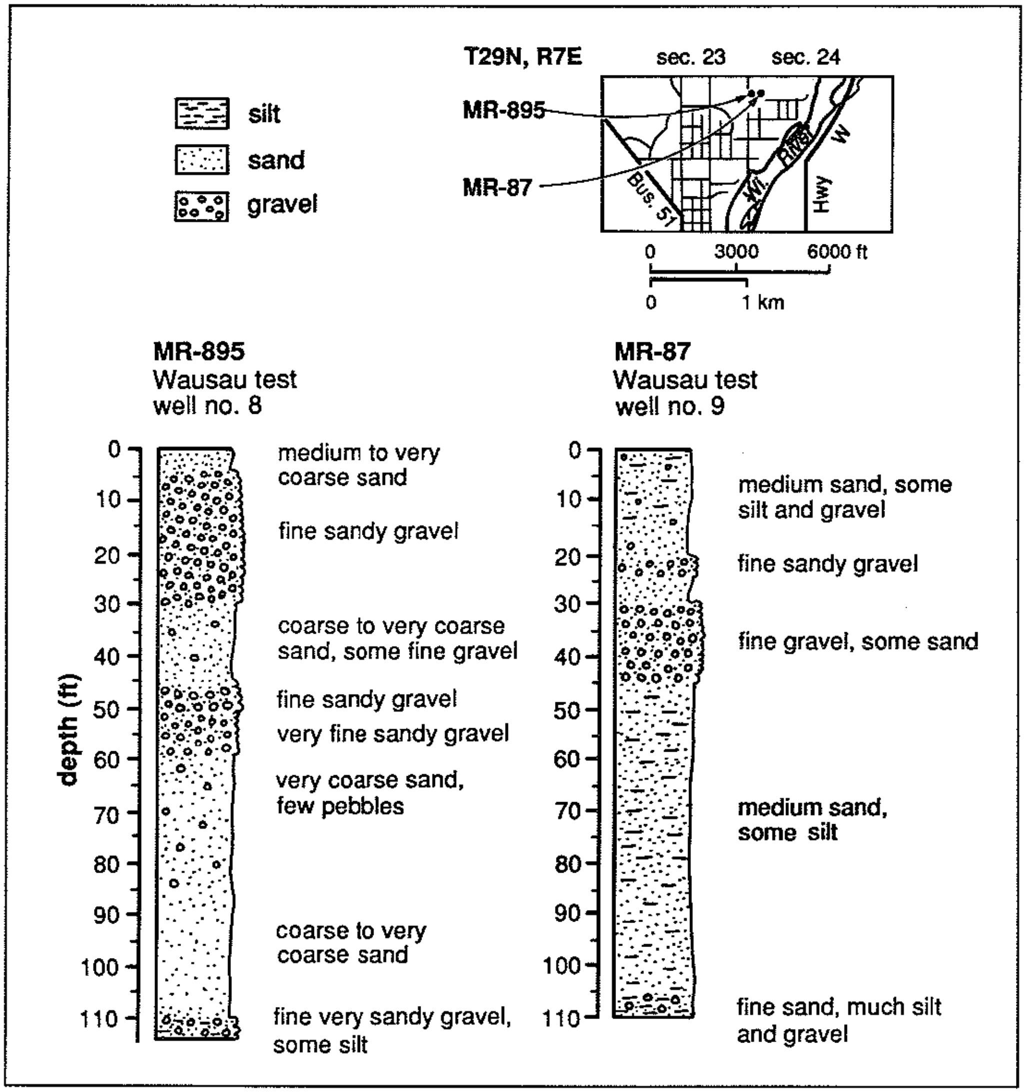

Figure 10. *Stratigraphy of two sites in north Wausau. Sand and gravel beds are difficult to correlate because of the heterogeneous nature of braided outwash deposits. The two sites are less than 500 ft apart.*

bedrock residuum often lies between the unweathered bedrock and the glacial stream material. In these places, the base of the aquifer is the top of the residuum.

In the Rib River valley, where silt and clay were heterogeneously deposited in a slack-water meandering-stream environment, the aquifer's lower boundary is especially complicated. Most boreholes in this valley contain fine-grained sand, silt, and clay interbedded with sand and gravel (fig. 11). We did not take into account any fine-grained bed above the lowermost sand and gravel when we constructed plate 1. In reality, however, each clayey or silty bed forms a significant impediment to groundwater flow within the aquifer. As such, flow patterns in the Rib River valley are probably more complex than anywhere else in the Wausau aquifer.

The contour lines in plate 1 represent the base of the sand and gravel aquifer. The solid lines are accurate to $\pm$ 30 ft, and the dashed lines to $\pm$ 60 ft. The

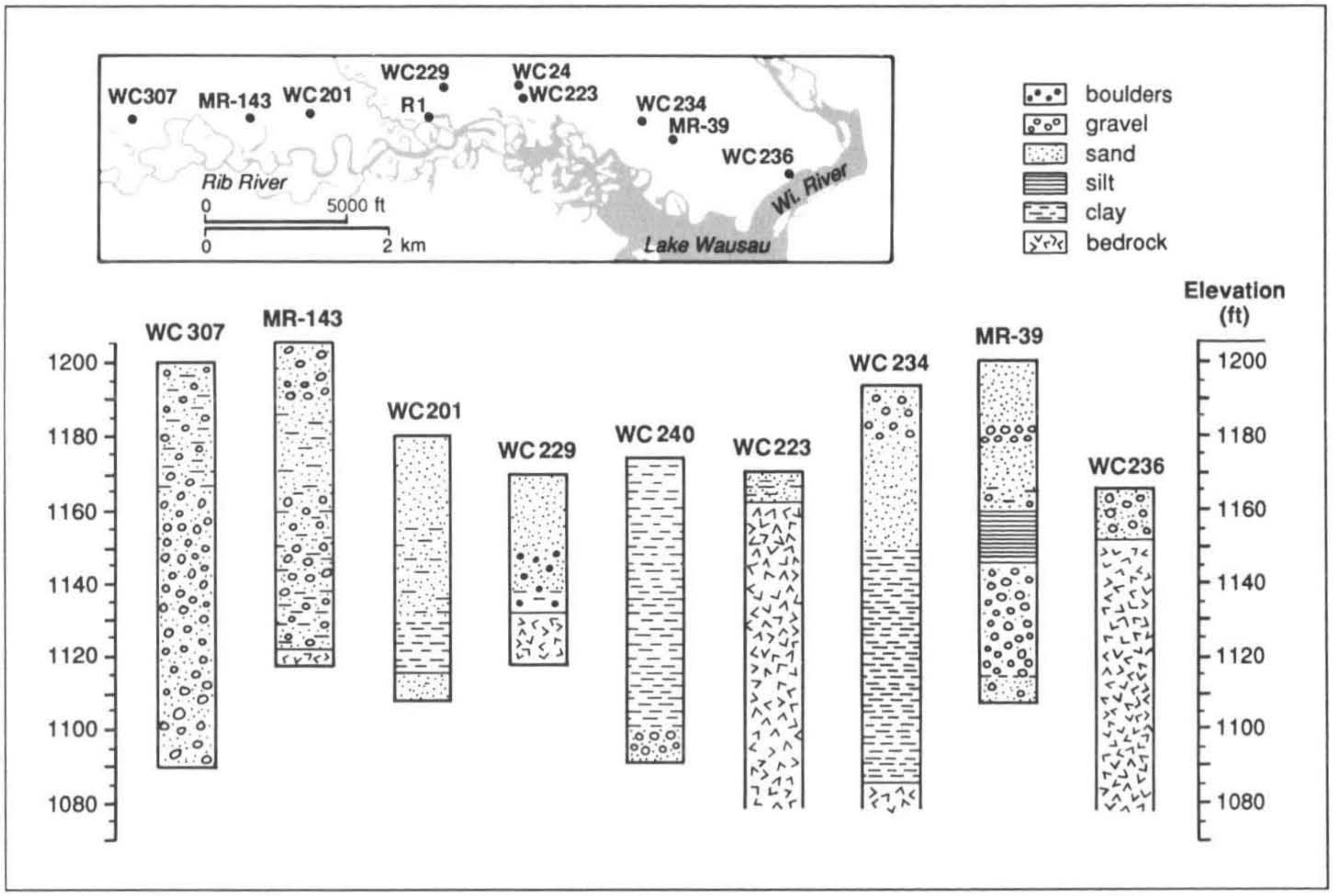

Figure 11. *Representative stratigraphy of the Rib River valley near its confluence with the Wisconsin River. Well numbers are recorded in appendix B.*

nature of the data sources partly explains this seemingly excessive caution. First, well constructor's reports often vaguely or inaccurately locate wells. An incorrect borehole location means that in addition to misplacing the data point, the depth to the base of the aquifer reported by the driller may be subtracted from the wrong surface elevation, leading to an inaccurate elevation of the base of the aquifer on plate 1. Second, the depths may be incorrectly reported. Finally, linear interpolation between data points in some cases may not be warranted because the base of the aquifer is so irregular that minor peaks and valleys can easily be missed. In summary, plate 1 and the contours in the Rib River valley should be viewed as a generalization at the scale of the map. For any detailed local work, the aquifer base should be determined independently by boreholes and/or geophysical methods.

Water table. Plate 2 is a contour map of the water table, the upper boundary of the Wausau aquifer. The elevation and shape of the water table vary through time because of seasonal changes in precipitation, groundwater use, and river levels. The contour lines in plate 2 represent an "average" water table spanning the 40 years covered by the data sources.

To construct plate 2, static water levels reported by drillers were recorded, along with the dates they were measured. Most of the wells used for construct-

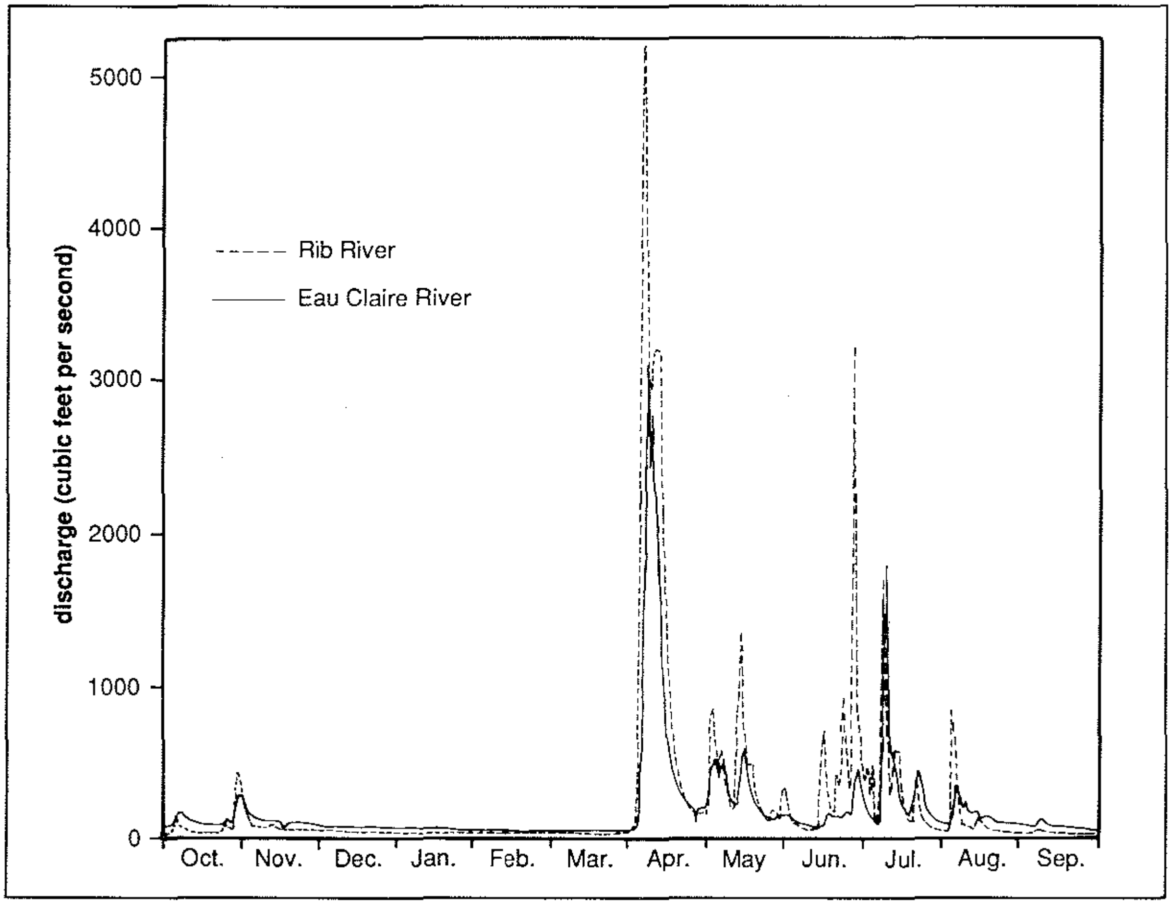

Figure 12. *Hydrographs of Rib and Eau Claire Rivers in Marathon County, 1955-56. The Rib River has "flashy" discharge because its relatively impermeable, clayey valley promotes overland flow; the permeable sand in the Eau Claire River valley allows more precipitation to infiltrate to the aquifer. As groundwater, it then provides a steady base flow into the Eau Claire River.*

ing plate 2 have screens located far below the water table, which introduces an error in areas with large vertical hydraulic gradients. But because this error is at most about 0.1 ft, it is considered negligible compared to other errors, which are discussed later.

The recorded water levels were qualitatively "averaged" over time by comparing them to the same standard: the continuous water-level record for high-capacity well MR-28 (fig. 13). Although this well is not located in the study area, it is the only nearby well in the Wisconsin River valley outwash with a long, continuous record.

The mean water depth in MR-28 is 20.5 ft below land surface (Zaporozec, 1980). To "correct" the water level reported at another well, the reported value was adjusted according to how close the water level in the standard, MR-28, was to 20.5 ft at that time. For example, high-capacity well number MR-20 was drilled in October 1970. At that time, the static water depth in MR-20 was 30 ft (appendix B, part 1). In October 1970, the water level in the standard, MR-28, was 17 ft. To bring this to the average level of 20.5 ft, we must add 3.5 ft. The "corrected" value of 30 + 3.5 = 33.5 ft was therefore used as the static water depth of MR-20 for plate 2. As another example, when high-capacity well MR-63 was drilled in October 1957, its reported water depth was 38 feet. In

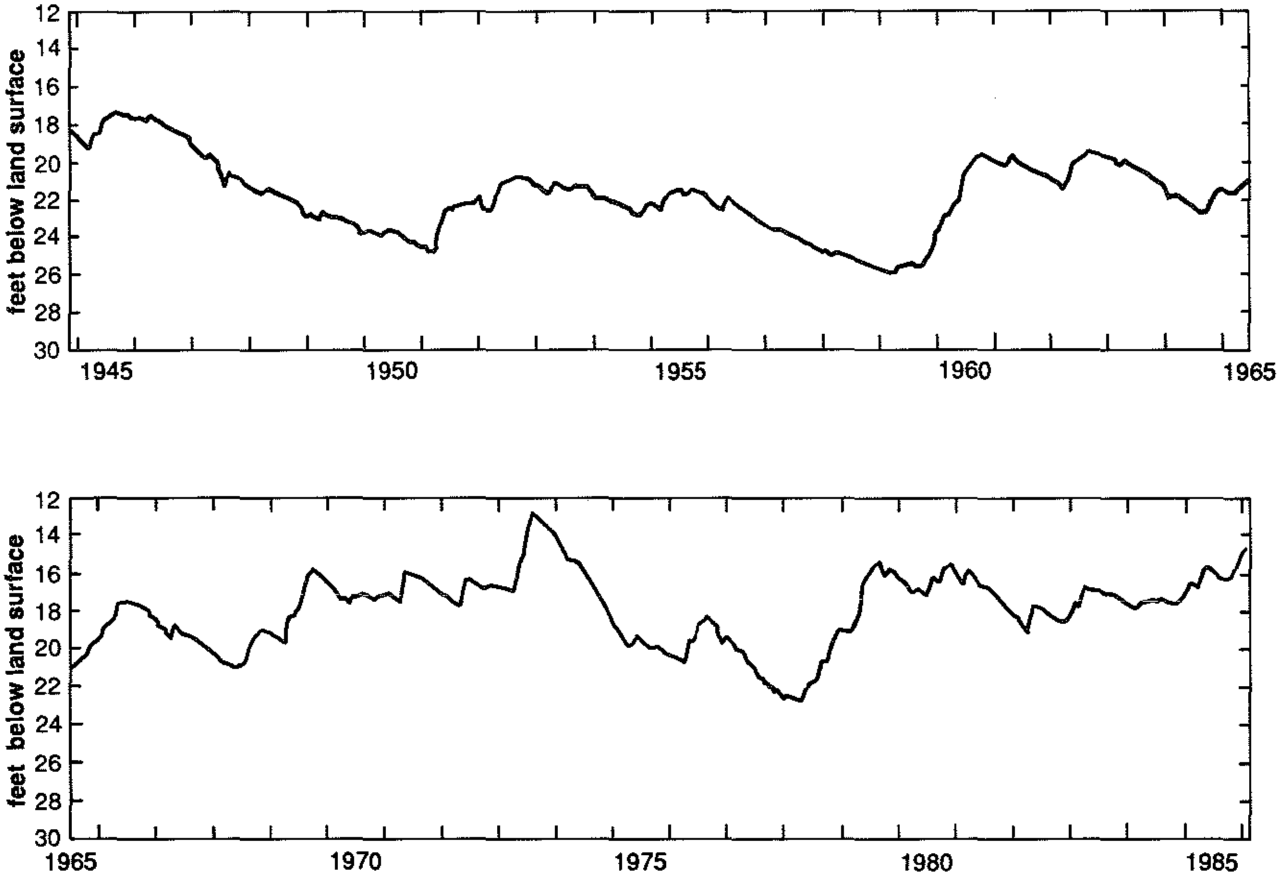

Figure 13. *Hydrograph of well MR-28, 1945-85, used to standardize all other reported groundwater levels for plate 2. For location see figure A-1, site 6.*

October 1957, the water level in MR-28 was 24.5 ft. To bring this to 20.5 ft, we must subtract 4 ft. The static water depth used on plate 2 for well MR-63 was 38 - 4 = 34 ft.

Contour lines were hand-drawn to smooth the data and blend with the topography, using surface water bodies as control points.

Using well MR-28 as a standard may be questioned. Rarely would we expect all wells in an aquifer to behave identically. In a recharge area, for example, the water table tends to fluctuate more than in discharge areas, especially when the water level in the discharge area is as highly regulated as the Wisconsin River. But for lack of any other long, continuous record, well MR-28 was used. The only other well in the Wausau aquifer for which the USGS has kept a semi-continuous record is high-capacity well MR-139 (fig. A-1, site 21).

Other errors inherent in plate 2 are caused by inaccurate data-point locations and water levels. Drillers commonly measure the water level immediately after a well is installed, possibly without waiting for the water level in the well to equilibrate. The likelihood that the water level in the well was not recorded at equilibrium is highest in fine-grained material, which may take days to equilibrate.

However, production wells (which provided most of the data for plate 2) are almost always finished in coarse-grained material, and the large number of data points used for plate 2 helped considerably in smoothing out these types of errors. Furthermore, the topographic base map provided numerous control points such as creeks and ponds where the water table is at the elevation indicated on the base map. The contour lines were drawn to follow the topography in a subdued manner, as is typical of shallow unconfined aquifers (Blanchard and Bradbury, 1987). For these reasons, we consider plate 2 to be an accurate representation of the average water-table configuration. However, a review of long-term records for wells MR-28 and MR-139 suggests that in places the water table can fluctuate seasonally as much as 8 ft above or below the average elevations shown on plate 2.

The water table is generally deepest and the horizontal hydraulic gradient steepest in the topographic highs; the water table gradually flattens out and becomes shallower as it approaches low, wet areas. Presumably, groundwater flow has a downward component under topographic highs and an upward component near wet areas, especially the Wisconsin River and its tributaries. This is illustrated in the cross sections on plate 2. Notable exceptions are the anomalous lows in the water table in Schofield, Rothschild, and Wausau. The lowering in these areas is caused by large-scale regional pumping, which creates large cones of depression in the water table. As a result, groundwater flows in toward the cones from all directions, including the Wisconsin River and Lake Wausau.

Less extensive cones of depression exist in other parts of the aquifer where pumping wells draw the water table down, but they are not apparent at the scale and contour interval of plate 2. They do, however, exert the same effect of causing local radial groundwater flow. If the wells are near the Wisconsin River, flow can be induced from the river (Wright, 1985).

Lateral boundaries. After the top and bottom boundaries of the Wausau aquifer were contoured, the lateral extent of the aquifer was determined by overlaying the two maps and drawing the line that represents the points at which the water table and the base of the aquifer are of equal elevation (plates 1 and 2). This is the edge of the saturated sand and gravel. The straight lines along the edges of the maps are arbitrary boundaries that do not coincide with the edge of the aquifer, but limit the study area to a manageable size.

Cross sections

Cross sections along lines A-A′, B-B′, C-C′, and D-D′ (plate 2) illustrate the changes in aquifer morphology from north to south, along the depositional flow direction. In the north (A-A′), the Wisconsin River valley is steep and narrow above and below the surface of the sand and gravel. The depth of the aquifer gradually decreases as its width increases from north to south. The magnitude of the horizontal hydraulic gradient correspondingly decreases from north to south. Furthermore, the sediment grain size decreases from dominantly gravel in the north to fine- to medium-grained sand in the south. The consequence of these trends is that groundwater tends to move more rapidly in the northern part of the aquifer.

The vertical components of the groundwater flow directions indicated by flow lines in the cross sections (plate 2) were determined from water levels in piezometer nests. Where no piezometers were present, flow lines were based on theoretical considerations.

The base of the aquifer is about equally rugged in all the cross sections. However, its influence on the groundwater flow direction increases as the aquifer becomes shallower, from north to south. Toth (1963) used analytical methods to show that an irregular water table leads to the development of local flow systems, each with its own recharge and discharge area. Streamlines indicated in the cross sections show that an irregular aquifer base similarly complicates groundwater flow. Toth also showed that with increasing aquifer thickness, regional and intermediate flow systems develop. Hence, cross section D-D' has only local (shallow streamlines) and intermediate (deeper streamlines) flow systems; the thickest cross section (A-A') has regional flow (deepest streamlines) as well. The flow systems are less affected by the irregular aquifer base in the deeper (A-A') than in the shallower (D-D') part of the aquifer.

Aquifer morphology also determines the direction in which groundwater contaminants flow. The hilly topography that surrounds the Wisconsin River valley and continues beneath the surficial deposits has important implications in terms of heavy VOC transport. Tetrachloroethylene (PCE), trichloroethylene (TCE), and trans-dichloroethylene (DCE) are some carcinogenic VOCs that have been detected at unacceptably high levels in parts of the Wausau aquifer (Weston, Inc., 1985). All three are denser than water; they tend to sink to the bottom of the aquifer and then move along bedrock valleys. Therefore, it is essential that the bottom of the aquifer be well defined for a thorough investigation of heavy VOC contamination.

Other contaminants, such as toluene, which also is present in the Wausau aquifer (Weston, Inc., 1985), are lighter than water and therefore tend to float near the water table. These types of contaminants flow perpendicular to the water-table contour lines (plate 2) and remain near the upper boundary of the aquifer.

In addition, accurate knowledge of aquifer boundaries optimizes placement of future production wells because production tends to be maximized at the thickest portion of the aquifer, when all other factors are equal.

Hydraulic characteristics

Aquifer pumping tests

The ability of geologic material to contain and transmit water is quantifiable by various physical parameters. *Hydraulic conductivity* (coefficient of proportionality describing the rate at which water moves through a permeable medium under a given hydraulic gradient) was determined for 254 points in the sand and gravel of the Wausau aquifer on the basis of pumping tests, specific-capacity tests, piezometer tests, and grain-size analyses. The results are summarized in table 3. In addition, *storage coefficient* (volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head) and *transmissivity* (rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gratient) were determined for some of these points.

Ideally, a pumping test is performed on a well having a screen open to the entire thickness of the aquifer, and the parameter value obtained represents an average over the entire thickness. In practice, the value reflects the most permeable material penetrated by the well because that is where most of the water comes from during the test. Pumping tests are often performed on large wells to determine their production capacity, regardless of the screen length. Corrections are then made to account for test assumptions that are violated, and the

Table 3. Summary of hydraulic conductivity values (in ft/s) as determined by various methods

Method	Number of samples	Minimum value	Maximum value	Geometric mean	Log-normal standard deviation
Aquifer pumping test	5	1.6×10^{-3}	6.4×10^{-3}	3.1×10^{-3}	0.24
Specific capacity test	218	4.2×10^{-5}	4.3×10^{-2}	1.3×10^{-3}	0.59
Piezometer test	20	3.5×10^{-5}	2.5×10^{-2}	2.3×10^{-3}	0.80
Grain-size analysis	11	1.3×10^{-4}	9.6×10^{-4}	3.3×10^{-4}	0.29

resulting values are considered representative of the geologic material that intersects the well screen.

Table 4 is a summary of five pumping tests performed on wells finished in the Wausau aquifer. Figure 14 shows the locations of these tests. In addition, Summers (1972) reports that "pumping tests show that" the outwash conductivity is 1.7×10^{-3} ft/s (5.2×10^{-2} cm/s) and storage coefficient is 0.10 to 0.25, without citing any particular tests or data.

Specific-capacity tests

After installing a new well, drillers routinely perform a specific-capacity test on the well and submit the results to the WDNR in the well constructor's report. The specific capacity, which indicates discharge of water per unit of drawdown, is a function of the aquifer material and the well construction. Hydraulic conductivity and transmissivity, on the other hand, are functions only of the aquifer.

In this study specific-capacity data were analyzed following the procedure described by Bradbury and Rothschild (1985), in which transmissivity and hydraulic conductivity are estimated from the specific-capacity data obtained by well drillers. We calculated hydraulic conductivity and transmissivity for all the wells listed in appendix B, part 2, that are screened in sand and gravel. The program requires estimates of specific yield and well loss. We used a specific yield of 0.1, which was based on pumping test results (table 4). We estimated the well-loss coefficient to be 1. Because almost no wells screened in the Wausau aquifer actually penetrate the full depth of the aquifer, the aquifer thicknesses were estimated from plate 1. Results of the specific-capacity tests are listed in appendix B, part 2. The geometric mean hydraulic conductivity obtained from these tests is 1.3×10^{-3}ft/s (3.9×10^{-2}cm/s). The specific-capacity values, normalized by dividing by screen length, are contoured in figure 15.

Areas of high specific capacity contain the most highly productive wells. Therefore, these areas may be expected to yield large amounts of water for future supplies. Data given in appendix B allow determination of the depths that produce the high water yields in these areas.

Piezometer tests

Pumping tests determine *in-situ* characteristics averaged over the entire aquifer thickness; piezometer tests are useful for determining the hydraulic conductivity of a small fraction of that thickness. Of the 26 piezometers installed for this study, 17 were used for piezometer tests during which a solid rod of known

Table 4. Results of pumping tests

Well	Test length (hr)	Storage coefficient	Transmissivity $\left(\frac{ft^2}{s}\right)$	Hydraulic conductivity $\left(\frac{ft}{s}\right)$
Brokaw no. 16A (MR-21)[1]	72.0	0.143	3.4×10^{-1}	3.3×10^{-3}
Rib Mountain no. 1 (WC350)[2]	69.9	0.120	1.6×10^{-1}	1.6×10^{-3}
Rib Mountain no. 2 (WC351)[2]	68.0	0.091	4.3×10^{-1}	4.3×10^{-3}
Rib Mountain no. 3 (WC352)[2]	70.8	0.125	6.4×10^{-1}	6.4×10^{-3}
Wausau no. 9 (MR-100)[3]	26.0	0.016	1.9×10^{-1}	2.0×10^{-3}

[1]Test performed and analyzed by Layne-Northwest Co. (1970).
[2]Tests performed by Donohue & Associates, Inc. (1985).
[3]Test performed by Becher-Hoppe Engineers, Inc., (1962).

volume was suddenly introduced to or removed from the water in the well. A pressure transducer and chart recorder documented the recovery of the water level. Results were analyzed by the method of Hvorslev (1951). (See Kendy, 1986, for additional details of piezometer test analyses used for this report.) Appendix C, part 1, contains piezometer test results.

Of the 10 piezometer tests performed on wells completed in sand or sand and gravel, the geometric mean hydraulic conductivity was 5×10^{-4} ft/s (2×10^{-2}cm/s). The standard deviation for piezometer tests was higher than for any other method (table 3) because the piezometers were intentionally installed in a wide variety of lithologies to define the variation in hydraulic conductivity of the Wausau aquifer. Values as low as 4×10^{-7} ft/s were obtained for piezometers that were screened in clayey material within or beneath the outwash.

STS Consultants (1985) performed piezometer tests on 10 monitoring wells on the east bank of the Wisconsin River in the north-central part of the Wausau aquifer (fig. 15, site 5); they found a geometric mean hydraulic conductivity of 9×10^{-3} ft/s (4×10^{-1} cm/s).

Grain-size analyses

Another way to estimate the hydraulic conductivity of a particular thickness interval is to perform a sieve test on a sample of the aquifer to determine the distribution of grain sizes present by weight percent, as in figure 8. However, moving the aquifer material from the field to the laboratory disturbs the sample, causing lab results to differ from field results. Specifically, grain-size analyses usually predict hydraulic conductivity values one order of magnitude lower than do field tests. However, sieve analyses are relatively easy and inexpensive to perform compared to *in-situ* tests. Furthermore, engineers routinely prepare curves like those illustrated in figure 8 for purposes other than groundwater studies, including the grading of concrete sand, foundry sand, earth materials for dams and embankments, and filter sands. Consequently, the data are often available prior to any groundwater work in an area.

Hydraulic conductivity was estimated from 11 grain-size analyses, including those shown in figure 8, using the method of Masch and Denny (1966). (See Kendy, 1986, for details of the estimation procedure.) The results are summarized in table 5. The geometric mean hydraulic conductivity of the samples analyzed in table 5 is 3×10^{-4} ft/s (1×10^{-2} cm/s). The log-normal standard

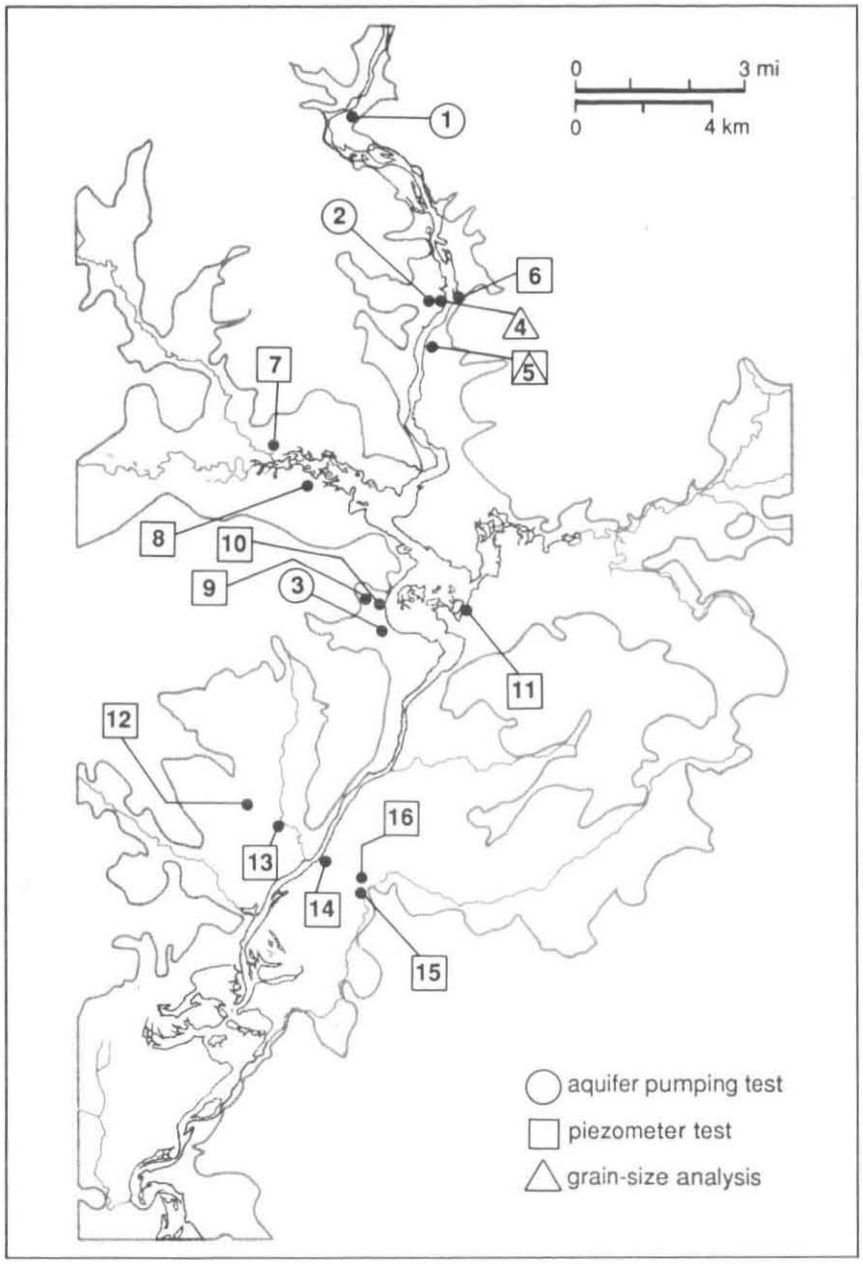

Figure 14. *Locations of aquifer pumping tests, piezometer tests, and samples for grain-size analyses discussed in text.*

1. *Brokaw Well no. 16A (MR-21).*
2. *Wausau Well no. 9 (MR-100)*
3. *Rib Mountain wells (WC350-352).*
4. *Bugbee and Tienery Streets (fig. 13)*
5. *Sec. 27, T29N, R7E (STS Consultants, Ltd., 1984)*

6-16. *Piezometers installed as part of this study.*

deviation is 0.3 ft/s (8.7 cm/s). These results are only slightly lower than results from piezometer tests reported above; they suggest that grain-size data may provide useful estimates of hydraulic conductivity of the sand and gravel of the Wausau aquifer.

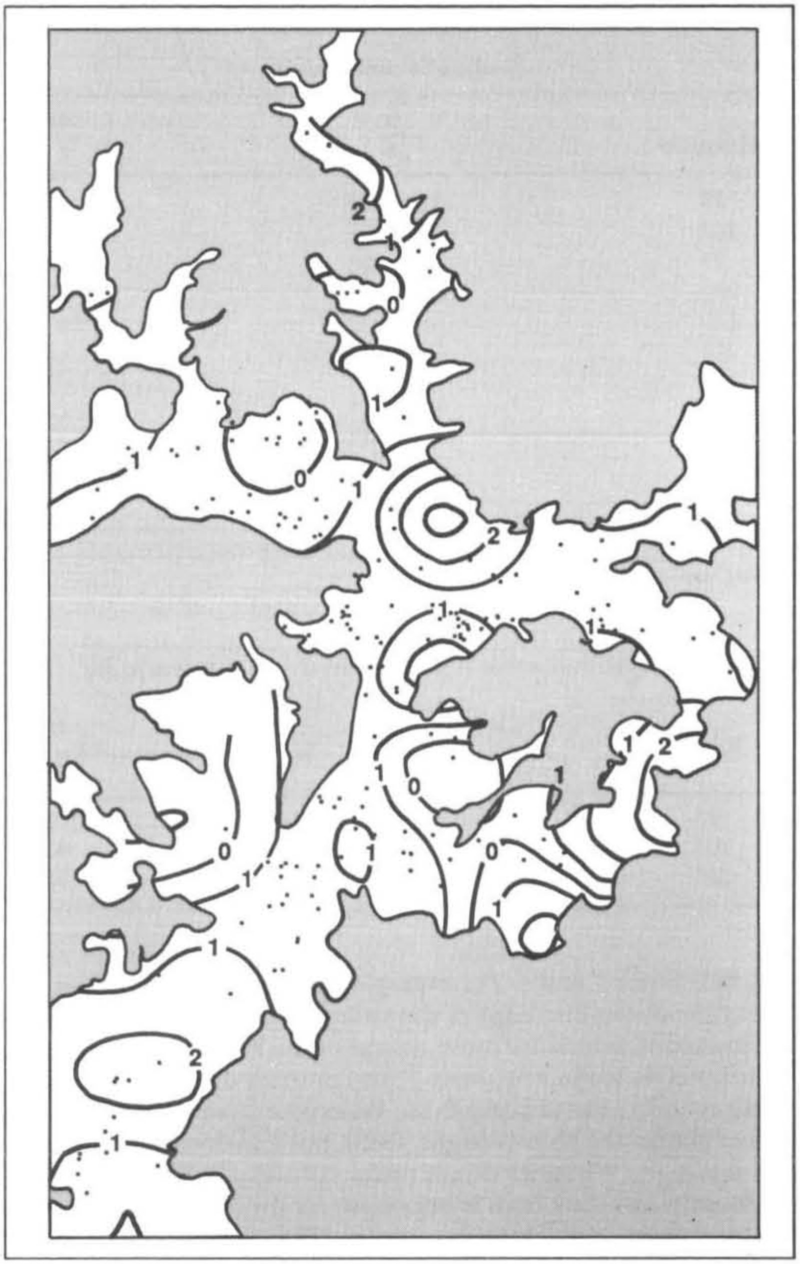

Figure 15. *Contour map of specific capacity of the Wausau aquifer. Dots indicate data points. Contours represent logarithms (base 10) of specific capacity in gallons per minute per foot of drawdown. For example, the contour line labeled "1" corresponds to a specific capacity of 10 gpm/ft, and the contour labeled "2" corresponds to 100 gpm/ft. Areas of high specific capacity produce high yields to wells. Contour interval is one log10 unit.*

Groundwater movement

Horizontal component of flow

Horizontal groundwater flowpaths in the Wausau aquifer tend to be short, ranging from less than 100 ft near Brokaw to nearly 5 miles south of Rothschild,

Table 5. Results of grain-size analyses used to determine hydraulic conductivity

Sample	Depth (ft)	Hydraulic conductivity gal/day/ft^2	Hydraulic conductivity $\frac{ft}{s}$	Hydraulic conductivity $\frac{cm}{s}$
B1-S3*	4-5.5	75	1.3 x 10^{-4}	4.0 x 10^{-3}
B1-S9*	23-24.5	162	2.8 x 10^{-4}	8.5 x 10^{-3}
B2-S6*	10-11.5	75	1.3 x 10^{-4}	4.0 x 10^{-3}
B2-S7*	15-16.5	360	6.3 x 10^{-4}	1.9 x 10^{-2}
B3-S6*	25-26.5	120	2.1 x 10^{-4}	6.4 x 1^{-3}
B3-S25*	120-121.5	212	3.7 x 10^{-4}	1.1 x 10^{-2}
Fig. 8A	100-115	550	9.6 x 10^{-4}	2.9 x 10^{-2}
Fig. 8B	115-125	460	8.0 x 10^{-4}	2.4 x 10^{-2}
Fig. 8C	125-130	175	3.0 x 10^{-4}	9.1 x 10^{-3}
Fig. 8D	130-135	175	3.0 x 10^{-4}	9.1 x 10^{-3}
Fig. 8E	135-150	175	3.0 x 10^{-4}	9.1 x 10^{-3}

* Sample obtained from soil borings by split barrel sampler from sec. 25, T29N, R7E. B1, B2, B3 are monitoring well identification numbers; S3, S6, S7, S9, and S25 are sample numbers. Source: STS Consultants, Ltd., 1984.

Table 6. Typical horizontal groundwater flow rates in the Wausau aquifer

Area	$K\left(\frac{ft}{s}\right)$	$\frac{\delta h}{\delta l}$	$q\left(\frac{ft}{yr}\right)$	$\bar{v}\left(\frac{ft}{yr}\right)$
Brokaw	10^{-3}	0.013	410	1170
Rothschild	10^{-4}	0.010	32	90
Mosinee	10^{-5}	0.006	19	54

between Cedar and Bull Junior Creeks. For example, a long, continuous flow path begins at the eastern or western edge of the valley and ends at the Wisconsin River. Shorter flowpaths, which are more typical of the Wausau aquifer, end at pumping wells, tributaries to the Wisconsin River, or other discharge areas. Some flowpaths may actually extend beneath the Wisconsin River in response to pumping on the other side of the river (Wright, 1985), but it is doubtful that groundwater flows under the Wisconsin River under natural conditions.

Knowledge of groundwater flow rates is important for predicting the movement and fate of contaminants in the Wausau aquifer. The specific discharge, or Darcy velocity (q), depends on the hydraulic conductivity (K) and the hydraulic gradient ($\delta h / \delta l$), as expressed by Darcy's law:

$$q = -K \frac{\delta h}{\delta l} \qquad (2)$$

Table 6 lists typical horizontal specific discharge rates for three areas of the aquifer. Hydraulic conductivities and gradients are estimated from information in this section, appendices B and C, and plate 2.

Specific discharge is an apparent velocity, representing the velocity at which groundwater would flow through an open conduit (Fetter, 1980). The presence of grains and pores in the aquifer decreases the cross-sectional area through which groundwater flows so that the average linear velocity ($\bar{v}$) at which the water actually moves is greater than the specific discharge. Specifically,

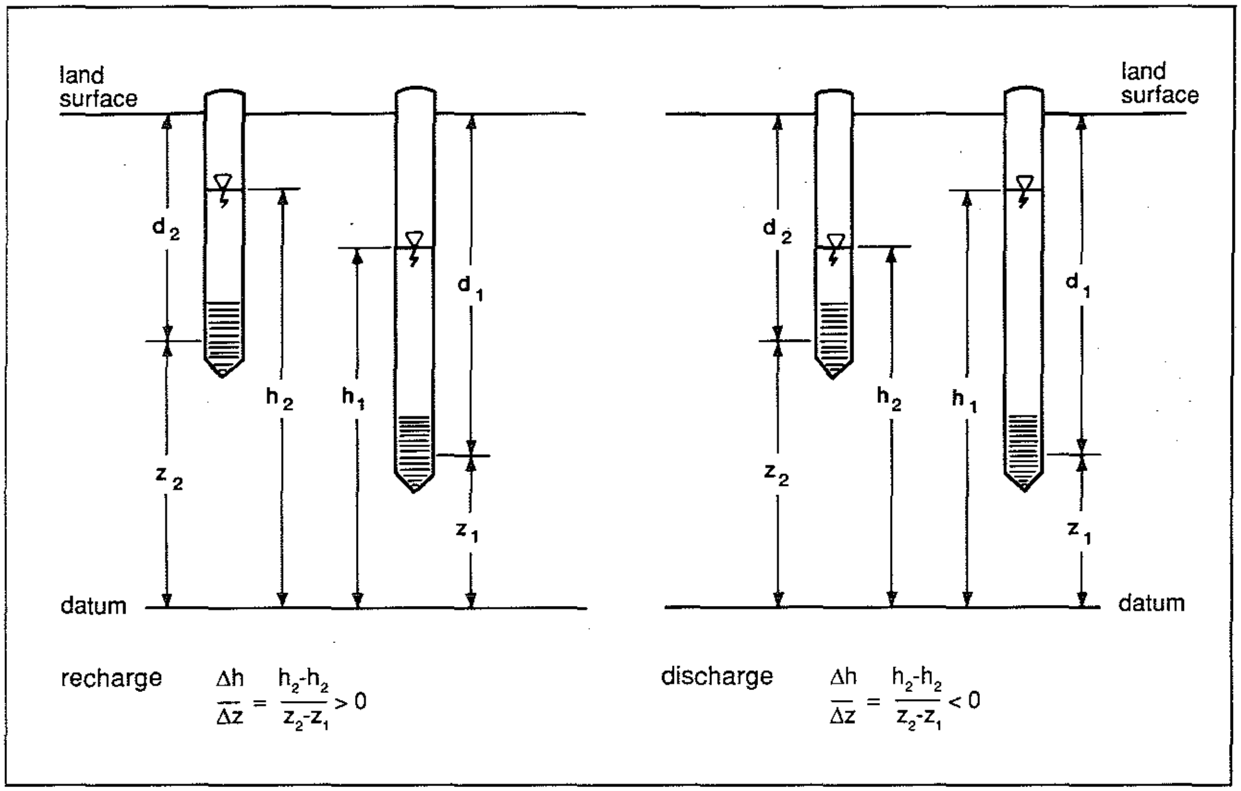

Figure 16. *Piezometer nest for determining vertical hydraulic gradient. The gradient is positive and flow is directed downward in recharge areas; the gradient is negative and flow is directed upward in discharge areas.*

$$\bar{v} = \frac{q}{n} = \frac{-K}{n}\frac{\delta h}{\delta l} \qquad (3)$$

where n = effective porosity. The effective porosity of sand and gravel ranges from about 25 to 50 percent (Freeze and Cherry, 1979, p. 37). The values of horizontal specific discharge in table 6 were divided by 0.35 to obtain $\bar{v}$. The values in table 6 are generalizations representing the north, central, and south Wausau aquifer. Extreme local variations are undoubtedly present.

Vertical component of flow

Equations 2 and 3 were also used to calculate vertical flow rates. To determine the vertical hydraulic gradient, two piezometers were installed as closely together as possible with well screens at different elevations, as shown in figure 16. The net vertical component of groundwater flow is downward in recharge areas and upward in discharge areas. With the datum and geometry as shown in figure 16, the hydraulic gradient is positive in recharge areas and negative in discharge areas.

Table 7 lists vertical flow rates for 16 piezometer nests in the Wausau aquifer. The first ten nests were installed as part of this study (appendix C, part 1); the others were being used for other projects, as indicated in footnotes to the table. The hydraulic conductivity (K) for each piezometer nest is an arithmetic mean of

Table 7. Vertical groundwater flow rates measured in the Wausau aquifer, assuming isotropic conditions

Piezometers	$K\left(\frac{ft}{s}\right)$	d_2(ft)	d_1(ft)	Δz(ft) [1]	Δh(ft)	$\left(\frac{\Delta h}{\Delta z} \approx \frac{\delta h}{\delta z}\right)^{(2)}$	$q\left(\frac{ft}{yr}\right)^{(3)}$	$\bar{v}\left(\frac{ft}{yr}\right)$	Direction
R1-C, R1-A	2.0×10^{-4}	7.9	60.2	52.3	-0.6775	-1.3×10^{-2}	-83	-29	up
A2-B, A2-A	3.3×10^{-3} [4]	16.9	95.3	78.4	0.0650	$+8.3 \times 10^{-4}$	86	30	down
B3-B, B3-A	6.4×10^{-4}	18.2	66.6	48.4	-0.0745	-1.5×10^{-3}	-31	-11	up
C1-B, C1-A	1.8×10^{-5}	34.1	38.2	4.1	-0.1600	-3.9×10^{-2}	-22	-8	up
C2-C, C2-A	8.4×10^{-4}	31.8	63.6	31.8	0.1978	$+6.2 \times 10^{-3}$	165	58	down
C2A-B, C2A-A	7.5×10^{-4} [4]	40.8	62.4	21.6	0.0	0.0	0.0	0	--
C3-A, C3-B	6.5×10^{-4}	27.0	45.2	18.2	-0.0063	-3.4×10^{-4}	-7	-3	up
D1-B, D1-A	1.9×10^{-4}	11.3	35.8	24.5	0.2229	$+9.1 \times 10^{-3}$	54	19	down
D2-A, D2-B	6.6×10^{-6}	18.3	60.4	42.1	-0.3100	-7.4×10^{-3}	-2	-1	up
D4-A, D4-B	1.3×10^{-3}	20.5	71.5	51.0	-0.3700	-7.3×10^{-3}	-297	-104	up
DNR-12, -11 [5,6]	3.4×10^{-4}	55.0	64.6	9.6	0.0050	$+5.2 \times 10^{-4}$	6	2	down
DNR-20, -17 [5,6]	4.9×10^{-4}	28.0	159.5	131.5	0.1015	$+7.7 \times 10^{-4}$	12	4	down
DNR-3, -2 [5,7]	8.0×10^{-4} [4]	55.0	95.0	40.0	-0.0583	-1.5×10^{-3}	-37	-13	up
DNR-4, -5 [5,7]	8.0×10^{-4} [4]	70.0	135.0	65.0	-0.0464	-7.1×10^{-4}	-18	-6	up
A1, A5 [8]	3.3×10^{-3} [4]	114.4	174.8	60.4	-0.2767	-4.6×10^{-3}	-478	-167	up
Y1, Y5 [8]	3.3×10^{-3} [4]	28.4	147.7	119.3	-0.0143	-1.2×10^{-4}	-13	-4	up

1 $\Delta z = z_1 - z_1 = -(d_2 - d_1)$

2 $\frac{\Delta h}{\Delta z} = \frac{h_2 - h_1}{z_2 - z_1} \approx \frac{\delta h}{\delta z}$ = vertical hydraulic gradient

3 3.1536×10^7 ft/yr = 1.0 ft/s.

4 Piezometer tests not performed. Hydraulic conductivity estimated from nearby pumping test(s), piezometer tests, and/or grain size analyses.

5 Water levels recorded by WDNR.

6 Well installation and piezometer tests by STS Consultants, Ltd. (1984, 1985).

7 Well installation by Weston, Inc., in 1984.

8 Well development and water level measurements by Geraghty and Miller, Inc. (1986).

the hydraulic conductivities determined by tests of each piezometer in the nest. These calculations assume an isotropic aquifer that has horizontal hydraulic conductivity equal to vertical hydraulic conductivity. Few data are available on the actual anisotropy ratio in the Wausau area, but Weeks (1969) reported that the anisotropy ratio in the sand plains south of Wausau ranges from 2 to 20. Thus, the vertical groundwater velocities calculated here may be somewhat greater than actual velocities.

To calculate vertical hydraulic gradients, hydrogeologists customarily assign a datum below the well screens (usually mean sea level), rather than above the screens (that is, ground surface). However, the exact elevations relative to sea level of the piezometers installed for this study are not known. Instead, the distance (*d*) from the ground surface to the middle of the screen of each piezometer is listed in table 7. Figure 16 shows that

$$z_2 - z_1 = -(d_2 - d_1) \quad \text{or} \quad \Delta z = -(\Delta d) \qquad (4)$$

where z is the height of the screen above a datum. The customary Δz is listed for each piezometer nest in table 7, rather than Δd. Similarly, although the raw water-level data were recorded as depths below the top of one of the well casings at each nest (appendix C, part 2), the customary Δh (as shown in fig. 16) is listed in table 7. The vertical hydraulic gradient for each well nest shown in table 7 is the arithmetic mean of available hydraulic gradient measurements. For the WDNR wells, these measurements were taken in October and November 1984, and January and April 1985. Geraghty and Miller, Inc. (1986) monitored piezometers A1 and A5 in November and December 1983 and April 1985, and piezometers Y1 and Y5 in April, November, and December 1983, April 1984, April and November 1985, and May 1986. Water levels were measured in the other wells approximately monthly from October 1985 through July 1986 (appendix C, part 2). The resulting vertical hydraulic gradients are plotted on the water-table map (plate 2).

In general, groundwater recharges in uplands along the eastern and western boundaries of the aquifer and discharges near the Wisconsin River and its major tributaries. However, local conditions contribute to numerous exceptions. Furthermore, hydraulic gradients change over time in response to precipitation, fluctuations in river levels, and other perturbations.

Some areas of recharge near the Wisconsin River might be attributed to pumping from nearby high-capacity municipal wells that are screened near the bottom of the aquifer. For example, piezometer nests WDNR-12/WDNR-11 and WDNR-20/WDNR-17 indicate recharge in Wausau's east wellfield. But WDNR-3/WDNR-2 and WDNR-4/WDNR-5 indicate discharge in Wausau's west wellfield. Although vertical flow is consistently downward at piezometer nest C2-C/C2-A, there is a strong upward gradient from each of the piezometers in the nest toward the Wisconsin River, which is about 500 ft away. The nearest municipal supply well, Rib Mountain 3, is about 1,100 ft away from C2-C/C2-A, so it is not clear to what the vertical flow at the piezometer nest is responding. Recharge and discharge patterns in the Wausau aquifer are complicated, and probably respond to many factors, including pumping, geology, and short-term infiltration events. However, detailed delineation of recharge and discharge areas was beyond the scope of this study.

Computer models of the Wausau aquifer

Purpose

Hydrogeologists often use deterministic mathematical models to analyze groundwater flow and to predict aquifer response to an imposed stress. Typical applications include predicting water-level drawdown near a proposed pumping well or tracking contaminant transport. Kendy (1986) developed a computer model of a part of the Wausau aquifer to demonstrate that the data presented in this study are sufficient to model groundwater behavior accurately in the Wausau aquifer. In addition, her model was intended to determine the groundwater parameters to which the model is most sensitive, and therefore the input data that must be most accurate and complete; the approximate distribution of recharge to the aquifer; and the approximate flux of groundwater to and from the Wisconsin and Eau Claire Rivers.

Procedure

The city of Schofield was chosen as the focus of the model, with the model boundaries extending east to the edge of the aquifer. Twenty rows and thirteen columns of nodes were used; the node sizes gradually increase from 1,000 ft^2 in Schofield to 3,000 ft^2 along the eastern boundary. The smaller nodes in Schofield allowed for greater precision in the area of interest. Figure 17 shows the boundaries used in the model. Specified head boundaries are set to average water elevations of the Eau Claire River (north), Lake Wausau (west), and wetlands (southeast) taken from the USGS Wausau East Quadrangle, Wisconsin (7.5-minute series, topographic, 1978).

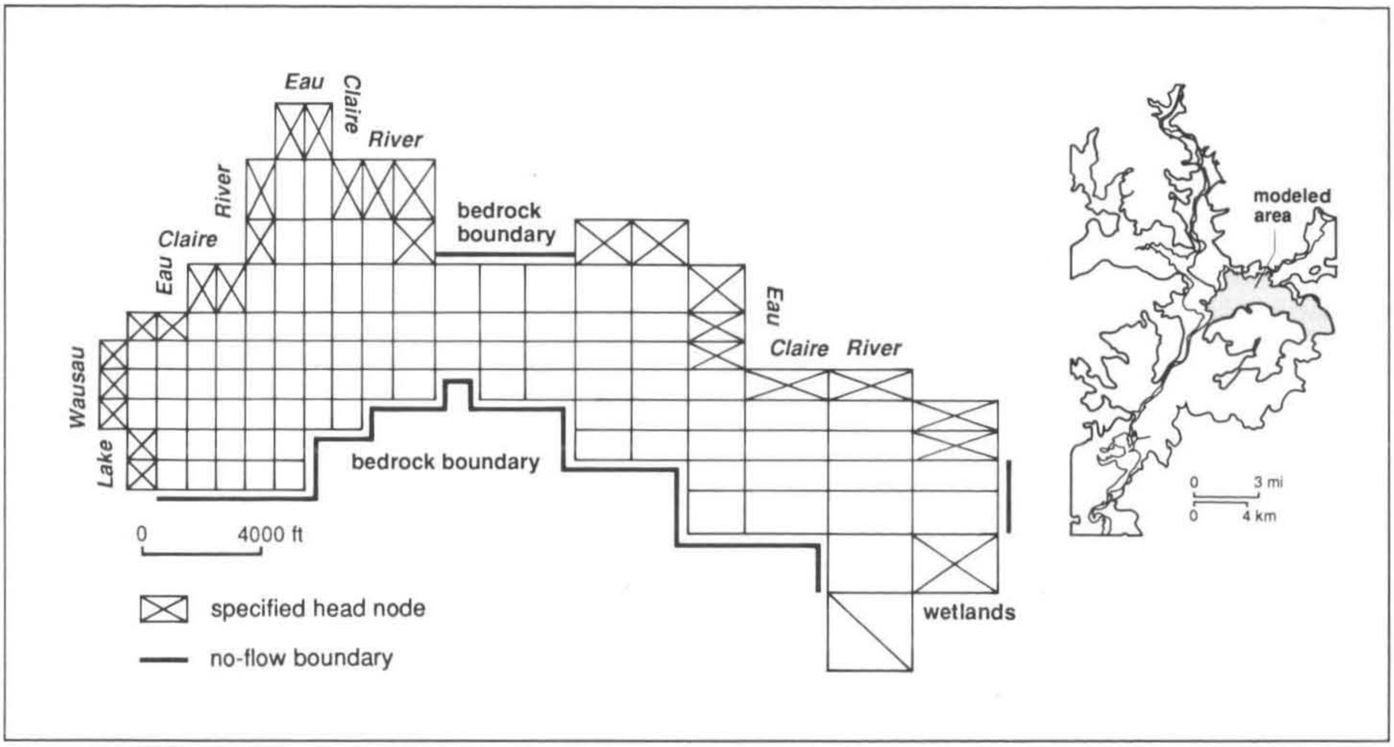

Figure 17. *Nodal grid and boundaries of the Schofield model.*

A steady-state calibration was accomplished by running the USGS three-dimensional finite-difference groundwater model (McDonald and Harbaugh, 1984) in two dimensions on a Masscomp MC5500 mainframe computer. (See Kendy, 1986, for details of model assumptions and development.)

Input parameters

Input parameters were manipulated through a series of computer runs until the model was judged to reproduce the water-table map shown in plate 2.

Average rainfall in the area is about 32 in./yr (81 cm/yr) (Wisconsin Public Service Corporation, 1975), most of which runs off the surface or evapotranspires. The rest becomes groundwater recharge. In Wisconsin it is generally assumed that average groundwater recharge is about one-third of the average annual precipitation, although recent studies suggest that this estimate may be high (James Krohelski, U.S. Geological Survey, verbal communication, 1986).

Recharge rates of 10 to 30 in./yr (25 to 76 cm/yr) were used in Kendy's (1986) model. A recharge rate of 10 in./yr was initially assigned to every node in the model because the Wausau aquifer is so permeable that the highest estimate for recharge in Wisconsin was considered appropriate. To achieve calibration, however, 20 to 30 in./yr was assigned to nodes along the southern boundary of the model to account for surface runoff and bedrock fracture flow from portions of the groundwater basin outside the Wausau aquifer (fig. 18A).

Hydraulic conductivity values were taken directly from appendix B, part 2. For each node for which no values were available, a weighted average of the hydraulic conductivities of surrounding nodes was assigned initially. During the calibration procedure, no hydraulic conductivity was changed from its

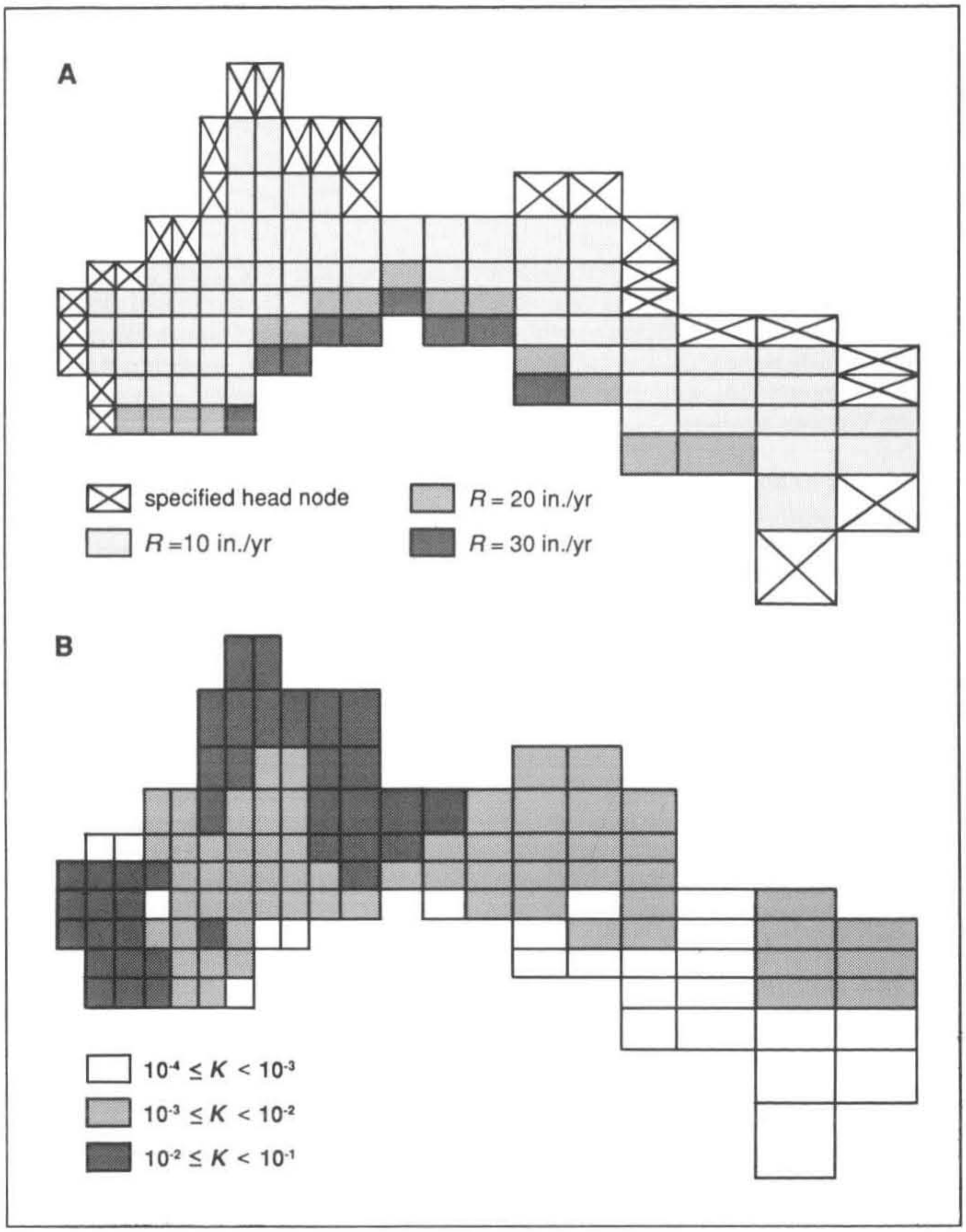

Figure 18. *A. Areal distribution of recharge assigned to calibrated model. B. Areal distribution of hydraulic conductivity assigned to calibrated model.*

initially assigned value by more than one order of magnitude. Figure 18b illustrates the heterogeneity of the hydraulic conductivity input data.

Adding pumping wells to the model to simulate pumpage from high-capacity municipal wells did not produce sufficient drawdown to match the *cone of depression* (part of the water table or potentiometric surface that is lowered around a well as a result of pumping) on the water-table map (plate 2). Therefore, the entire city of Schofield was modeled as a diffuse area of pumpage from domestic as well as municipal wells, with pumping rates ranging from 0.25 to 1.95 cfs (112 to 874 gpm) per node, or a total of 11.11 cfs (4,983 gpm) pumped from the entire area. Of this amount, 6.76 cfs (3,000 gpm) accounts for high-capacity municipal wells, and the remainder was estimated from well constructor's reports of domestic wells in the area.

The elevation of the bottom of the model was taken directly from plate 1. Some elevations were adjusted to aid calibration.

Model results

Calibration. After a series of calibration runs (Kendy, 1986), *head values* (a measure of the potential energy of groundwater) predicted by the model almost exactly reproduced the water table (fig. 19). Comparison of figure 19a and 19b shows that Kendy's (1986) model apparently represents the observed data well and suggests that numerical models of this type can be applied with success to the Wausau aquifer.

Seepage to and from surface water bodies. Prior to development, groundwater flowed from the Wausau aquifer toward the Wisconsin and Eau Claire Rivers. Now that pumping wells are used near the rivers, some of this flow has been diverted. The calibrated model provides a means to estimate the amount of groundwater seepage to and from Lake Wausau (Wisconsin River) and the Eau Claire River.

The model suggests that the small amount of groundwater influx to the aquifer from the southeastern wetlands (0.35 cfs) is negligible compared to the 5.60 cfs from recharge and the 8.02 cfs that enters from Lake Wausau because of lowered water levels from pumpage in Schofield. Less than one-fourth of the groundwater that discharges from the modeled portion of the aquifer does so naturally to the Eau Claire River (2.86 cfs); the rest discharges through pumping wells (11.11 cfs). Of the pumped water, more than two-thirds (8.02 cfs) flows in from the Wisconsin River, and less than one-third comes from the rest of the aquifer.

Other modeling efforts

At least two hydrogeologic consultants modeled parts of the Wausau aquifer. As part of an investigation of paper mill lignin contamination, Wright (1985) constructed physical hydraulic (sand tank) and electric analog models to define lignin travel paths through the aquifer, quantify contaminant transport rates, and investigate remedial action options in Rothschild. His models showed that pumping on one side of the Wisconsin River can change the position of the major groundwater divide to the extent that lignin-contaminated groundwater flows under the river to pumping wells on the other side.

An advective contaminant transport model of part of the Brokaw area (Camp, Dresser & McKee, 1982) also showed that pumping near the Wisconsin River reverses the natural hydraulic gradient, thereby inducing infiltration from the river to the aquifer, and then to the pumping well. However, the model inaccurately predicted that leachate from a nearby landfill would be captured by the wells. Fluctuations in the level of the Wisconsin River, which were not included in the model, were probably responsible for the discrepancy (Ashco, Inc., 1985). This illustrates the important point that an approximation that is apparently valid at a regional scale (that is, average constant heads taken from surface-water features on topographic maps) is not necessarily appropriate for modeling at a local scale, and also shows the limitations of steady-state models in areas of transient groundwater conditions.

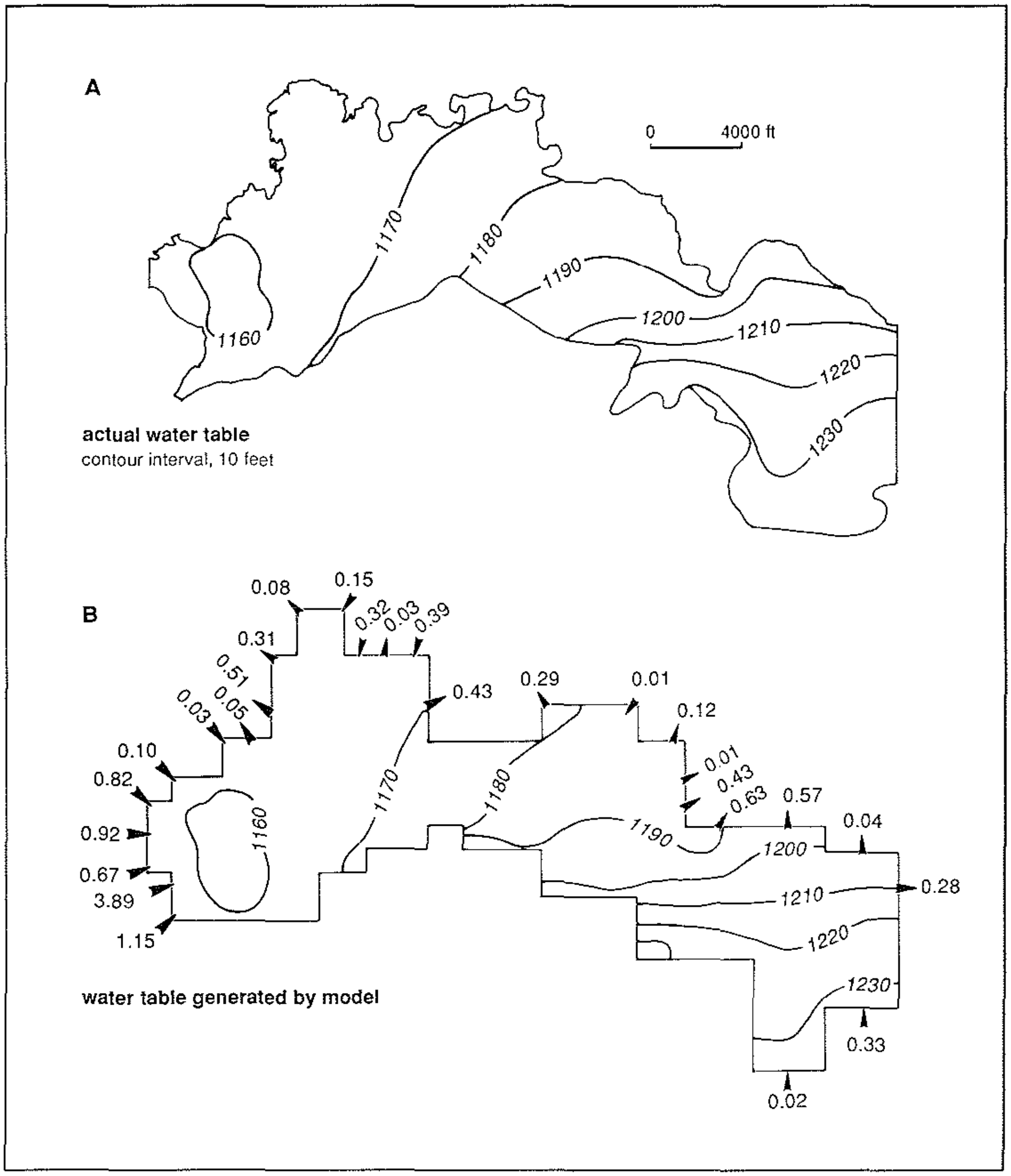

Figure 19. *Comparison between actual water table (A) and water table generated by calibrated model (B). Contour interval 10 ft. Arrows on (B) indicate flow direction, either to or from specified head nodes. Corresponding numbers indicate magnitude of flow in cubic ft per second.*

Implications of modeling

The modeling exercises conducted on various parts of the Wausau aquifer lead to several conclusions (Kendy, 1986).

- The aquifer can be modeled successfully at the scale of the Schofield model, using the data available in this report as model input. It is crucial, however, that the aquifer be modeled as a heterogeneous system or as a system of several different homogeneous zones, not as a single "equivalent" homogeneous system, because the model is extremely sensitive to spatial variation in hydraulic conductivity.

- The model implies that a significant amount of recharge enters the aquifer along its boundaries through fractures in the bedrock and/or surface runoff from the hills surrounding the aquifer. The recharge rate near those boundaries may be as much as three times the maximum expected recharge rate in Wisconsin. Currently available data are not sufficient to test this model finding. An investigation of groundwater recharge along the valley margins should be a focus of future research.
- Groundwater pumping reverses the natural hydraulic gradient toward the Wisconsin River to the extent that wells near the river pump water pulled through the aquifer directly from the river and possibly some groundwater from the other side of the river. In these areas, the natural flux of groundwater into the river has been eliminated.

CONTAMINANT ATTENUATION POTENTIAL OF SOILS OVERLYING THE WAUSAU AQUIFER

Background

Soil, which usually composes the upper 2 to 4 ft of unconsolidated materials, provides an initial barrier to surface-applied contaminants before they reach the water table. Because significant contaminant attenuation may occur within the soil zone, it is important to consider soil properties as part of any management scheme designed to protect groundwater. A thorough examination of the soils overlying an unconfined aquifer also provides useful insight about the reasons for groundwater contamination in certain areas.

Attenuation is defined as any process that reduces the concentration of a chemical. In this report, attenuation specifically refers to a concentration reduction from that which is applied to the land surface to that which enters groundwater. This definition necessarily excludes all subsoil contamination sources such as recharge wells or landfills that are located beneath the A and B soil horizons.

The mechanisms that cause attenuation are complex and interrelated. Processes that attenuate contaminants in the soil include surface adsorption, dilution, volatilization, mechanical filtration, precipitation, buffering, neutralization, ion exchange, microbial metabolism, plant uptake, hydrolysis, oxidation, and photodegradation (Chesters and others, 1982; Wehtje and others, 1984). In simpler terms, these can be broken into chemical and physical mechanisms. In general, physical mechanisms reduce contaminant mobility by physically retaining contaminants; chemical mechanisms may also reduce their toxicity by breakdown into harmless components. The longer the soil physically holds the contaminant, the more opportunity is available for them to react chemically to each other before the contaminant leaches through the soil to the groundwater. Physically, the soil is able to retain some contaminants for a certain period of time, depending on the thickness, permeability, texture, and drainage regime of the soil.

However, the natural purification capacity of the soil, like that of any other natural resource is limited, and sometimes soils that retain contaminants may themselves become contaminated. Cleaning contaminated soil can be as difficult as cleaning contaminated groundwater. The evaluation system presented here must be looked upon as a supplemental planning tool only, as a time- and cost-saving guide for preliminary screening of the county for areas sensitive to the impact of normal land-use activities.

The greater the soil thickness, the greater the transit time of the applied contaminant. Deep soils tend to contain more organisms whose metabolism result in contaminant attenuation (Pye and Patrick, 1983). Therefore, a thick soil solum provides better protection for groundwater than a thin solum. In general, the more permeable a soil, the faster water flows through it. To maximize the interaction time between contaminants and soil, the permeability should be minimized. Although soil permeability is usually based on saturated soils (Soil Survey Staff, 1975), soils are rarely saturated, and soil permeability decreases with decreasing water content. The exact relationship between water content and permeability is unique for each soil, difficult to determine (Hillel, 1980, chapter 9), and usually ignored in standard soil classifications. Hence, soil permeability here refers to the saturated hydraulic conductivity, which is usually higher than the permeability normally encountered under field conditions.

Soil texture describes the grain-size distribution of a soil. In general, the coarser the soil texture, the faster water will flow through it. Loamy soils tend to retain contaminants longer than sandy soils (Chesters and others, 1982). Clay particles can actually adsorb dissolved matter and sometimes even immobilize it. But too much clay at the surface causes water to run off into streams rather than infiltrate into the soil. From the standpoint of contaminant attenuation, the ideal surface soil horizon, or A horizon, would have a silt loam or loam texture to ensure infiltration and percolation to the B horizon, which would have a silty clay loam texture to maximize the soil/water contact time.

Soil drainage is an indicator of the nature and extent of soil wetness, including how water moves through the soil profile over the seasons. For high contaminant attenuation capacity, a soil should be well drained, indicating that the water table remains well below the soil zone.

Many contaminants break down at the same rate regardless of chemical interaction with the soil; for them, retention is the only soil mechanism that prevents flow to the water table. Radioactive elements, for example, decay naturally at a constant rate, regardless of other chemical processes. Some pesticides also break down at specific rates. The amount of time necessary for pesticides to become harmless to the environment is commonly indicated by the manufacturer, but these times vary under different environmental conditions (Chesters and others, 1982). Also, pesticide users may sometimes apply more than directed. Therefore, it is not surprising that numerous accounts of pesticide contamination in groundwater have been reported in Wisconsin (Hindall, 1978; Holden, 1986; Manser, 1983; Mell, 1985; Rothschild and others, 1982). Most of these incidents occurred when pesticides infiltrated quickly through sandy soils into groundwater.

Trace metals from municipal wastewater treatment sludge can accumulate to hazardous levels, although they may never reach groundwater because they readily adsorb onto clay particles in the soil. Chromium concentrations, for example, may be reduced by as much as 99.9 percent simply by passing through the upper soil horizons (Dreiss, 1986). Only when the adsorption capacity of the soil is exceeded do trace metals leach to the groundwater.

Several chemical and biological processes may attenuate contaminants in the soil. These processes, including cation exchange, chelation, hydrolysis, oxidation, denitrification, and complexation, are complicated and depend on several parameters, including soil pH and organic content.

Organic material increases the adsorption potential of a soil by 10 to 100 times that of an equivalent inorganic soil (Clark and others, 1985, p. 48). In

Table 8. Ranking system for evaluating the attenuation potential of soils (Zaporozec, 1985)

Physical/chemical weighted characteristics	Classes	Weighted values
Texture[1] of surface (A) horizon	l[1], sil, scl, si	9
	c, sic, cl, sicl, sc	8
	lvfs, vfsl, lfs, fsl	4
	s, ls, sl, organic materials, and all textural classes with coarse fragment class modifiers	1
Texture[1] of subsoil (B) horizon	c, sic, sc, si	10
	scl, l, sil, cl, sicl	7
	lvfs, vfsl, lfs, fsl	4
	s, ls, sl, organic materials, and all textural classes with coarse fragment class modifiers	1
Organic matter content[1]	Mollisols[3]	8
	Alfisols	5
	Entisols, Inceptisols, Spodosols	3
	Histosols; Aquic suborder; Lithic, Aquollic, and Aquic subgroups	1
pH of surface (A) horizon	≥6.6	6
	<6.6	4
Depth of soil solum (A and B horizons)	> 40 inches	10
	30-40 inches	8
	20-30 inches	3
	< 20 inches	1
Permeability[3] of subsoil (B) horizon	very low	10
	moderate	8
	high	4
	very high	1
Soil drainage class	well drained	10
	well to moderately well drained	7
	moderately well drained	4
	somewhat poorly, poorly, and very poorly drained; excessively well drained	1

[1] Soil textural classes: l=loam, sil=silt loam, scl=sandy clay loam, si=silt, c=clay, sic=silty clay, cl=clay loam, sicl=silty clay loam, sc=sandy clay, lvfs=loamy very fine sand, vfsl=very fine sandy loam, lfs=loamy fine sand, fsl=fine sandy loam, s=sand, ls=loamy sand, sl=sandy loam.

[2] Based on the ordinal, subordinal, or subgroup levels of the soil classification system; soils are assigned a lower number if they are wet or less than 20 inches thick over bedrock.

[3] Based on the particle-size class at the family level of the soil classification system, type and grade of structure, and consistence.

addition, organic matter can absorb heavy metals present in leachate from industrial, rural, and urban wastes, essentially immobilizing them. Finally, organic material provides the energy for microorganisms, which break down organic wastes and some pesticides (Zaporozec, 1985, p. 34). Atrazine, for example, is a water-soluble organic herbicide that breaks down by hydrolysis and microbial activity in the presence of organic colloids, but leaches directly to groundwater in the absence of such colloids (Wehtje and others, 1984).

Breakdown processes involving organic material function most effectively at a neutral pH (Zaporozec, 1985, p. 34). Bacteria that degrade contaminants survive longer in neutral and alkali soils (Clark and others, 1985, p. 51). The rates of hydrolysis of atrazine and the systemic pesticide, aldicarb, increase at low pH (Wehtje and others, 1984; Chesters and others, 1982). Solubilities of several contaminants decrease with increasing pH (Foth, 1978, p. 207), and alkaline soils tend to attenuate contaminants more than acidic soils.

Procedure

The U.S. Soil Conservation Service publishes readily available county soil survey reports, which contain classifications of the soils described and mapped in each county. The taxonomy used to classify soils is based on soil morphology, physical characteristics, and chemical data (Soil Survey Staff, 1975). The scheme used to classify soils according to their contaminant attenuation potential in this report was first designed and implemented by Madison (as cited in Zaporozec, 1985). Each series classified in the preliminary Marathon County soil survey (U.S. Soil Conservation Service, in press) was assigned a rating according to the seven physical and chemical characteristics listed in table 8. Each characteristic was weighted differently, according to its relative importance, and the values for each characteristic of a given soil were summed to give the overall attenuation potential rating of that particular soil. Finally, the soils were grouped into four associations according to their ratings. The highest rating association has the greatest capacity to attenuate pollutants.

The soil attenuation map (plate 3) should be viewed only in a regional sense because of its scale (1:100,000). The map does not replace the need for detailed site-specific investigations.

Results

Most of the soils overlying the Wausau aquifer have low attenuation potentials (table 9). No soil in the area ranked in the highest group of best attenuation potential. The low ranking is to be expected, considering the genesis of the soils. Sandy deposits from outwash streams rarely contain the fine material and the organic content necessary for effective contaminant attenuation. In many soils, these constituents may develop over time as the soil weathers; however, the granite and rhyolite from which the sand is derived are among the most weather-resistant rock types (Birkeland, 1984, p. 174). As a result, soils in the area are almost all coarse-grained, and therefore extremely permeable. The soils rated as having good attenuation potential are almost all found on the bedrock hills that surround the Wisconsin River valley. Because the soils often form in the clayey residuum that overlies the bedrock, they have higher attenuation capacities than the soils formed from sand and gravel.

The soils rated as marginal are found mainly along streams and gullies where wet conditions promote a high organic matter content and accelerate weather-

Table 9. Soil series overlying the Wausau aquifer, listed by attenuation potential

	Attenuation potential			
	Least potential	Marginal potential	Good potential	Best potential
Sum of weighted values	0-30	31-40	41-50	51+
	Au Gres (22)*	Alban (38)	Fenwood (47)	
	Chetek (17)	Dancy (31)	Marathon (49)	
	Fordem (27)	Dunnville (31)	Rozellville (50)	
	Minoqua (12)	Fenwood, stony (33)	Withee (41)	
	Moberg (14)	Guenther (31)		
	Mohtmedi (14)	Meadland (38)		
	Mosinee (28)	Mylrea (31)		
	Oesterle (14)	Rietbrock (34)		
	Plover (23)	Rosholt silt loam(36)		
	Ribhill (27)	Sherry (39)		
	Rosholt, sandy (28)			

* Numbers in parentheses indicate ratings of individual soil series.

ing processes. These areas require careful management, comparable to the areas of poorly attenuating soils because of their proximity to sensitive surface waters.

The low ranking of soils in the study area explains why the Wausau aquifer is so susceptible to contamination. Every documented case of contamination in the area underlies soil of the lowest attenuation potential group, which emphasizes the need for careful land management to protect the aquifer.

CONCLUSIONS

- The Wausau aquifer has experienced three partly overlapping phases of change due to human intervention. First, dam construction raised the base level in places, resulting in large-scale alterations of groundwater flow patterns. Second, groundwater pumping created local cones of depression. Third, urbanization and industrialization led to groundwater contamination affecting about 45,000 people, approximately 60 percent of the population of the Wisconsin River valley in Marathon County.
- The elevation of the base of the aquifer varies greatly over short distances because of the hilly bedrock topography and the presence of irregularly distributed clayey deposits.
- Hydraulic conductivity of the aquifer varies from about 10^{-5} to 10^{-3} ft/s (10^{-4} to 10^{-2} cm/s). The areal and vertical distribution of hydraulic conductivity is extremely variable; however, hydraulic conductivity generally increases from south to north.
- The typical water-table gradient ranges from about 0.006 ft/ft in the south to 0.013 ft/ft in the north. Groundwater velocities may be expected to range from about 50 ft/year (15 m/year) in the south to 1100 ft/year (330 m/year) in the north.

- Parts of the Wausau aquifer can be modeled mathematically using the data contained in this report as model input. However, additional data may be required for model calibration and verification.
- Groundwater pumping reduces the amount of groundwater that would otherwise discharge to the Wisconsin River. Pumping near the river reverses the pre-pumping hydraulic gradient, resulting in induced aquifer recharge from the river.
- Because the soils overlying the Wausau aquifer provide poor protection from groundwater contamination and the aquifer itself is highly permeable, the Wausau aquifer is extremely susceptible to contamination.
- The heterogeneity of the aquifer material and the irregularity of its boundaries make site-specific investigations particularly difficult. Therefore, it is more prudent to protect the aquifer from future contamination than to continue to contaminate it and then attempt restoration. The data compiled in this report are intended to assist resource managers in formulating plans to protect the aquifer.

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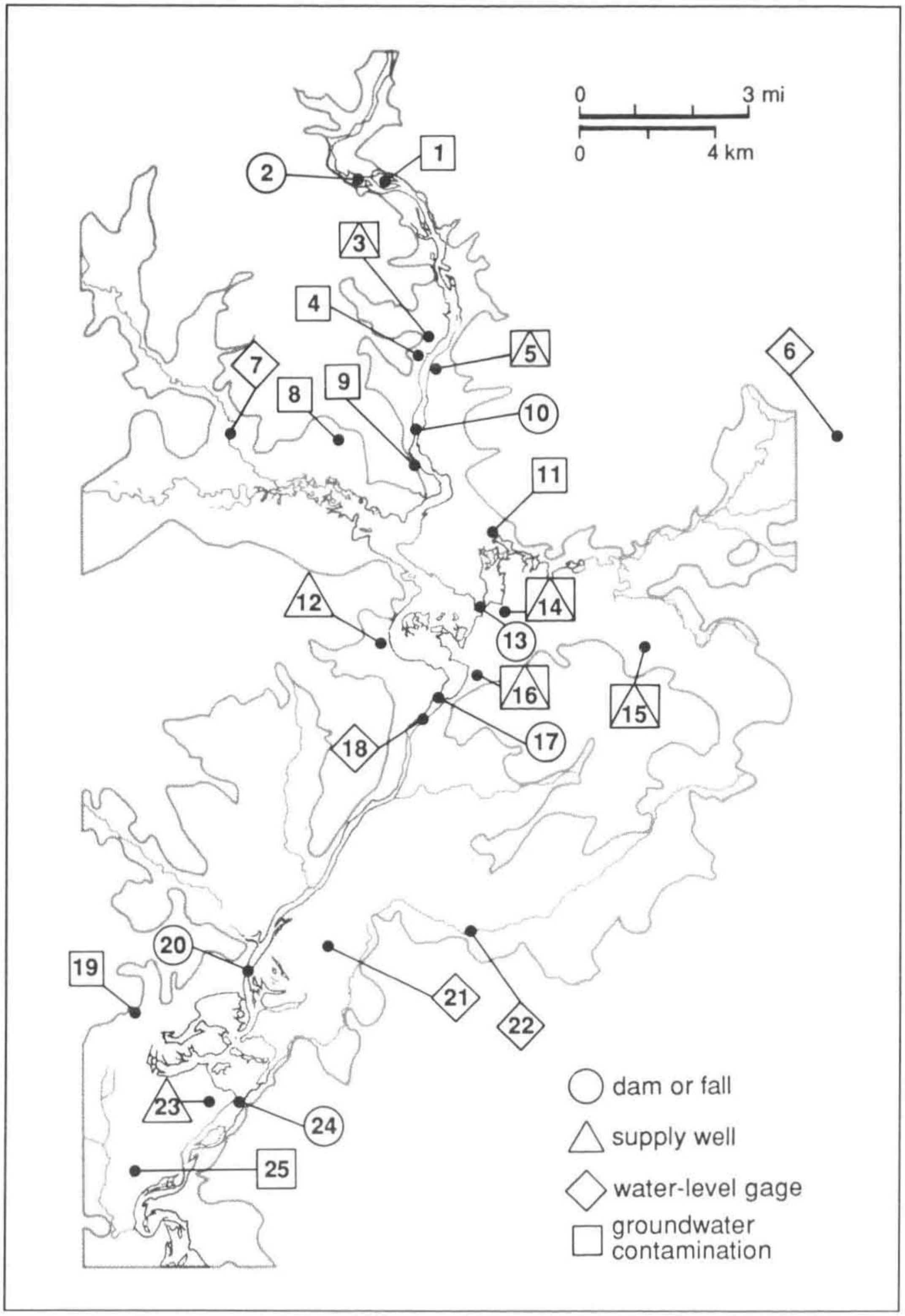

Figure A-1. *Locations cited in appendix A.*

1. *Island near Brokaw with spent sulphite liquor contamination.*
2. *Five-Mile Dam.*
3. *VOC contamination of Wausau municipal supply wells (west wellfield).*
4. *City of Wausau landfill, 1948-55.*
5. *Wausau Water and Sewerage Utility; VOC contamination of Wausau municipal supply wells (east wellfield).*
6. *Well MR-28. Water levels recorded by USGS since 1944.**

APPENDIX A. Chronology of development of the Wausau area

Numbers in parentheses following dates refer to site numbers indicated in figure A-1.

1836
40 by 6 mile strip along Wisconsin River (including the entire segment through Marathon County) ceded from Menomonee Indians to U.S. government (Ladu, 1907; Snyder, Van Vechten & Co., 1878).

1837
(10) George Stevens was first non-Indian settler of Marathon County. Lumber sawmill established at Big Bull Falls (Malaguti and others, 1984).

1839
(24) John L. Moore was first to settle southern Marathon County. Established sawmill at Little Bull Falls, which had a 21-ft fall through four channels between four granite islands (*Mosinee Times*, 1976; Snyder, Van Vechten & Co., 1878).

1840
(10) Wausau Dam built at Big Bull Falls.

About 1849
(24) Dam built at Mosinee.

1850
Marathon County established February 9. The population of about 500 was almost completely dependent on the timber industry (Fenhaus, 1985).

1856
First farmers began to settle Marathon County (Snyder, Van Vechten & Co., 1878).

1860
(13) Brooks & Ross Dam constructed at mouth of Eau Claire River.

1870-75
The population of Marathon County nearly doubled. 1875 census counted 10,111 residents (Snyder, Van Vechten & Co., 1878).

1880-81
(2) Five-Mile Dam was constructed on a 9-ft fall by the Wausau Boom Company. This created a pond for log storage, which enabled logs to be sorted by

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7. *USGS gauging station on Little Rib River.*
8. *VOC and salt contamination in Stettin.*
9. *Pentachlorophenol and mineral spirit contamination.*
10. *Wausau Dam (Big Bull Falls).*
11. *Holtz-Krause landfill.*
12. *Rib Mountain Sanitary District's new supply wells.*
13. *Brooks and Ross Dam.*
14. *VOC contamination of Rothschild village supply wells.*
15. *VOC contamination of Weston town supply wells.*
16. *VOC contamination of Schofield municipal supply wells.*
17. *Rothschild Dam.*
18. *USGS gauging station on Wisconsin River at Rothschild.*
19. *Gorski landfill.*
20. *Falls in sec. 17, T27N, R7E.*
21. *Well MR-139. Water levels recorded by USGS since 1968.**
22. *USGS gauging station on Bull Junior Creek.*
23. *Mosinee town supply wells.*
24. *Mosinee Dam (Little Bull Falls).*
25. *Aldicarb pesticide contamination near Mosinee.*

**Hydrograph in fig. 13.*

size prior to floating downstream so they could be directed to the correct mill in Wausau (*The Central Wisconsin*, 1900; Marchetti, 1913). The dam was 350 ft long (Smith, 1908).

1881
Drought in Wisconsin caused fire hazard, which prompted the development of public water supplies (Kirchoffer, 1905; Wausau Water and Sewerage Utility, 1985).

1885
(5) Wausau Water Works established. First municipal well began operation December 1 with a pumping capacity of 2,100 gpm (Wausau Water & Sewerage Utility, 1985; Zaporozec, 1979). The well, which was located 150 ft from the Wisconsin River, was 35 ft deep and 40 ft in diameter (Weidman and Schultz, 1915).

1886
First recorded groundwater quality evaluation in Marathon County from private well in Wausau (Weidman and Schultz, 1915).

1899
USGS surveyed Wausau and surrounding areas (Renshaw, 1902).

(2) Five-Mile Dam raised to create 14 ft of fall, for an estimated 5,600 horsepower potential (Marchetti, 1913).

1903
USGS authorized preliminary report on the water powers of the northern Wisconsin River (Smith, 1908).

1905
(5) Wausau water-distribution mains had become so clogged with *crenothrix* bacteria from naturally occurring iron in the water that 30 (Weidman, 1907) or 40 (Weidman and Schultz, 1915) 6-inch diameter, 134-ft deep, wells were drilled to serve the city's 14,458 inhabitants (Weidman, 1907).

1906
USGS published river survey of Wisconsin River at 1:24,000 scale with 1-ft contours along river and 10-ft contours along its banks (Smith, 1906). The Marathon County segment is summarized in tables 1 and A-2.

1909
(17) Rothschild Dam constructed.

1910
(24) Wausau Sulphite Fibre Co. (changed name to Mosinee Paper Mills in 1928) bought Mosinee Dam, mill site, and flowage rights at Mosinee. Became the first U.S. mill to use the sulfate processing method (Daily Herald, 1983).

1910-12
(5) Wausau Water Utility improved its pumping capacity to 3,000 gpm (Wausau Water & Sewerage Utility, 1985).

1913
(5) Average daily pumpage from Wausau municipal wells in 1913 was 2,650,000 gallons. Meanwhile, untreated sewage was emptied into the Wisconsin River (Weidman and Schultz, 1915).

1915
(23) Weidman and Schultz (1915) state that "city supply was recently installed, being obtained from a well 15 ft deep in Mosinee."

Mid-1920s
(5) Wausau's first water treatment plant began to remove naturally occurring iron and manganese from public water supplies (Wausau Water & Sewerage Utility, 1985).

1933-34
(5) Chlorination added to Wausau Treatment Plant process (Wausau Water & Sewerage Utility, 1985).

1948-55
(4) City of Wausau landfill accepted residential, industrial, and commercial waste from Wausau (CH2M Hill, 1986).

1950
(11) Holtz Krause Landfill began operation in which solid waste was deposited into standing water in gravel pit and, because of trenching, directly into groundwater (MacDonald, 1974).

1951
(3,5) Wausau Water Utility began to drill the presently used municipal wells (Wausau Water and Sewerage Utility, 1985).

1953-57
(1) Wausau Paper Mills Co. disposed spent sulfite liquor in unlined seepage lagoons on a small island in the Wisconsin River (Geraghty & Miller, Inc., 1980).

1962
(5) Present Wausau water treatment facility built with capacity to treat 10 million gallons with fluoride and chlorine and to remove iron and manganese (Wausau Water & Sewerage Utility, 1985).

(11) First complaint of groundwater and surface-water pollution from Holtz Krause landfill by nearby resident, Mrs. Amelia Pils (MacDonald, 1974).

1963-64
(1) System of removal and barrier wells installed to contain spent sulfite liquor contamination plume (Geraghty & Miller, 1980).

1967-76
(19) Gorski Landfill operated, accepting waste in "rotten granite" pit (Ken Markart, Wisconsin Department of Natural Resources, Antigo office, verbal communication, 1986).

1968
(21) USGS began continuous recording of well MR-139 (Zaporozec, 1980).

1973
(24) WDNR water pollution abatement orders of 1970 led to improvements at Mosinee Paper Mill, including two reactor clarifiers to remove biological oxygen demand (BOD) from wastewater (*Mosinee Times*, 1976).

1982
(25) Aldicarb pesticide detected at >10 parts per billion (ppb) in private wells. Moratorium imposed on further land application of aldicarb near affected areas until concentrations in wells reduce to <2 ppb (Ron Becker, Wisconsin Department of Natural Resources, Rhinelander office, verbal communication, 1986).

Early 1980s
(9) Pentachlorophenol and mineral spirit contamination detected in private wells near Wisconsin River. Effects on the river are currently being investigated (Wisconsin Department of Natural Resources, 1986).

1981
(16) VOCs detected in Schofield Well 3. Well is now used only on a limited basis, and has been retrofitted with VOC removal equipment (Wisconsin Department of Natural Resources, 1986).

1982
(3,5) VOCs detected in Wausau municipal water supply. Well 4 was taken off-line, and uncontaminated water from Wells 7 and 9 was blended with contaminated water from wells 3 and 6 to meet public demand (Weston, Inc., 1985).

1982-83
(14) VOCs detected in Rothschild wells 3, 4 and 5. Water from well 5 was pumped into the Wisconsin River in an attempt to protect the other two wells (Wisconsin Department of Natural Resources, 1986; Ed Kruel, Wisconsin Department of Natural Resources, verbal communication, 1986).

1983-84
(19) VOCs detected in private wells near Gorski Landfill (Ken Markart, Wisconsin Department of Natural Resources, Antigo office, verbal communication, 1986).

1984
(14) Tetrachloroethylene concentrations in Rothschild Wells 3 and 4 exceeded the 20 micrograms per liter health advisory limit (Wisconsin Department of Natural Resources, 1986).

(3) Granular activated carbon system installed on Wausau Well 6 to treat VOCs (Weston, Inc., 1985).

1984-85
(8) VOCs and excessive salt detected in private wells in the town of Stettin. Residents annexed that portion of the town to the city of Wausau to receive water from Wausau's municipal supply.

1985
(12) Educational campaign launched by Rib Mountain Sanitary District to protect new town wells (Hennings and others, 1985).

1985-86
(15) VOCs detected in Sternberg and Mesker Wells in the town of Weston. Both wells are now out of service, leaving the town dependent on its one remaining well (Wisconsin Department of Natural Resources, 1986).

1986
(14) VOC air stripping system retrofitted to Rothschild water supply (Wisconsin Department of Natural Resources, 1986).

(24) Mosinee Paper Mill submitted plans to Wisconsin Department of Natural Resources for remedial action to collect and treat paper-mill sludge contamination of groundwater (Ken Markart, Wisconsin Department of Natural Resources, Antigo office, verbal communication, 1986).

Table A-1. Falls on the Wisconsin River in 1899
(From *The Central Wisconsin*, 1900)

Name (site on fig. A-1)	Height (ft)
Brokaw (2)	14
Wausau (10)	23
Rothschild (17)	20
Sec. 17, T27N, R7E (20)	20
Mosinee (24)	2

Table A-2. Water power of the Wisconsin River in Marathon County in 1907*
(From Weidman, 1907)

Location	Head (ft)	Rated horse-power of turbine installed	Theoretical horsepower	Remarks
Mosinee	20	--	6,100	Partly developed
Rothschild, sec. 24, T29N, R7E	20	--	6,000	Undeveloped
Wausau	23	5,200	4,900	Partly developed
Brokaw	12	3,960	2,500	Developed

* As estimated by L.S. Smith, based on a discharge of 6.10 cubic ft per second per square mile of drainage area.

APPENDIX B. Well construction data

Part 1. Selected well and soil-boring data used to construct plates 1 and 2

Drill depth and maximum base of aquifer elevation are indicated only for wells that do not hit the aquifer base; base of aquifer depth and elevation are indicated for wells that hit the base.

Well number	Latitude (dg/m/s)	Longitude (dg/m/s)	Date drilled (m/y)	Elev. (ft)	Drill depth (ft)	Aquifer depth (ft)	Static water depth (ft)	Static water elev. (ft)	Maximum elev. of base of aquifer (ft)	Elev. of base of aquifer (ft)
CATER	445958	893709	10/81	1220		107	24	1196	1113	
HICKORY	445957	893705	7/82	1220	77		31	1189		1143
MR20	450206	893918	10/70	1215	138		30	1185		1077
MR21	450204	893918	70	1225	138		25	1200		1087
MR22	450204	893918	70	1225	100		24	1201		1125
MR23	450204	893918	70	1225	80		23	1202		1145
MR24	450210	893910	70	1225	150		39	1186		1075
MR26	445401	893657	47	1184	100					1084
MR30	450147	893936	48	1209	148		20	1189		1061
MR32	444724	894336	48	1152		42	24	1128	1110	
MR35	445600	894049	39	1205	60		18	1187		1145
MR39	445647	893902	2/47	1200	93		37	1164		1107
MR41	445546	893741	5/51	1204	97		41	1163		1107
MR42	445835	893738	41	1201	96		19	1183		1105
MR43	445320	893737	54	1160	100		23	1138		1060
MR44	450051	893819	3/54	1224	97		37	1188		1127
MR47	445140	893917	6/54	1170		61	25	1146	1109	
MR56	445316	893746	56	1154		124			1030	
MR58	450145	893934	56	1215	158		25	1191		1058
MR62	445132	893857	9/57	1185	85		38	1147		1100
MR63	445132	893857	10/57	1185	85		38	1147		1100
MR64	445418	893312	4/57	1223	69		36	1187		1154
MR65A	445604	893745	5/57	1203		140	45	1158	1063	
MR67	450134	893908	2/57	1220	84		31	1189		1136
MR68	450154	893932	9/56	1212	143		26	1186		1069
MR69	444649	894338	5/58	1149		116	28	1121	1033	
MR82	445429	893635	9/60	1190	100		19	1172		1090
MR84	445837	893739	4/61	1200	100		17	1184		1100
MR85	444616	894421	3/61	1145	57		27	1118		1088
MR86	450158	893912	6/62	1225	92		30	1195		1133
MR88	445554	893945	62	1180	59		24	1156		1121
MR89	445440	893406	63	1216		48	33	1183	1168	
MR91	445903	893743	51	1218	100		30	1189		1118
MR92	445907	893732	51	1222	100		34	1188		1122
MR93	444702	894341	7/62	1150	89		24	1126		1061
MR105	445247	893811	7/63	1152	41		9	1143		1112
MR106	445255	893752	12/63	1158		87	13	1145	1071	
MR107	445255	893752	12/63	1155		79	14	1141	1076	
MR108	445249	893727	63	1150		109	7	1143	1041	
MR109	445357	893658	63	1184		48	17	1167	1136	
MR110	445357	893658	63	1184		73	14	1170	1111	
MR111	445351	893643	63	1180		10		1170		
MR114	445414	893548	7/63	1205	79		38	1167		1126
MR115	445414	893548	4/63	1205	80		38	1167		1125
MR125	444739	894242	12/4	1152		39	17	1135	1113	
MR128	444724	894337	8/59	1150	99		19	1131		1051
MR129	445404	893655	11/63	1185	71		27	1158		1114
MR130	444723	894321	10/64	1149	55		20	1130		1094
MR131	444842	894111	10/64	1160	60		23	1137		1100
MR132	444842	894111	9/64	1160	60		23	1137		1100
MR139	445000	893919	5/65	1170	50		8	1162		1120
MR142	445548	894010	9/65	1196	50		16	1180		1146
MR143	445655	894227	6/64	1205		70	18	1187	1135	
MR145	445651	894221	12/65	1170	89		23	1147		1081
MR146	445155	893831	65	1180		80	30	1150	1100	

Well number	Latitude (dg/m/s)	Longitude (dg/m/s)	Date drilled (m/y)	Elev. (ft)	Drill depth (ft)	Aquifer depth (ft)	Static water depth (ft)	Static water elev. (ft)	Maximum elev. of base of aquifer (ft)	Elev. of base of aquifer (ft)
MR147	445140	893917			0					
MR150	450200	893805	69	1440	150					1290
MR151	444616	894400	8/68	1145		70	29	1116	1075	
MR152	445811	893743	7/66	1200	130		11	1189		1070
MR154	444609	894044	9/69	1253		7	11	1242	1246	
MR156	445517	893602	9/69	1205		80	34	1171	1125	
MR157	444724	894335	1/74	1150	45		22	1128		1105
MR158	445547	893949	7/69	1195		57	26	1169	1138	
MR159	445547	893949	7/69	1195		63	26	1169	1133	
MR160	445547	893949	7/69	1195		63	25	1170	1132	
MR161	444724	894336	1/74	1150	45		21	1129		1105
MR162	445433	893324	2/73	1221	92		30	1191		1129
MR800	445553	893943	1/73	1180	48		24	1157		1133
MR801	445553	893943	1/73	1180	48		24	1156		1132
MR802	445553	893943	1/73	1180	48		24	1156		1132
MR804	445132	893822	7/74	1172	80		29	1143		1092
MR805	445132	893822	6/74	1172	60		31	1141		1112
MR850	445140	893852	9/78	1180	90		35	1145		1090
MR851	445140	893852	11/78	1180	85		35	1145		1095
MR854	445405	893611	9/80	1190	70		30	1160		1120
MR859	445721	894223	5/80	1210		80	30	1180	1130	
MR865	445435	893651	10/81	1181	73		24	1157		1108
MR870	445852	893808		1210	63	1147				
MR895	445910	893752		1220	114		35	1185		1106
MR899	445400	893649	9/82	1183	65		24	1159		1118
MR900	445436	893651	10/81	1182	73		24	1158		1109
MR959	445706	894135	9/85	1178	72		15	1163		1106
MR991	445121	893834	8/74	1174	60		27	1147		1114
MR992	450142	893929	82	1215	80		1135			
NRD	450003	893714	7/81	1212		105	24	1188	1107	
PLUM	445914	893800	5/85	1215		106	20	1195	1109	
MR1001	450145	893927	7/84	1221	85		33	1188		1136
B-C57	450329	893845		1203	21		2	1201		1182
B60	445641	893959	1/60	1161		37	0	1161	1125	
B61	445652	893959	1/60	1161		57	0	1161	1105	
B63-E	445351	893728	4/72	1180		10			1170	
B63-W	445351	893729	4/72	1176		14			1162	
B6579A	445912	893846	7/79	1212	31		5	1207		1181
B6579B	445912	893852	7/79	1215	33		4	1211		1182
B6579C	445900	893847	7/79	1247		8			1239	
B71	444828	894030		1151		6	2	1149	1145	
B79-E	445350	893706		1156		22			1134	
B79-W	445350	893707		1151		37			1114	
B87-79	445916	893846	12/79	1207	17		1	1206		1190
B89-96	444725	894153	11/61	1165		5			1160	
B98	445203	893841		1174		68			1105	
B110	445812	893922	10/65	1292	12					1280
B12131	445703	894415	6/69	1181		48	0	1181	1133	
B122	445712	894147	4/68	1176		31	7	1169	1146	
B123-E	445716	894147	4/68	1176		25			1152	
B123-W	445716	894148	4/68	1176		14	13	1164	1162	
B124-E	445713	894141	7/68	1167		29			1138	
B124-W	445713	894142	7/68	1169		87			1083	
B125-W	445715	894143	7/68	1170		86			1084	
B125-E	445715	894142	7/68	1167		23			1144	
B126	445723	894021	3/68	1193		43	13	1180	1150	
B127	445723	894027	3/68	1179		28		1151		
B128	445732	894016	2/68	1199		52		1147		
B129	445730	894014	2/68	1199		56			1143	

Well number	Latitude (dg/m/s)	Longitude (dg/m/s)	Date drilled (m/y)	Elev. (ft)	Drill depth (ft)	Aquifer depth (ft)	Static water depth (ft)	Static water elev. (ft)	Maximum elev. of base of aquifer (ft)	Elev. of base of aquifer (ft)
B140	445437	893624	10/69	1178		12			1166	
B149	444710	894049	9/70	1255		2			1253	
B150	450010	893931	10/69	1300		0	17	1283	0	
B153	445922	893922	1/73	1250		10			1240	
B154	445924	893924	1/73	1250		8	4	1246	1242	
B155	450009	893927	9/72	1297		2	4	1293	1295	
B157-1	450102	894007	3/72	1421		4			1417	
B157-2	450102	894009	3/72	1421		5	7	1414	1416	
B157-3	450102	894005	3/72	1421		5	10	1411	1416	
B158	450130	894008	3/72	1318		7	15	1303	1311	
B159	450130	894008	3/72	1299		13	0	1299	1286	
B160	450225	893945	2/72	1200	22		3	1197		1178
B161	450407	893830	8/72	1226	91		23	1203		1136
B162-2	450407	893834	8/72	1226	101		25	1201		1125
B162-3	450405	893834	8/72	1226	91		23	1203		1136
B163-4	450602	893809	4/72	1222	21		5	1217		1202
B166-1	450615	893813	4/72	1248	57					1191
B166-3	450616	893814	4/72	1248	60					1188
B167	445951	893927	2/72	1222	21		2	1220		1201
B170-1	445917	893709	6/72	1197	66		8	1190		1131
B170-3	445917	893710	6/72	1195		82			1113	
B170-4	445918	893711	6/72	1193		95			1098	
B170-5	445918	893717	6/72	1188	113		0	1188		1075
B170-6	445918	893715	6/72	1188	106		0	1188		1082
B170-7	445918	893713	6/72	1188	112		0	1188		1076
B170-8	445918	893719	6/72	1188	107		0	1188		1081
B186	445202	893821	10/78	1145	64		4	1141		1081
B189-1	450431	893630	5/81	1226	13		7	1219		1213
B189-2	450431	893633	5/81	1226		5	18	1208	1221	
B195	450452	893617	3/81	1220	81		17	1203		1139
B197	445757	894204	5/81	1178		46	16	1163	1132	
B232-W	445809	893754	9/84	1187		36	0	1187	1151	
B232-E	445809	893753	9/84	1187	100		0	1187		1087
WC3	445914	894454	11/74	1225	38		16	1209		1187
WC4	445843	894407	8/78	1235		25	18	1217	1210	
WC7	445756	894339	8/66	1201		20	16	1185	1181	
WC8	445822	894420	8/75	1270		0	39	1231	1145	
WC9	445820	894354	8/70	1212	53		25	1187		1159
WC10A	445700	894413	10/55	1189		70	14	1175	1119	
WC10B	445700	894413	10/55	1189		10	16	1173	1179	
WC14	450107	893834	5/64	1200	130		33	1167		1070
WC15	450107	893814	2/69	1200	160		33	1167		1040
WC16	450155	893850	10/71	1320		0	25	1295	1320	
WC20	450136	894130	2/60	1421		0	39	1382	1421	
WC24	450154	894020	11/60	1370		0	9	1361	1370	
WC25	450150	894220	4/64	1350		0	11	1339	1350	
WC26	450102	894326	11/76	1262		0	30	1232	1262	
WC28	450008	894335	2/77	1262		0	40	1222	1262	
WC29	450012	894249	3/65	1360		0	24	1336	1360	
WC30	450010	894134	4/78	1262		0	20	1242	1262	
WC31	450010	894215	10/74	1350		0	27	1323	1350	
WC32	450035	894135	12/73	1334		0	30	1304	1334	
WC33	450100	894136	9/56	1328		0	6	1322	1328	
WC34	450041	894040	5/75	1350		0	12	1338	1350	
WC35	450011	894025	7/77	1330		0	20	1310	1330	
WC41	450024	893713	7/56	1220		25	30	1190	1195	
WC42	450011	893724	2/57	1205	45		8	1197		1160
WC43	450011	893642	4/72	1225		80	22	1203	1145	
WC44	450011	893700	7/69	1220		18	25	1195	1202	

Well number	Latitude (dg/m/s)	Longitude (dg/m/s)	Date drilled (m/y)	Elev. (ft)	Drill depth (ft)	Aquifer depth (ft)	Static water depth (ft)	Static water elev. (ft)	Maximum elev. of base of aquifer (ft)	Elev. of base of aquifer (ft)
WC45	445929	893655	6/56	1222	51		36	1186		1171
WC46	445844	893654	5/54	1270	48		24	1246		1222
WC47A	445944	893750	3/76	1210		20	20	1190	1190	
WC47B	445944	893750	10/74	1210		0	16	1194	1210	
WC49	450007	893711	7/74	1220		20	9	1211	1200	
WC50	445930	893838	4/68	1220		22	16	1204	1198	
WC51	445852	893814		1240		0	16	1224	1240	
WC53	445944	893943	8/45	1235		0	20	1215	1235	
WC54	445918	894002	2/77	1330		0	15	1315	1330	
WC55	445922	894242	6/77	1210		11	12	1198	1199	
WC57	445918	894134	8/49	1300		0	24	1276	1300	
WC58	445955	894254	11/68	1395		0	17	1378	1395	
WC59	445940	894257	11/68	1354		0	54	1300	1354	
WC60A	445423	893950	5/67	1220	65	0	27	1193	1220	1155
WC60B	445423	893950	12/67	1220	65	0	34	1186	1220	1155
WC61A	445421	893955	5/68	1230	65	0	27	1203	1230	1165
WC61B	445421	893955	1/68	1230	97	0	23	1207	1230	1133
WC62	445425	893951	2/76	1230		0	24	1206	1230	
WC63	445415	894004	10/72	1225	106		25	1200		1119
WC64A	445408	893957	4/75	1220	165	0	12	1208	1220	1055
WC64B	445408	893957	6/77	1220	96	8	16	1204	1212	1124
WC64C	445408	893957	10/74	1220	127	42	38	1182	1178	1093
WC65	445423	893950	6/73	1220	97	0	28	1192	1220	1123
WC66	445409	893958	1/73	1220	51		21	1199		1169
WC67	445428	893951	10/65	1243	112	0	51	1192	1243	1131
WC68A	445444	893926	8/66	1290	85	0	21	1269	1290	1205
WC68B	445444	893926	9/69	1290	51		34	1256		1239
WC69	445447	893912	8/65	1208	50	0	20	1188		1158
WC73	445429	893847	4/67	1190	37		23	1167		1153
WC74	445426	893840	10/77	1185	51		22	1163		1135
WC75	445405	893827	6/67	1186	56		24	1162		1130
WC76	445434	893842	7/76	1193	51		29	1164		1142
WC77	445421	893902	7/76	1190	66		23	1167		1124
WC78	445414	893837	12/76	1191	45		28	1163		1147
WC79	445314	893817	12/76	1225	58		32	1193		1167
WC81	445425	893848	2/72	1190	54		26	1164		1136
WC82	445446	893856	9/76	1199		31	31	1168	1168	
WC83	445515	893823	12/67	1198		19	19	1179	1179	
WC84	445444	893848	4/77	1198		43	24	1174	1155	
WC85	445442	893843	9/78	1195	63		36	1159		1133
WC90	445436	893744	6/72	1165	61		6	1159		1104
WC92	445508	893810	7/76	1180		32	30	1150	1148	
WC93	445517	893802	9/80	1165	26		5	1160		1140
WC94	445537	893841	9/7	1180		14	18	1162	1166	
WC95	445510	893708	10/68	1185		88	33	1152	1097	
WC98	445407	893804	8/73	1181	53		24	1157		1128
WC100	445407	893615	4/68	1200	55		41	1159		1145
WC101A	445407	893621	1/64	1195	58		40	1155		1137
WC101B	445407	893621	11/67	1200	54		38	1162		1146
WC102	445407	893614	1/65	1200	54		38	1162		1146
WC103	445419	893607	11/65	1200	56		32	1168		1144
WC104	445420	893611	11/63	1200	55		38	1162		1145
WC106	445409	893615	4/63	1201	52		40	1161		1149
WC107	445415	893613	4/67	1200	5		37	1163		1146
WC108	445423	893615	7/67	1200	54		37	1163		1146
WC109	445429	893627	12/65	1190	52		31	1159		1138
WC110	445414	893603	7/63	1200	52		37	1163		1148
WC111	445417	893616	8/66	1201	56		36	1165		1145
WC112	445428	893620	1/69	1198	53		35	1163		1145

Well number	Latitude (dg/m/s)	Longitude (dg/m/s)	Date drilled (m/y)	Elev. (ft)	Drill depth (ft)	Aquifer depth (ft)	Static water depth (ft)	Static water elev. (ft)	Maximum elev. of base of aquifer (ft)	Elev. of base of aquifer (ft)
WC113	445423	893542	4/67	1205	54		39	1166		1151
WC114	445417	893605	5/64	1200	55		37	1163		1145
WC115	445425	893527	5/62	1206	67		38	1168		1139
WC116	445406	893458	6/65	1210		28	24	1186	1182	
WC117	445415	893532	5/67	1202		20	24	1178	1182	
WC118	445342	893555	9/59	1235		0	10	1225	1235	
WC119	445426	893440	3/67	1215		38	35	1180	1177	
WC120	445400	893426	6/68	1265		18	12	1254	1247	
WC121	445410	893441	7/66	1250		20	25	1225	1230	
WC122	445424	893641	11/67	1190	47		34	1156		1143
WC123	444956	894153	10/77	1172		0	16	1156	1172	
WC126	444947	894017	8/60	1180	45		25	1155		1135
WC127	444946	894058	9/75	1185	41		25	1160		1144
WC128	445012	893959	4/75	1162	47		26	1136		1115
WC129	445039	893947	8/75	1170	51		29	1141		1119
WC130	444929	893946	12/77	1170	42		13	1157		1128
WC131	444932	893946	5/76	1170	30		5	1165		1140
WC132	444946	894058	9/74	1150	41		26	1124		1109
WC133	444904	894016	10/74	1165	36		12	1153		1129
WC134	444920	894236	5/74	1165		20	19	1146	1145	
WC135	444616	894443	8/76	1148		0	33	1115	1148	
WC136	444544	894413	12/77	1145		41	23	1122	1104	
WC137	444612	894422	3/61	1149		57	27	1122	1092	
WC138	444617	894348	10/73	1144	53		30	1114		1091
WC139	450631	893752		1250		11			1239	
WC140	450610	893836		1241		48			1193	
WC141	450404	893847		1225	48					1177
WC143	444617	893720	2/78	1200		0	24	1176	1200	
WC144	444615	893809	8/77	1152		26	12	1140	1126	
WC145	444614	893913	5/75	1168		0	13	1155	1168	
WC146	444606	894243	10/78	1144	58		32	1112		1086
WC147	444525	894105	11/70	1190		0	14	1176	1190	
WC148	444637	894350	4/75	1149	41		27	1122		1108
WC149	444619	894356	6/70	1149		80	24	1125	1069	
WC150	445058	893732	4/76	1175		30	27	1148	1145	
WC151A	445051	893729	10/74	1176	36		21	1155		1140
WC151B	445051	893729	6/75	1176	48		12	1164		1128
WC152	445056	893655	9/74	1187		35	20	1167	1152	
WC154	445057	893636	5/74	1192		22	14	1178	1170	
WC156	445043	893659	5/77	1190		40	17	1174	1150	
WC157	445052	893636	5/77	1193		17	14	1179	1176	
WC158	445058	893644	10/77	1190		35	28	1162	1155	
WC159	445126	893726	7/77	1180	55		20	1160		1125
WC164	445107	893807	7/75	1175	78		16	1159		1097
WC165	445037	894008	12/72	1160	44		19	1141		1116
WC166	445039	894006	6/61	1155	32		22	1133		1123
WC169	445128	894020	3/65	1180	58		18	1162		1122
WC170	445057	894127	12/78	1170		22	16	1154	1148	
WC171	445039	894235	11/68	1159		22	6	1153	1137	
WC172	444946	894333	11/73	1205		0	17	1188	1205	
WC176	445041	894002	4/81	1158	46		15	1143		1112
WC177	445113	893830	10/83	1176	51		24	1152		1125
WC178	445041	894129	8/81	1160		45	18	1142	1115	
WC179	444954	894244	8/81	1260		0	49	1211	1260	
WC180	445023	894232	8/83	1165		27	13	1153	1138	
WC181	445002	894023	12/81	1165	44		26	1139		1121
WC182	445005	894005	11/80	1166	46		26	1140		1120
WC183	444948	894005	9/83	1178		0	23	1155	1178	
WC184	445012	893927	10/83	1170	42		26	1144		1128

Well number	Latitude (dg/m/s)	Longitude (dg/m/s)	Date drilled (m/y)	Elev. (ft)	Drill depth (ft)	Aquifer depth (ft)	Static water depth (ft)	Static water elev. (ft)	Maximum elev. of base of aquifer (ft)	Elev. of base of aquifer (ft)
WC185	445029	894008	12/80	1170	43		27	1143		1127
WC187	445009	893709	11/83	1183		58	3	1180	1125	
WC188	445010	893708	5/81	1186		38	6	1180	1148	
WC190	444904	894005	5/82	1162	33		8	1154		1129
WC191	444932	893936	7/80	1171		30	8	1163	1141	
WC192	444910	894253	9/80	1160		0	24	1136	1160	
WC193	444842	893949	6/83	1161		60	7	1154	1101	
WC194	444848	893930	3/81	1170		9	21	1149	1161	
WC195	445524	893839	5/83	1193		25	28	1165	1168	
WC196	445518	893841	9/80	1192		19	24	1168	1173	
WC197	450140	894133	6/80	1429		8	7	1422	1421	
WC198	445929	893829	6/83	1220		0	8	1212	1220	
WC199	445739	894129	12/82	1205	34		14	1192		1171
WC200	445756	894335	5/81	1205		20	8	1197	1185	
WC201	445658	894155	10/82	1180	72		20	1160		1108
WC202	445710	894237	4/80	1200		60	25	1175	1140	
WC203	445648	893922	12/80	1191	72		30	1161		1119
WC204	445707	893938	5/80	1195	56		24	1171		1139
WC205	445702	894012	10/83	1170	80		10	1160		1090
WC206	445703	893943	7/83	1192	56		23	1169		1136
WC207	445648	893915	11/80	1190		24	35	1155	1166	
WC208	445700	893911	9/80	1201	53		30	1171		1149
WC209	445651	893925	10/82	1193		122	30	1163	1071	
WC210A	445730	894002	4/82	1200		65	20	1180	1135	
WC210B	445730	894002	5/81	1200		35	18	1182	1165	
WC211	445519	893837	5/83	1195		25	28	1167	1170	
WC212	445533	893841	8/82	1194		0	39	1155	1194	
WC213	445455	893839	3/81	1200		16	8	1192	1184	
WC214	445447	893833	11/83	1195		40	33	1162	1155	
WC220	445032	893652	11/83	1180		58	3	1177	1122	
WC221	445035	893651	5/81	1185		60	6	1179	1125	
WC222	444855	894340	10/81	1157		26	5	1152	1131	
WC223	444723	894457	1/81	1170		0	40	1130	1170	
WC224	444722	894338	4/65	1151	75		20	1132		1076
WC225	444627	894326	6/78	1140		50	12	1128	1090	
WC226	444627	894245	8/63	1125		13	11	1114	1112	
WC227	444718	894438	4/69	1150		0	9	1141	1150	
WC228	445720	894106	9/71	1211		0	26	1185	1211	
WC229	445706	894047	5/73	1170		30	6	1164	1140	
WC231	445733	894014	9/61	1205		33	19	1186	1172	
WC232	445705	893934	8/55	1195		22	20	1175	1173	
WC234	445654	893912	6/72	1193		45	30	1163	1148	
WC235	445722	893921	11/72	1205		22	24	1181	1183	
WC236	445637	893757	12/72	1165		9	9	1156	1156	
WC237	445640	893810	8/67	1175		17	6	1169	1158	
WC238	445603	894154		1198	48		14	1184		1150
WC239	445721	893943	8/64	1198	59		14	1184		1139
WC240	445707	894011	8/53	1174	82		5	1169		1092
WC241	445654	893912	8/79	1191	71		21	1170		1121
WC242	445701	893910	6/78	1200	56		28	1172		1144
WC243	445705	894111	7/60	1172	35		7	1165		1137
WC244	445707	894025	9/70	1172	72		18	1154		1100
WC245	445721	894111		1175	41		20	1155		1134
WC246	445641	893835	4/55	1205	59		40	1165		1147
WC247	445627	893833	8/49	1170	43		21	1149		1128
WC248	445629	893849	6/64	1185	68		28	1157		1117
WC249	445640	893813	9/66	1175	57		28	1147		1118
WC250	445725	894011	11/83	1200	45		16	1184		1155
WC251	445732	893921	3/83	1210	61		26	1184		1149

Well number	Latitude (dg/m/s)	Longitude (dg/m/s)	Date drilled (m/y)	Elev. (ft)	Drill depth (ft)	Aquifer depth (ft)	Static water depth (ft)	Static water elev. (ft)	Maximum elev. of base of aquifer (ft)	Elev. of base of aquifer (ft)
WC252	444632	894339	6/80	1146	43		27	1119		1103
WC253	444627	894339	6/81	1146	41		29	1117		1105
WC254	444558	894423	5/77	1145	65		15	1130		1080
WC255	444541	894411	10/69	1145	44		24	1121		1101
WC256	445503	893531	5/66	1200	55		40	1160		1145
WC257	445504	893504	11/77	1210	56		42	1168		1154
WC258	445518	893322	6/73	1200	46		18	1182		1154
WC259	445407	893115	7/61	1233	54		20	1213		1179
WC260	445424	893314	12/76	1220	56		15	1205		1164
WC261	445414	893221	4/75	1210	62		24	1186		1148
WC262	445437	893305	5/74	1220	54		34	1186		1166
WC263	445413	893255	6/83	1225	57		29	1196		1168
WC264	445448	893346	6/84	1219	52		37	1182		1167
WC265	445447	893330	12/81	1219	63		36	1183		1156
WC266	445423	893508	12/81	1210	55		36	1174		1155
WC267	445404	893339	6/81	1222	48		20	1202		1174
WC268	445336	893027	5/80	1238	44		25	1213		1194
WC270	445740	894128	12/82	1210	34		14	1197		1176
WC271	450202	893917	10/70	1225	138		30	1195		1087
WC272	450130	893901	4/67	1210	150		17	1193		1060
WC274	444602	894406	5/75	1145		53	23	1122	1092	
WC275	444535	894417	4/64	1145		30	22	1123	1115	
WC276	445025	894230	8/77	1165		32	14	1152	1133	
WC277	445025	894226	4/77	1165		55	9	1156	1110	
WC278	445519	893603	2/70	1200		83	34	1166	1117	
WC279	445501	893421	7/61	1215		41	28	1187	1174	
WC280	445539	893439	9/77	1173		107	15	1158	1066	
WC281	445516	893313	6/77	1205		36	26	1179	1169	
WC282	445514	893240	2/60	1225		18	16	1209	1207	
WC283	445504	893258	8/73	1200		20	18	1182	1180	
WC284	445440	893125	8/76	1220		22	30	1190	1198	
WC285	445440	893201	11/80	1218		28	10	1208	1190	
WC286	445354	893028	11/83	1237		35	17	1220	1202	
WC287	445846	893811	11/80	1225		52	17	1208	1173	
WC288	450126	893855	1/65	1193		125	3	1190	1068	
WC289	445903	894245	1/76	1211	49		14	1197		1162
WC290	445854	893907	6/66	1225		34	8	1217	1191	
WC291	445742	894224	9/74	1210		24	27	1183	1186	
WC292	450005	893650	4/72	1225	50		22	1203		1175
WC293	450041	893709	6/57	1212	34		17	1195		1178
WC294	445939	893654		1220	54		32	1188		1166
WC295	445947	893738	4/77	1215	63		31	1184		1152
WC296	445955	893702	7/60	1230	52		31	1199		1178
WC297	445945	893802	6/65	1220	46		17	1203		1174
WC298	445943	893753	8/62	1218	68		15	1203		1150
WC299	445919	893854	2/73	1215	38		7	1208		1177
WC300	445921	893829	1/67	1215	60		12	1203		1155
WC301	445852	893909	11/77	1222	44		10	1212		1178
WC302	445920	893842	8/74	1215	42		15	1200		1173
WC303	445908	893737	11/64	1222	44		30	1192		1178
WC304	445738	894224	1/69	1200	93		30	1170		1107
WC305	445732	894335		1188	65		10	1178		1123
WC306	445821	894334	11/61	1205	42		26	1179		1163
WC307	445657	894322	7/53	1200		107	15	1185	1093	
WC308	445727	893728	7/76	1215	83		34	1181		1132
WC309	445557	894009	10/81	1200	42		29	1171		1158
WC310	445537	893925	4/81	1200	40		20	1180		1160
WC311	445555	893909	3/81	1185		40	25	1160	1145	
WC312	445616	893929	5/80	1168		18	16	1152	1150	

Well number	Latitude (dg/m/s)	Longitude (dg/m/s)	Date drilled (m/y)	Elev. (ft)	Drill depth (ft)	Aquifer depth (ft)	Static water depth (ft)	Static water elev. (ft)	Maximum elev. of base of aquifer (ft)	Elev. of base of aquifer (ft)
WC313	445537	894000	5/81	1205		31	16	1189	1174	
WC314	445429	893906	9/80	1195		33	20	1175	1162	
WC315	445339	893811	1/80	1179	51		30	1149		1128
WC316	445341	893756	1/80	1180	51		30	1150		1129
WC317	445317	893737	9/81	1161	92		20	1142		1069
WC318	445130	894023	8/81	1178		36	22	1156	1142	
WC319	445555	893934	9/77	1180		50	23	1157	1130	
WC320	445635	893800	11/67	1170		28	8	1162	1142	
WC321	445617	893940	7/73	1170		41	6	1164	1129	
WC322	445616	894046	6/73	1205	39		17	1188		1166
WC323	445600	894110	11/61	1208		54	22	1186	1154	
WC324	445612	893921	8/76	1167	75		8	1159		1092
WC325	445548	894010	7/67	1200		47	17	1183	1153	
WC326	445555	894003	3/62	1200		58	25	1175	1142	
WC327	445617	894032	11/68	1195	94		19	1176		1101
WC328	445603	894154	6/74	1200		21	10	1190	1179	
WC329	445612	894136	6/75	1201		54	28	1173	1147	
WC330	445612	894135	1/61	1201	38		25	1176		1163
WC331	445622	894211	4/55	1170		27	27	1143	1143	
WC332	445601	894320	6/78	1220		21	38	1182	1199	
WC333	445600	894323	6/78	1224		0	38	1186	1224	
WC334	445602	894332	6/66	1215		40	25	1190	1175	
WC335	445502	893830	6/66	1190	40		8	1182		1150
WC336	445510	893707	7/68	1185		88	30	1155	1097	
WC337	445540	893918	9/59	1190	69		29	1161		1121
WC338	445336	894101	4/79	1200		22	10	1190	1178	
WC339	445402	893758	5/58	1184		134	26	1158	1050	
WC340	445239	893652	3/70	1183		104	25	1158	1079	
WC341	445246	893713	11/62	1184		35	35	1149	1149	
WC342	445239	893652	7/65	1190	44		29	1161		1146
WC343	445257	893757		1160	51		28	1132		1109
WC344	445231	893759	3/73	1150		56	2	1148	1094	
WC345	445237	893805	9/73	1150	50		11	1139		1100
WC346	445148	893817	9/76	1179	42		29	1150		1137
WC347	445131	893637	11/56	1190		35	30	1160	1155	
WC348	445147	893723	11/76	1181		22	32	1149	1159	
WC349	445131	893738	7/67	1180	48		29	1151		1132
WC350	445414	893839	9/84	1192	75		35	1157		1117
WC351	445418	893842	9/84	1190	90		32	1158		1100
WC352	445427	893847	10/84	1190	90		27	1163		1100
WC353	445107	893649	7/73	1188	38		13	1175		1150
WC354	445110	893726	8/71	1177	39		13	1164		1138
WC355	445047	893850	9/78	1170	67		20	1150		1103
WC356	445039	893918	7/63	1171	64		25	1146		1107
WC357	445112	894117	7/78	1170	48		11	1159		1122
WC358	445042	894024	7/64	1160	57		22	1138		1103
WC359	445028	893924	8/67	1170	61		21	1149		1109
WC360	445032	893844	6/75	1175	44		25	1150		1131
WC361	444954	893633	8/78	1190	42		6	1184		1148
WC362	445051	893719	6/78	1182	48		9	1173		1135
WC363	445021	893639	7/77	1180	75		10	1170		1105
WC364	444848	894023	4/76	1163		55	13	1150	1108	
WC365	444920	894020	8/77	1161		25	6	1155	1136	
WC366	444925	894039	9/71	1148		30	17	1131	1118	
WC367	444910	894240	7/79	1161		41	17	1144	1120	
WC368	444859	894243	11/69	1160	44		22	1138		1116
WC369	444852	894258	5/61	1158	80		22	1136		1078
WC370	444844	894028	8/70	1163	34		17	1146		1129
WC371	445106	893457	4/75	1203		28	14	1190	1175	

Well number	Latitude (dg/m/s)	Longitude (dg/m/s)	Date drilled (m/y)	Elev. (ft)	Drill depth (ft)	Aquifer depth (ft)	Static water depth (ft)	Static water elev. (ft)	Maximum elev. of base of aquifer (ft)	Elev. of base of aquifer (ft)
WC372	445045	893452	6/78	1201	32		8	1193		1169
WC373	445103	893427	7/78	1205	40		8	1197		1165
WC374	445038	893629	4/75	1191		70	10	1182	1121	
WC375	445045	893628	8/78	1191	40		5	1187		1151
WC376	445102	893552	9/78	1199	35		3	1196		1164
WC377	444959	893532	4/66	1193	38		10	1183		1155
WC378	445040	893406	7/77	1206	31		13	1193		1175
WC379	445039	893356	1/79	1208		53	12	1196	1155	
WC380	445643	892955	10/72	1210		61	7	1203	1149	
WC381	445612	893037	12/57	1219		14	18	1201	1205	
WC382	445643	893049	5/76	1218		26	16	1202	1192	
WC383	445521	893312	12/77	1208	50		29	1179		1158
WC384	445546	893414	8/71	1188		30	15	1173	1158	
WC385	445532	893405	9/70	1200		60	31	1169	1140	
WC386	445536	893313	3/70	1213	55		40	1173		1158
WC387	445525	893246	5/75	1225		56	30	1195	1169	
WC388	445544	893139	8/71	1190		45	20	1170	1145	
WC389	445533	893141	4/67	1215	44		25	1190		1171
WC390	445513	893144	7/73	1225		12	5	1220	1213	
WC391	445412	893050	4/78	1235	45		28	1208		1190
WC392	445236	893621	12/64	1180	43		26	1154		1137
WC393	445224	893612	5/65	1185		16	17	1168	1169	
WC394	445246	893632	1/68	1180		52	21	1159	1128	
WC395	445510	893707	5/79	1182	48		26	1156		1134
WC396	445125	893504	10/69	1202	67		9	1193		1135
WC397	445215	893212	6/78	1222	21		6	1217		1201
WC398	445618	894402	11/50	1221		32	52	1169	1189	
WC399	445601	894447	2/68	1191		81	11	1180	1110	
WC400	445553	894406	2/79	1210	55		26	1184		1156
WC401	445624	894352	4/75	1211		77	58	1153	1134	
WC402	445619	894400	1/74	1210	80		47	1163		1130
WC403	445917	894408	12/67	1195	45		11	1184		1150
WC404	445918	894347	7/71	1200	51		25	1175		1149

Part 2. Specific capacity, hydraulic conductivity, and transmissivity data for selected wells

Well number	Latitude (dg/m/s)	Longitude (dg/m/s)	Well diam. (in.)	Water depth (ft)	Drwdn depth (ft)	Test time (hr)	Pump rate (gpm)	Est'd aquifer depth (ft)	Screen length (ft)	Specific capacity (gpm/ft)	Specific capacity per foot (gpm/ft/ft)	Trans-missivity (sqft/s)	Hydraulic conduct. (ft/s)
CATER	445958	893709	6	24	40	10	250	107	20	16.5	0.83	1.5E-01	1.4E-03
MR32	444724	894336	26	24	31	45	350	42	10	54.8	5.48	2.5E-01	5.9E-03
MR35	445600	894049	10	18	54	10	40	65	13	1.1	0.0	6.9E-03	1.1E-04
MR41	445546	893741	24	41	51	8	1000	100	30	198.4	6.61	9.6E-01	9.6E-03
MR43	445320	893737	16	23	36	8	1000	125	40	117.1	2.93	6.0E-01	4.8E-03
MR44	450051	893819	16	37	57	10	838	100	20	50.1	2.51	3.4E-01	3.4E-03
MR47	445140	893917	16	25	31	12	300	61	15	54	3.60	2.9E-01	4.8E-03
MR58	450145	893934	6	25	27	4	165	160	10	88.5	8.85	2.1E+00	1.3E-02
MR62	445132	893857	15	38	42	12	400	85	15	124.8	8.32	9.2E-01	1.1E-02
MR63	445132	893857	15	38	45	12	400	85	15	64.5	4.30	4.7E-01	5.5E-03
MR64	445418	893312	10	36	46	5	100	70	10	10	1.00	8.6E-02	1.2E-03

Well number	Latitude (dg/m/s)	Longitude (dg/m/s)	Well diam. (in.)	Water depth (ft)	Drwdn depth (ft)	Test time (hr)	Pump rate (gpm)	Est'd aquifer depth (ft)	Screen length (ft)	Specific capacity (gpm/ft)	Specific capacity per foot (gpm/ft/ft)	Trans-missivity (sqft/s)	Hydraulic conduct. (ft/s)
MR65A	445604	893745	6	45	65	3	30	140	10	1.5	0.15	3.0E-02	2.1E-04
MR67	450134	893908	10	31	64	12	80	170	18	2.4	0.13	3.2E-02	1.9E-04
MR69	444649	894338	18	28	40	6	1050	116	36	160.8	4.47	8.2E-01	7.0E-03
MR82	445429	893635	16	19	26	24	800	110	35	209.1	5.97	1.1E+00	1.0E-02
MR85	444616	894421	20	27	46	3	780	70	20	48.8	2.44	2.2E-01	3.1E-03
MR86	450158	893912	12	32	61	11	500	100	30	17.8	0.59	9.4E-02	9.4E-04
MR88	445554	893945	6	24	29	1	15	60	6	3	0.50	3.7E-02	6.1E-04
MR93	444702	894341	18	24	49	5	1000	90	30	49.9	1.66	2.2E-01	2.4E-03
MR114	445414	893548	12	38	53	12	600	85	21	45.4	2.16	2.8E-01	3.3E-03
MR125	444739	894242	26	17	25	8	500	39	6	74	13.45	3.9E-01	1.0E-02
MR129	445404	893655	20	27	47	4	1760	105	21	458.9	22.17	3.1E+00	2.9E-02
MR130	444723	894321	16	20	35	72	600	50	10	43.7	4.37	2.7E-01	5.3E-03
MR131	444842	894111	12	23	46	24	400	65	20	18	0.90	8.9E-02	1.4E-03
MR132	444842	894111	12	23	46	24	400	65	20	18	0.90	8.9E-02	1.4E-03
MR139	445000	893919	6	8	10	6	11	60	3	4.8	1.92	1.2E-01	2.0E-03
MR142	445548	894010	6	16	39	4	12	55	3	0.52	0.17	1.0E-02	1.8E-04
MR143	445655	894227	6	18	48	4	80	70	11	2.7	0.25	2.4E-02	3.4E-04
MR145	445651	894221	12	23	70	8	200	90	15	4.3	0.29	3.3E-02	3.7E-04
MR152	445811	893743	20	11	47	12	2000	135	40	123.8	3.09	6.6E-0	4.9E-03
MR156	445517	893602	20	34	54	48	1200	80	20	93.3	4.67	5.3E-01	6.6E-03
MR157	444724	894335	16	2	29	24	200	50	10	28.6	2.86	1.7E-01	3.3E-03
MR158	445547	893949	6	26	44	4	35	57	5	2	0.40	2.6E-02	4.6E-04
MR159	445547	893949	6	26	30	4	35	63	5	9	1.80	1.3E-01	2.2E-03
MR160	445547	893949	6	25	27	4	40	63	3	20.1	6.70	4.7E-01	7.4E-03
MR161	444724	894336	16	21	28	24	200	50	10	30.3	3.03	1.8E-01	3.5E-03
MR162	445433	893324	20	30	42	24	1000	95	20	136.2	6.81	8.8E-01	9.2E-03
MR800	445553	893943	6	24	28	1	18	60	5	4	0.80	5.8E-02	9.6E-04
MR801	445553	893943	6	24	30	1	18	60	5	3	0.60	4.3E-02	7.1E-04
MR802	445553	893943	6	24	30	1	18	60	5	3	0.60	4.3E-02	7.1E-04
MR804	445132	893822	10	29	55	8	50	80	20	1.9	0.10	1.1E-02	1.4E-04
MR805	445132	893822	8	31	47	8	100	80	5	6.3	1.26	1.2E-01	1.4E-03
MR847	445137	893915	16	25	31	12	300	61	15	54	3.60	2.9E-01	4.8E-03
MR850	445140	893852	10	35	41	8	400	90	15	75.4	5.03	6.5E-01	7.3E-03
MR851	445140	893852	10	35	48	24	375	90	15	30.5	2.03	2.7E-01	2.9E-03
MR854	445405	893611	10	30	55	6	330	75	15	13.5	0.90	9.3E-02	1.2E-03
MR865	445435	893651	20	24	31	24	800	120	20	198.6	9.93	1.6E+00	1.3E-02
MR899	445400	893649	14	24	38	24	700	75	20	60.5	3.03	3.4E-01	4.5E-03
MR900	445436	893651	20	24	31	24	800	120	20	198.7	9.93	1.6E+00	1.3E-02
MR991	445121	893834	8	27	46	8	100	170	5	5.3	1.06	2.3E-01	1.4E-03
WC63	445415	894004	6	25	30	2	5	107	1	1	1.00	1.2E-01	1.2E-03
WC66	445409	893958	6	21	20	2	5	55	1	1.3	1.30	6.6E-02	1.2E-03
WC73	445429	893847	6	23	30	2	5	120	5	0.71	0.14	2.2E-02	1.9E-04
WC74	445426	893840	6	22	30	2	20	110	3	2.5	1.00	1.3E-02	1.2E-03
WC75	445405	893827	6	24	27	2	20	130	4	6.7	1.68	2.8E-01	2.2E-03
WC76	445434	893842	6	29	34	1	20	120	2	4	2.50	3.7E-01	3.1E-03
WC77	445421	893902	6	23	52	1	20	110	2	0.69	0.33	4.4E-02	4.0E-04
WC78	445414	893837	6	28	35	1	15	100	2	2.1	0.88	1.0E-01	1.0E-03
WC79	445314	893817	6	32	37	2	20	140	2	4	2.00	3.6E-01	2.6E-03
WC81	445425	893848	6	26	28	2	19	120	5	9.5	1.90	3.0E-01	2.5E-03
WC90	445436	893744	6	6	10	1	15	90	4	3.7	0.93	1.0E-01	1.1E-03
WC93	445517	893802	6	5	9	1	20	90	2	5.4	2.45	2.5E-01	2.8E-03
WC98	445407	893804	6	24	28	2	20	150	2	5	2.50	4.9E-01	3.3E-03
WC100	445407	893615	6	41	44	2	9	60	5	3	0.60	4.3E-03	7.2E-04
WC101A	445407	893621	6	40	42	2	15	60	4	7.5	1.88	1.3E-01	2.2E-03
WC101B	445407	893621	6	38	41	2	15	60	4	5	1.25	8.7E-02	1.5E-03
WC102	445407	893614	6	38	45	4	15	85	3	2.1	0.70	7.2E-02	8.4E-04
WC103	445419	893607	6	32	35	2	15	85	4	5	1.25	1.3E-01	1.5E-03
WC104	445420	893611	6	38	40	1	15	75	5	7.5	1.50	1.3E-01	1.8E-03
WC106	445409	893615	6	40	42	1	15	60	2	7.5	3.75	2.4E-01	4.0E-03
WC108	445423	893615	6	37	40	2	15	100	5	5	1.00	1.3E-01	1.3E-03

Well number	Latitude (dg/m/s)	Longitude (dg/m/s)	Well diam. (in.)	Water depth (ft)	Drwdn depth (ft)	Test time (hr)	Pump rate (gpm)	Est'd aquifer depth (ft)	Screen length (ft)	Specific capacity (gpm/ft)	Specific capacity per foot (gpm/ft/ft)	Trans-missivity (sqft/s)	Hydraulic conduct. (ft/s)
WC109	445429	893627	6	31	34	2	15	55	3	5	1.67	1.0E-01	1.8E-03
WC110	445414	893604	6	37	39	1	15	90	2	7.5	3.75	3.9E-01	4.3E-03
WC111	445417	893616	6	36	37	2	15	60	5	15	3.33	2.4E-01	4.0E-03
WC112	445428	893620	6	35	37	2	15	55	5	7.5	1.50	1.0E-01	1.8E-03
WC113	445423	893542	6	39	41	1	15	75	5	7.5	1.50	1.4E-01	1.8E-03
WC114	445417	893605	6	37	39	2	15	85	4	7.5	1.88	1.9E-01	2.3E-03
WC115	445425	893527	6	38	42	2	15	75	4	3.8	0.95	8.4E-02	1.1E-03
WC116	445406	893458	6	24	32	2	6	45	2	0.75	0.38	1.6E-02	3.6E-04
WC122	445424	893641	6	34	37	1	10	90	5	3.3	0.66	7.3E-02	8.1E-04
WC127	444946	894058	6	25	27	1	15	100	3	10	3.33	4.0E-01	4.0E-02
WC128	445012	893959	6	26	32	2	20	70	2	3.3	1.65	1.3E-01	1.8E-03
WC129	445039	893947	6	29	44	2	20	80	2	1.3	0.65	6.0E-02	7.5E-04
WC130	444929	893946	6	13	16	1	20	70	3	7.1	2.09	1.7E-01	2.4E-03
WC131	444932	893946	6	5	17	2	15	70	2	1.3	0.65	4.7E-01	6.8E-04
WC132	444946	894058	6	26	30	2	20	100	2	5	2.50	3.0E-01	3.0E-03
WC133	444904	894016	6	12	21	2	20	65	2	2.2	1.10	7.7E-02	1.2E-03
WC137	444612	894422	20	27	46	3	780	57	12	48.8	4.07	2.5E-01	4.4E-03
WC138	444617	894348	6	30	36	2	20	65	2	3.3	1.65	1.2E-01	1.8E-03
WC146	444606	894243	6	3	36	2	15	60	3	3.8	1.27	8.1E-02	1.3E-03
WC148	444637	894350	6	27	33	2	12	112	2	2	1.00	1.4E-01	1.2E-03
WC151A	445051	893729	6	21	23	2	10	75	2	5	2.50	2.1E-01	2.8E-03
WC151B	445051	893729	6	12	20	2	20	75	2	2.5	1.25	1.0E-01	1.4E-03
WC164	445107	893807	6	16	21	2	20	80	2	4	2.00	1.8E-01	2.3E-03
WC165	445037	894008	6	19	30	2	22	70	2	2	1.00	7.6E-02	1.3E-03
WC166	445039	894006	6	22	28	1	7	70	2	1.7	0.85	4.4E-02	6.3E-04
WC176	445041	894002	6	15	19	1	20	70	3	5	1.67	1.3E-01	1.9E-03
WC177	445113	893830	6	24	27	2	35	75	8	11.7	1.56	1.6E-01	2.1E-03
WC181	445002	894023	6	26	28	2	30	65	3	15	5.00	3.7E-01	5.7E-03
WC182	445005	894005	6	26	28	2	30	65	3	15	5.00	3.7E-01	5.7E-03
WC184	445012	893927	6	26	28	1	25	80	3	12.5	4.17	3.9E-01	4.9E-03
WC185	445029	894008	6	27	31	2	12	75	3	3	1.20	9.9E-02	1.3E-03
WC186	445035	893718	6	12	36	1	20	85	3	0.83	0.28	1.3E-01	3.2E-04
WC190	444904	894005	6	8	10	2	30	50	3	15	5.17	2.8E-01	5.6E-03
WC199	445739	894129	6	14	19	2	25	40	3	4.5	1.50	6.4E-02	1.6E-03
WC201	445658	894155	6	20	60	2	12	75	3	0.3	0.12	1.0E-02	1.3E-03
WC203	445648	893922	6	30	50	2	15	80	2	0.75	0.31	2.7E-02	3.4E-03
WC204	445707	893938	6	24	40	2	12	140	3	0.75	0.25	4.6E-02	3.3E-04
WC205	445702	894012	6	10	60	2	20	90	3	0.4	0.16	1.7E-02	1.9E-04
WC206	445703	893943	6	23	42	2	25	140	3	1.3	0.43	8.0E-02	5.7E-04
WC208	445700	893911	6	30	44	2	15	70	3	1.1	0.44	3.0E-02	4.7E-04
WC224	444722	894338	8	20	22	24	250	75	10	147.9	14.79	1.6E+00	2.1E-02
WC238	445603	894154	6	14	30	2	30	100	5	1.9	0.38	4.7E-02	4.7E-04
WC239	445721	893943	6	14	48	2	15	140	6	0.44	0.07	1.4E-02	1.0E-04
WC240	445707	894011	6	5	60	3	25	90	3	0.45	0.15	1.6E-02	1.7E-04
WC241	445654	893912	6	21	55	2	20	75	3	0.59	0.24	2.0E-02	2.6E-04
WC242	445701	893910	6	28	48	2	6	70	3	0.3	0.10	7.6E-03	1.1E-04
WC243	445705	894111	8	7	25	3	14	40	2	0.78	0.39	1.3E-02	3.3E-04
WC244	445707	894025	6	18	35	2	10	90	3	0.59	0.20	2.1E-02	2.3E-04
WC245	445721	894111	6	20	35	3	10	45	2	0.67	0.34	1.4E-02	3.2E-04
WC247	445627	893833	6	21	30	3	20	125	5	2.2	0.44	7.2E-02	5.8E-04
WC248	445629	893849	6	28	33	2	15	125	4	3	0.75	1.2E-01	9.5E-04
WC249	445640	893813	6	28	30	3	5	60	3	2.5	0.83	5.5E-02	9.2E-04
WC250	445725	894011	6	16	35	2	20	70	3	1.1	0.37	2.8E-02	4.0E-04
WC251	445732	893921	6	26	38	4	15	62	3	1.3	0.46	3.0E-02	4.9E-04
WC252	444632	894339	6	27	30	1	25	80	3	8.3	2.77	2.6E-01	3.2E-03
WC253	444627	894339	6	29	30	1	20	80	3	20	6.67	6.2E-01	7.8E-03
WC254	444558	894423	6	15	30	2	30	70	2	2	1.00	7.4E-02	1.1E-03
WC255	444541	894411	6	24	30	2	15	45	3	2.5	0.83	4.0E-02	8.8E-04
WC256	445503	893531	6	40	41	2	15	90	5	15	3.00	3.4E-01	3.8E-03
WC257	445504	893504	6	42	43	1	20	65	3	26.7	8.34	6.0E-01	9.3E-03

Well number	Latitude (dg/m/s)	Longitude (dg/m/s)	Well diam. (in.)	Water depth (ft)	Drwdn depth (ft)	Test time (hr)	Pump rate (gpm)	Est'd aquifer depth (ft)	Screen length (ft)	Specific capacity (gpm/ft)	Specific capacity per foot (gpm/ft/ft)	Trans-missivity (sqft/s)	Hydraulic conduct. (ft/s)
WC258	445518	893322	6	18	24	2	2	60	2	3.3	1.65	1.1E-01	1.8E-03
WC259	445407	893115	6	20	23	4	15	60	3	5	1.67	1.1E-01	1.8E-03
WC260	445424	893314	6	15	39	2	15	80	3	0.63	0.21	1.9E-02	2.4E-04
WC261	445414	893221	6	24	29	2	20	65	2	4	2.00	1.4E-01	2.1E-03
WC262	445437	893305	6	34	45	2	30	55	2	2.7	1.35	7.7E-02	1.4E-03
WC263	445413	893255	6	29	33	2	30	65	3	7.5	2.50	1.8E-01	2.8E-03
WC264	445448	893346	6	37	40	1	20	60	3	6.7	2.23	1.5E-01	2.4E-03
WC266	445423	893508	5	36	40	2	30	60	3	7.5	2.50	1.7E-01	2.8E-03
WC267	445404	893339	6	20	34	1	20	50	3	1.4	0.47	2.5E-02	5.0E-03
WC268	445336	893027	6	25	30	3	12	45	3	2.4	0.80	3.7E-02	8.2E-04
WC270	445740	894128	6	14	19	2	25	40	3	4.5	1.50	6.4E-02	1.6E-03
WC278	445519	893603	20	34	54	48	1200	100	20	93.3	4.67	6.3E-01	6.3E-03
WC288	450126	893855	20	3	53	3	2200	125	30	84.6	2.82	4.9E-01	3.9E-03
WC290	445854	893907	6	8	21	2	6	50	3	0.46	0.15	8.1E-03	1.6E-04
WC292	450005	893650	6	22	30	2	15	60	4	1.9	0.48	3.2E-02	5.4E-04
WC293	450041	893709	8	17	24	2	20	50	6	2.9	0.48	2.7E-02	5.3E-04
WC294	445939	893654	6	32	44	1	5	80	2	0.42	0.21	1.9E-02	2.3E-04
WC297	445945	893802	6	17	34	1	8	60	4	0.47	0.12	7.7E-03	1.3E-04
WC298	445943	893753	6	15	65	2	7	90	4	0.14	0.04	3.8E-03	4.2E-05
WC299	445919	893854	6	7	27	2	20	60	2	1	0.50	3.1E-02	5.2E-04
WC300	445921	893829	6	12	35	1	5	60	3	0.22	0.07	4.7E-03	7.8E-05
WC301	445852	893909	6	10	80	3	25	50	4	0.36	0.09	4.9E-03	9.9E-05
WC302	445920	893842	6	15	30	2	10	45	3	0.67	0.22	1.0E-02	2.3E-04
WC303	445908	893737	6	30	35	2	15	120	4	3	0.75	1.1E-01	9.4E-04
WC304	445738	894224	6	30	80	3	25	95	5	0.05	0.10	1.2E-02	1.3E-04
WC307	445657	894322	6	15	40	8	118	107	10	4.7	0.47	7.2E-02	6.7E-04
WC308	445727	893728	6	34	43	1	20	100	2	2.2	1.16	1.4E-01	1.4E-03
WC309	445557	894009	6	30	33	1	20	60	3	5.7	1.90	1.3E-01	2.1E-03
WC310	445537	893925	5	20	29	1	15	50	3	1.7	0.57	3.0E-02	6.1E-03
WC311	445555	893909	6	25	30	1	10	40	3	2	0.67	2.7E-02	6.7E-04
WC315	445339	893811	6	30	35	1	20	75	3	4	1.33	1.1E-01	1.5E-03
WC316	445341	893756	6	30	35	1	20	90	3	4	1.33	1.4E-01	1.6E-03
WC317	445317	893737	10	20	60	12	450	100	16	11.5	0.74	1.0E-01	1.0E-03
WC322	445616	894046	6	17	31	2	8	55	3	0.57	0.19	1.1E-02	2.0E-04
WC323	445600	894110	6	22	29	3	22	54	16	3.1	0.19	1.6E-02	3.0E-04
WC324	445612	893921	6	8	50	2	15	100	4	0.36	0.09	1.1E-02	1.1E-04
WC325	445548	894010	6	17	28	15	17	50	7	1.5	0.23	1.5E-02	3.1E-04
WC326	445555	894003	6	25	35	2	15	58	5	1.5	0.30	2.1E-02	3.6E-04
WC327	445617	894032	6	19	80	3	15	115	4	0.25	0.06	9.0E-03	7.8E-05
WC330	445612	894135	6	25	36	1	5	54	2	0.45	0.23	1.2E-02	2.3E-04
WC335	445502	893830	6	8	30	2	15	45	3	0.68	0.23	1.0E-02	2.3E-04
WC336	445510	893707	6	30	40	3	15	88	4	1.5	0.38	4.0E-02	4.6E-04
WC337	445540	893918	6	29	50	2	5	70	1	0.24	0.24	1.7E-02	2.4E-04
WC339	445402	893758	9	26	42	2	100	134	6	6.3	1.05	1.7E-01	1.3E-04
WC342	445239	893652	6	29	37	2	5	60	2	0.63	0.32	2.0E-02	3.3E-04
WC345	445237	893805	6	11	14	2	20	100	2	6.7	3.35	4.0E-01	4.0E-04
WC346	445148	893817	6	29	34	1	15	70	2	3	1.33	1.0E-01	1.5E-03
WC349	445131	893738	6	29	34	1	15	65	5	3	0.60	4.7E-02	7.2E-04
WC350	445414	893839	16	35	51	72	450	100	15	29.3	1.95	2.5E-01	2.5E-03
WC351	445418	893842	16	32	44	72	650	100	20	63.5	3.18	4.6E-01	4.6E-03
WC352	445427	893847	16	27	44	72	650	100	20	43.5	2.18	3.1E-01	3.1E-03
WC353	445107	893649	6	13	18	2	20	85	2	4	2.00	1.9E-01	2.3E-03
WC354	445110	893726	6	13	28	2	15	70	3	1	0.33	2.6E-02	3.8E-03
WC355	445047	893850	?	20	36	2	150	75	13	9.2	0.71	1.5E+00	2.0E-02
WC356	445039	893918	6	25	28	2	20	75	4	6.7	1.68	1.5E-01	2.0E-03
WC357	445112	894117	6	11	20	2	6	50	2	0.67	0.32	1.5E-02	3.1E-04
WC358	445042	894024	6	22	18	2	20	60	7	1.4	0.20	4.3E-02	5.3E-04
WC359	445028	893924	1	6	20	23	20	80	5	5.7	1.14	2.2E-01	4.3E-02
WC360	445032	893844	6	25	30	1	15	55	3	3	1.00	5.9E-02	1.1E-03
WC361	444954	893633	6	6	20	2	30	60	2	2.1	1.05	6.8E-02	1.1E-03

Well number	Latitude (dg/m/s)	Longitude (dg/m/s)	Well diam. (in.)	Water depth (ft)	Drwdn depth (ft)	Test time (hr)	Pump rate (gpm)	Est'd aquifer depth (ft)	Screen length (ft)	Specific capacity (gpm/ft)	Specific capacity per foot (gpm/ft/ft)	Trans-missivity (sqft/s)	Hydraulic conduct. (ft/s)
WC362	445051	893719	6	9	20	2	30	70	3	2.7	1.08	8.5E-02	1.2E-03
WC363	445021	893639	6	10	19	1	20	90	3	2.2	0.82	8.6E-02	9.5E-03
WC368	444859	894243	6	22	31	2	15	45	3	1.7	0.57	2.6E-02	5.8E-03
WC369	444852	894258	18	22	47	5	1000	80	32	49.9	1.56	1.9E-01	2.3E-03
WC370	444844	894028	6	17	19	2	30	65	4	15	3.75	2.9E-01	5.4E-03
WC372	445045	893452	6	8	12	2	30	50	3	7.1	2.37	1.3E-01	2.6E-03
WC373	445103	893427	6	8	15	1	15	45	3	2.1	0.70	3.3E-02	7.4E-04
WC375	445045	893628	6	5	10	1	15	35	3	2.7	0.90	3.2E-02	9.2E-04
WC376	445102	893552	6	3	4	2	15	55	3	15	5.00	3.0E-01	5.4E-03
WC377	444959	893532	6	10	32	2	5	50	3	0.23	0.08	4.0E-03	7.9E-05
WC378	445040	893406	6	13	17	3	15	65	3	3.6	1.38	1.0E-01	1.6E-03
WC380	445643	892955	6	7	19	2	20	72	2	1.7	0.85	6.6E-02	9.1E-04
WC383	445021	893639	6	29	31	1	15	60	3	10	3.33	2.2E-01	3.7E-03
WC385	445532	893405	6	31	34	2	16	60	4	5.3	1.33	9.3E-02	1.5E-03
WC386	445536	893313	6	40	47	2	20	85	2	2.9	1.45	1.4E-01	1.6E-03
WC389	445533	893141	6	25	29	2	16	60	5	4	0.80	5.8E-02	9.6E-04
WC391	445412	893050	6	28	30	2	30	50	3	12	4.00	2.3E-01	4.4E-03
WC392	445236	893621	6	26	60	3	12	55	4	0.35	0.09	5.3E-03	9.6E-05
WC394	445246	893632	6	21	60	3	12	55	2	0.31	0.16	8.4E-03	1.5E-04
WC395	445218	893623	6	26	36	2	15	50	3	1.5	0.50	2.6E-02	5.2E-04
WC396	445125	893504	6	9	56	2	5	70	4	0.11	0.03	2.1E-03	3.0E-05
WC397	445215	893212	6	6	6	1	20	30	3	40.2	13.86	4.2E-01	1.4E-02
WC400	445553	894406	6	26	36	2	15	55	3	1.5	0.50	2.9E-02	5.3E-04
WC402	445619	894400	6	47	57	2	20	80	2	2	1.00	9.0E-02	1.1E-03
WC403	445917	894408	6	11	33	3	7	60	5	0.3	0.06	4.2E-03	6.9E-05
WC404	445918	894347	6	25	31	2	15	70	1	2.5	2.50	1.8E-01	2.5E-03

APPENDIX C. Data from wells installed for this study

Part 1. Well construction and piezometer test summary

Wells identified by A, B, and C (such as R1-A, R1-B, and R1-C) refer to piezometers of different depths at a single location.

Note: Detailed construction logs and geologic descriptions for all piezometers installed during this study are on file with the Wisconsin Geological and Natural History Survey under log numbers MR-1003 to MR-1031.

Well number	Latitude	Longitude	Mean K (ft/sec)	Std. dev.	Number of tests	Bottom of pipe length (ft)	Screen below top of well A (ft)
R1-A	445656	894058	6.6E-04	1.6E-04	4	63.2	63.2
R1-B	445656	894058	4.0E-07	--	1	44.49	44.51
R1-C	445656	894058	9.8E-06	--	1	10.71	10.94
R1-gauge	445656	894058	--	--	--	--	--
R2-A	445628	894011	1.5E-07	--	1	17.37	17.37
A2-A	450200	893936	--	--	--	100.11	100.11
A2-B	450200	893935	--	--	--	20.26	21.62
B3-A	445921	893706	5.9E-04	1.3E-04	5	20.64	20.64
B3-B	445921	893706	6.8E-04	1.4E-04	5	70.11	68.96
B3-gauge	445921	893706	--	--	--	--	--
C1-A	445443	893853	8.5E-07	--	1	42.46	42.46
C1-B	445443	893853	3.5E-05	4.3E-05	2	38.15	38.33
C2-A	445437	893843	1.8E-04	3.5E-05	3	66.66	66.66
C2-B	445437	893843	1.8E-03	3.5E-04	4	44.8	45.07
C2-C	445437	893843	--	--	--	35.1	34.9
C2-gauge	445437	893840	--	--	--	--	--
C2A-A	445451	893812	--	--	--	88.88	88.88
C2A-B	445451	893812	--	--	--	17.4	18.04
C3-A	445438	893652	--	--	--	29.52	29.52
C3-B	445438	893652	6.5E-04	8.7E-05	3	48	47.66
C3-gauge	445438	893652	--	--	--	--	--
D1-A	445132	894126	1.9E-04	1.7E-04	4	38.66	38.66
D1-B	445132	894126	1.9E-04	--	1	14.29	14.16
D2-A	445114	894051	6.6E-06	--	1	18.93	18.93
D2-B	445114	894051	--	--	--	63.31	63
D4-A	445046	893957	1.3E-03	1.2E-04	5	23.01	23.01
D4-B	445046	893957	--	--	--	74.97	74.96
D4-gauge	445047	893958	--	--	--	--	--
D5-A	445013	893910	4.2E-04	6.5E-05	4	33.44	33.44
D5-B	445013	893912	8.1E-04	8.2E-04	6	33.33	29.86

Part 2. Water levels

Note: This table give depths to water in standpipe piezometer nests consisting of two or three piezometers in close proximity to each other and labeled A, B, C. All measurements in feet are relative to the measuring point at the top of the casing of piezometer A in each nest.

Well number	Top of gauge or casing below top of well A (ft)	Measurement date (month/day/year)								
		10/26-8/85	12/7/85	1/24/86	3/2/86	4/6/86	5/15/86	6/3/86	6/30/86	7/22/86
R1-A	0	4.05	3.54	3.78	4.36	2.94	4.15	4.52	4.38	--
R1-B	0.02	4.3	3.65	3.89	4.44	3.03	4.26	4.59	4.47	--
R1-C	0.23	4.86	4.28	4.42	4.93	3.56	4.91	5.21	4.97	--
R1-river	2.66	4.94	4.86	4.98	5	3.7	5.04	5.26	4.98	--
R2-A	0	10.18	9.91	10.58	11.26	9.34	10.64	11.09	--	--
A2-A	0	--	--	--	--	--	--	--	9.07	8.49
A2-B	1.36	--	--	--	--	--	--	--	9.08	8.35
A2-river	--	--	--	--	--	--	--	--	8.66	--
B3-A	0	8.44	7.8	8.3	8.82	7.35	8.74	8.85	8.67	8.43
B3-B	-1.15	8.35	7.74	8.26	8.8	7.13	8.64	8.8	8.63	8.39
B3-river	5.94	(5.82?)	8.45	8.46	8.94	7.69	9.02	9.09	8.84	8.57
C1-A	0	24.37	23.94	26.05	28.06	25.75	25.44	26.32	27.38	27.95
C1-B	0.18	24.53	23.94	26.25	28.29	25.91	25.6	26.46	27.56	28.16
C2-A	0	30.75	30.2	31.01	31.95	31.13	31.24	31.79	31.87	32.07
C2-B	0.27	30.57	29.98	30.91	31.86	30.94	31.11	31.56	31.7	31.86
C2-C	-0.2	30.54	29.95	30.88	31.84	30.9	31.08	31.53	31.68	31.83
C2-river	29.97	33.54	33.55	33.67	33.71	36.04	--	--	--	--
C2A-A	0	--	--	--	--	--	--	--	8.07	8.18
C2A-B	0.64	--	--	--	--	--	--	--	8.06	8.19
C2A-river	--	--	--	--	--	--	--	--	8.01	--
C3-A	0	26.02	25.86	25.48	26.09	25.55	25.94	26.19	26	26.03
C3-B	-0.34	26.05	(22.86?)	25.46	26.08	25.54	25.94	26.19	25.97	26.02
C3-river	23.98	26.2	--	26.35	26.42	26.15	--	--	26.33	--
D1-A	0	5.94	(5.45?)	6.3	7.43	5.08	6.28	6.93	7.36	7.21
D1-B	-0.13	(5.90?)	5.24	6.07	7.27	4.78	6.01	6.66	7.18	7.06
D2-A	0	11.72	11.02	11.66	12.43	11.02	11.84	12.26	21.53	12.59
D2-B	-0.31	11.4	10.62	11.37	12.16	10.71	11.5	11.97	12.24	12.31
D4-A	0	15.52	14.14	14.54	--	12.04	15.24	15.8	15.41	15.03
D4-B	-0.01	--	--	--	--	--	--	--	15.07	14.63
D4-river	12.91	--	16.58	17.03	--	-12.99	--	--	17.52	--
D5-A	0	17.5	15.38	--	21.42	15.35	17.48	18.73	20.29	21.22
D5-B	-3.47	18.2	15.99	--	21.73	16.07	(29.10?)	22.17	20.67	21.59

APPENDIX D. Summary of geophysical data

The seismic reflection survey was conducted to identify the depth to bedrock beneath the Wisconsin River. The geophysical technique employed is known as continuous, single-channel, high-resolution profiling. During profiling, the marine reflection equipment was mounted in or towed by a 5.5-m long boat powered by an electric trolling motor. The sound source was a high-resolution, 300-Joule capacity boomer towed 0.1 m below the water surface. The input energy ranged from 105 to 280 J. The hydrophone string consisted of 12 sensing elements wired in parallel and mounted in a neutrally buoyant plastic tube towed about 0.3 m below the water surface. The hydrophone signals were passed through a signal processor and simultaneously recorded on analog tape and printed on a paper chart recorder. The magnetic tape and hardcopy printouts are stored in the WGNHS project files.

Profiling was done along transects between prominent landmarks and down river in the center of the channel. Boat speed was about 6.5 km/hr.

Data were collected during marine reflection survey of Wisconsin River between Brokaw and Mosinee. Survey conducted October 1986. Although data were gathered continuously, good records were obtained only sporadically because of difficulty penetrating bottom sediments. The following table presents the locations, bedrock elevations, and reliability ratings at these points. Ratings evaluated as follows: A: very reliable; B: probable; C: possible. Ranges of depths (for example, 45-55) indicate a sloping interface beneath the survey point. All measurements are in feet.

Site number	Latitude (dg/m/s)	Longitude (dg/m/s)	Rock depth	Rating	Water surface	Elev. of rock
1A	445654.1	893736.3	75	A	1165	1090
1B	445644.2	893730.9	75	A	1165	10902
2	445659.8	893754.0	45-55	A	1165	1120-1110
3	445709.1	893804.1	25	C	1165	1140
4A	445631.5	893750.7	50	C	1165	1115
4B	445627.2	893758.4	50	C	1165	1115
5	445613.5	893813.6	55	C	1165	1110
6	445557.4	893829.5	80-44	B	1165	1085-1121
7	445548.3	893831.0	38	A	1165	1127
8A	445535.1	893812.0	95-100	A	1161	1066-1061
8B	445531.6	893804.5	110	A	1161	1051
9	445517.1	893751.5	105	B	1161	1056
10	445511.0	893752.3	85	B	1161	1076
11	445505.6	893801.0	100	C	1161	1061
12	445450.3	893821.5	170	C	1161	991
13	445439.8	893828.9	180	C	1161	981
14	445402.7	893740.7	115	C	1161	1046
15	445351.9	893720.0	150	C	1161	1011
16	445348.3	893714.6	50	B	1161	1011
17A	450203.5	893931.4	80-70	A	1195	1115-1125
17B	450201.4	893942.5	65	A	1195	1130
18	450140.6	893949.9	Rock bottom	A	1195	1190
19	450125.9	893917.0	Rock bottom	A	1195	1190
20A	450114.0	893835.6	90-105	B	1190	1100
20B	450117.7	893822.0	105	B	1190	1085
21A	450115.3	893812.5	105	A	1190	1085
21B	450110.6	893806.4	105	A	1190	1085
23	450106.3	893758.9	Rock bottom	B	1195	1190
24	450103.0	893758.9	50-105	A	1190	1140-1085
25A	450100.3	893756.8	105-120	A	1190	1085
25B	450049.3	893752.9	120	A	1190	1070
26	450050.4	893749.3	120-80	A	1190	1070-1110
27	450048.6	893746.6	80-40	B	1190	1110-1150
28	450038.3	893739.9	70-70	B	1190	1120
29	450032.1	893736.4	74	B	1190	1116
30	450015.0	893733.4	120-120	A	1190	1070-1070

Site number	Latitude (dg/m/s)	Longitude (dg/m/s)	Rock depth	Rating	Water surface	Elev. of rock
31	445909.3	893716.0	105-80	A	1190	1085-1110
32A	445859.7	893724.3	95	A	1190	1095
32B	445854.8	893729.6	75	A	1190	1115
33	445851.9	893735.0	130	A	1190	1060
34	445842.8	893747.1	130-130	A	1190	1060
35A	445836.8	893753.1	125	A	1190	1065
35B	445827.4	893758.0	140	A	1190	1050
36	445822.3	893755.2	125-140-140	A	1190	1065-1050
37	445806.4	893753.7	120-120	B	1190	1070
38	445801.1	893754.8	95-135-135	A	1190	1095-1055-1055
39	445719.1	893802.8	20-20	A	1165	1145-1145
40A	445713.8	893757.7	25	B	1165	1140
40B	445711.6	893750.2	45	B	1165	1120
41	445709.3	893746.4	45-45	B	1165	1120-1120
42	445700.4	893745.2	40-40	C	1165	1125-1125
43	445657.1	893745.1	45	B	1165	1120
44A	445652.9	893725.4	105	B	1165	1060-1070
44B	445644.7	893724.0	95	B	1165	1070
45	445637.3	893723.5	80-80	A	1165	1085
46	445634.7	893730.1	80-75	A	1165	1085-1090
47	445232.8	893819.7	15-25	C	1140	1125-1115
48	445200.0	893845.3	30	C	1140	1110
49	445156.8	893854.5	25	C	1140	1115
50	445037.6	894016.0	50-50	C	1140	1090-1090

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