HYDROGEOLOGY OF BARRON COUNTY, WISCONSIN

Alexander Zaporozec

1987

Introduction

This summary of hydrogeologic conditions of Barron County was compiled from available literature and previous studies; it provides the reader with the background necessary for understanding the map of the Barron County Atlas entitled *Groundwater pollution potential of Barron County, Wisconsin.* No field work was performed to define the aquifers of the county in detail, their characteristics, or their relationship to lakes, and no measurements of water levels of county wells were taken because funding was not available. The maps of the water-table elevation and potential yields of aquifers were compiled using available data from well constructor's reports, geologic logs, and U.S. Geological Survey topographic maps.

Groundwater occurrence

Precipitation is the source of groundwater. When rain falls or snow melts, some water infiltrates the soil and the excess runs off into streams. As water percolates downward through the unsaturated zone, some is taken up by plants, some evaporates or is held in soil pores, and the remainder joins the groundwater stored in subsurface rocks.

Most of the rocks near the earth's surface contain numerous interconnected, small openings (pores or cracks) filled with water. These saturated rocks are called aquifers, which function as reservoirs that store and transmit water. The top of the saturated zone of groundwater is at atmospheric pressure and is called the water table. It has a shape approximately similar to the land surface; contours on the water table indicate its slope. Groundwater movement is generally perpendicular to the water-table contours and conforms in places to the direction of surface runoff.

Aquifers in Barron County include the sand-and-gravel aquifer, the sandstone aquifer, which consists of Cambrian sandstone and Ordovician dolomite, and the Precambrian aquifer. Groundwater in Barron County is obtained primarily from the sand-and-gravel aquifer and Cambrian sandstone, although small amounts of water can be obtained from the Ordovician dolomite and from the Precambrian aquifer (fig. 1).

The sand-and-gravel aquifer consists of sorted, stratified, medium to coarse sand and gravel deposited during Pleistocene glaciation. In the southern two-thirds of the county, this aquifer occurs primarily as outwash (sand and gravel deposited by meltwater streams) that fills preglacial bedrock valleys; in central, northwestern, and northeastern Barron County, the aquifer occurs in outwash plains and buried ice-contact deposits (fig. 1). Saturated thickness of the aquifer generally is between 50 and 150 ft in most areas of the county, but saturated outwash exceeds 250 ft in the deep bedrock valley extending from Rice Lake south toward Lake Chetek (see Barron County Atlas map, *Depth to bedrock of Barron County, Wisconsin*). The saturated thickness of the aquifer thins to zero in the Blue Hills area east of Rice Lake and in southern Barron County, where the water table is in bedrock below the unconsolidated (unlithified) deposits. One of the remarkable features of the outwash is its high permeability (ability to transmit water) and transmissivity (a measure of the rate at which water is transmitted through an aquifer), which sets it apart from other water-bearing units. Bell and Hindall (1975) gave the transmissivity range for sand and gravel from 200,000 to 1,000,000 gallons per day per foot (gal/d/ft).

The sandstone aquifer underlies almost the entire county and consists of saturated formations of Ordovician and Cambrian age (fig. 1). Bedrock formations (see Barron County Atlas map, *Bedrock geology of Barron County, Wisconsin*) may act as a single aquifer or, when separated by less permeable layers, as individual aquifers having moderate to large yields. The saturated thickness of the sandstone aquifer varies with the total thickness of the aquifer and the altitude of the water table.

The Upper Cambrian sandstone formations compose the bulk of the sandstone aquifer; the Ordovician Prairie du Chien Dolomite is a minor water source in the extreme western part of the county. There, its saturated thickness is 30 to 60 ft. The total thickness of Cambrian sandstone is as much as 900 ft in the southwestern part of the county (Mudrey, 1987). The transmissivity of sandstone generally is less than 50,000 gal/d/ft (Bell and Hindall, 1975).

Precambrian rocks are not a major source of water in Barron County relative to other aquifers. Over most of the county, they form the lower limit of groundwater movement.

Groundwater movement

Groundwater moves constantly from areas of recharge in topographic highs to areas of discharge--streams, lakes, wetlands, and springs (fig. 2).

Groundwater in recharge areas (the areas of highest elevation of the water table) has the greatest gravitational potential energy, which is the driving force for groundwater movement. The primary evidence for a recharge area is the water table sloping away from the area and hydraulic head (energy per unit weight of water) decreasing as depth increases. Some recharge beneath a groundwater divide (the boundary between groundwater basins from which the groundwater moves away in both directions) will move downward to the base of the aquifer and then flow laterally following the longest possible flow path and finally upward to the regional discharge area (fig. 2). Recharge that enters the aquifer farther from the groundwater divide follows shorter and shallower flow paths.

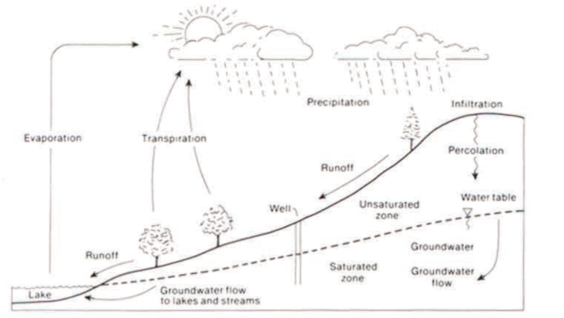


Figure 2. Idealized groundwater flow system (from Zaporozec, 1982).

Discharge areas have characteristics exactly opposite those of recharge areas: hydraulic head increases as depth increases and the water table is higher away from the area. One of the most significant differences between recharge and discharge areas in humid areas such as Barron County is that discharge areas are much smaller in areal extent than recharge areas. Discharge normally is limited to narrow bands along streams, lakes, and wetlands or springs. Consequently, recharge to groundwater may occur over most of the land area of the county.

In Barron County, recharge to the water table is intermittent and occurs mainly during short-term events -- spring snowmelt and heavy spring and summer rains. Groundwater discharge, on the other hand, occurs almost continuously as steady seepage to streams or lakes, as springflow, and as evapotranspiration. Groundwater is recharged intermittently when precipitation exceeds evapotranspiration. Some recharge may occur in the late fall after the end of the growing season when evapotranspiration is again low, if the fall rains come before the ground freezes.

Direction of groundwater flow

The general directions of groundwater flow in Barron County were derived from the configuration of the water table as approximated in figure 3. The primary source of data for compilation of the map was the Department of Natural Resources well constructor's reports, which include static water levels measured when the wells were constructed. As a result, these data describe water levels at different seasons of the year and over a period of many years. To precisely map the water table, water-level measurements from about the same time are needed. This was not possible because of limited funds for the study. However, water-level fluctuations have only a small effect on the overall configuration of the water table, and the resulting water-table contours are sufficient to demonstrate the patterns of groundwater movement in the county.

To supplement the data from well constructor's reports, elevations of streams and lakes were taken from the U.S. Geological Survey topographic quadrangle maps (scale, 1:24,000). The contours were drawn by interpolating between data points. Topographic contours were used as a guide where interpolation was not possible for lack of data. Groundwater divides are indicated only approximately on the map by showing the positions of surface-water divides. In areas such as Barron County, groundwater and surface-water divides generally coincide. Arrows have been added to the map to show general directions of flow. These arrows do not indicate actual flow lines.

No water-table contours are shown in the western part of the county, which drains into the St. Croix River, and in the upper portions of the Hay and Yellow River watersheds, where hydrogeologic conditions are complex and data on water levels are scarce. This area, accentuated by shading on the map, coincides with the limit of the most recent glaciation and is characterized by a typical, young glacial landscape. There are many lakes in this area; some receive groundwater (discharge lakes), some recharge groundwater (recharge lakes). Some of the longer lakes, such as Silver Lake in the town of Lakeland (Young and Hindall, 1972), have groundwater inflow at one end and groundwater outflow at the other (flow-through lakes). Some of the lakes may even be perched, separated from the water table by clayey sediment and the unsaturated zone. Determination of true conditions in this area would require extensive field work -- drilling and installing piezometers, measuring the water table, and sampling lakes to determine their relationship to groundwater.

Relatively shallow, local flow systems (mostly less than a few miles long, and several hundred feet deep) dominate the groundwater regime in the county. Much of the groundwater does not pass through the bedrock aquifers, but discharges directly from glacial deposits into streams and lakes. Thus each of the major drainage basins of the county -- Hay River, Yellow River, Red Cedar River, and Lake Chetek/Chetek River (see fig. 3 of Barron County Atlas map, *Physical Setting of Barron County, Wisconsin*) -- also contains local groundwater basins, especially in southern Barron County, where relief is well developed.

Local groundwater flow systems have an important implication for groundwater protection and management in the county. Because most groundwater withdrawn by wells in Barron County originates within the county, it is imperative that local management controls be instituted to protect the groundwater from pollution.

Rate of groundwater flow

Movement of water underground is very slow, which is an important factor to consider in groundwater pollution studies. The intricate maze of interconnected openings offers natural frictional resistance to the flow; therefore, water moves through the aquifers very slowly (several feet per day to several feet per year), depending on the size of the grains that compose the rocks. Water tends to move more quickly through coarse-grained rocks and more slowly through fine-grained rocks. Because of the slow movement of the water, it might take years for pollutants to appear in water wells or at the points of surface discharge. By that time, the source of pollution may be long forgotten and the aquifer polluted beyond repair.

In Barron County, groundwater moves a few feet or less per day except near pumping wells. Movement of a few tenths of a foot per day or even per year is common (compared to the flow in streams, which is measured in feet per second). It is very difficult to generalize or average the flow rate for the county, because it depends on many variables and differs greatly from place to place. To help the reader to appreciate at least the order of magnitude of groundwater movement, the following estimates are given.

The velocity of groundwater, v (feet per day), can be estimated from the hydraulic conductivity, K (older literature called the coefficient of permeability); hydraulic gradient, i; and effective porosity of the material, n:

$$v = K i / n$$

The values of hydraulic conductivity (a measure of the permeability of a rock) and porosity (the percentage of the total volume of a rock or sediment that consists of pore space) can be estimated from various groundwater textbooks that list the ranges for different types of soils and rocks derived from laboratory and field measurements or from data for similar rock types in other parts of Wisconsin (Young, in press). Hydraulic gradients (hydraulic head loss per foot of travel) were scaled as the slope between contours on the water table on figure 3. They are usually low, such as a fall of 1 ft per 500 ft (0.002) or 10 ft per 500 ft (0.02). The rate of groundwater flow varies directly with the hydraulic gradient. If the hydraulic gradient is doubled, the rate of flow is also doubled. Generally, the velocities in the sand-and-gravel aquifer may range from 0.5 to 5 ft/day; they would be less than 0.5 ft/day in the sandstone aquifer. The estimates are summarized in table 1.

Table 1. Estimated average velocities of groundwater in principal aquifers of Barron County

Aquifer	Effective porosity (%)	Hydraulic conductivity (ft/day)	Hydraulic gradient (ft/ft)	Velocity of flow (ft/day)
Sand and gravel	30	300	0.002	2
Sandstone	20	1	0.02	0.1

These values are given for illustration only and cannot be used for any practical considerations. By including them, the author wants to demonstrate the extremely slow movement of groundwater, which is the major obstacle for early detection of groundwater pollution. True velocities for specific areas can be determined only by laboratory or field tests.

Groundwater availability

Large amounts of water are being used for agricultural irrigation in Barron County (796 million gallons in 1985). Few years have adequate rainfall at the right time for optimum crop production, and the sandy, well drained soils lose water quickly. Crop moisture needs are supplemented by water pumped primarily from the sand-and-gravel aquifer.

The potential yield from the sand-and-gravel aquifer is very large. Yields between 500 and 1,000 gallons per minute (gpm) can be expected from the saturated outwash in the deep bedrock valley (fig. 4); yields exceed 1,000 gpm in many high-capacity wells, primarily irrigation wells near Rice Lake, Cameron, and Chetek. Yields exceeding 2,000 gpm in these areas could be sustained for many years (Bell and Hindall, 1975). Yields up to 500 gpm are found in the alluvial deposits along the Yellow River, Pine Creek, and southern portions of the Hay and Red Cedar Rivers (fig. 4). Sand-and-gravel deposits beneath or included in the till of ground and end moraines in the northwestern and northeastern parts of the county can yield up to 100 gpm. Domestic wells with adequate yields of 5 to 15 gpm can be completed in buried lenses of sand and gravel at depths from about 20 to 200 ft (Young and Hindall, 1972).

The sandstone aquifer provides reliable supplies for municipal, industrial, domestic, and irrigation uses throughout the county. Because sandstone is less permeable than unconsolidated sand and gravel, the high-capacity sandstone wells must penetrate greater saturated thickness than the sand-and-gravel wells to obtain comparable yields. Yields more than 1,000 gpm generally are available from the sandstone aquifer in most of the county; yields in the northeastern part are less than 100 gpm (fig. 4). In southwestern Barron County adequate well yields for domestic and stock uses also can be obtained from the Prairie du Chien Dolomite. The sandstone aquifer is the sole source of groundwater in the southern part of the county, where overlying unconsolidated deposits are thin or absent. Adequate water for high-capacity irrigation wells is also available from sandstone underlying the outwash in central Barron County. Because the two aquifers generally are connected hydraulically, wells penetrating the sandstone aquifer withdraw water indirectly from the sand-and-gravel aquifer. The sandstone aquifer is not used much in northern Barron County because the overlying glacial deposits yield adequate amounts of water to domestic wells.

The Precambrian aquifer, consisting of Barron Quartzite, is the sole source of groundwater in the Blue Hills area, where the two principal aquifers are absent. It yields small amounts of water (generally less than 10 gpm) from the weathered zone at the bedrock surface and from fractures within the rock.

Bell and Hindall (1975) calculated that average annual recharge in Barron County is about 6 inches, and ranges from less than 1 inch in the nearly impermeable Precambrian rocks of the Blue Hills to about 10 inches in the outwash plains of sand and gravel. At the rate of 6 inches annually, recharge would average approximately 250 million gallons of water per day (mgd). Estimated daily use of groundwater (see Barron County Atlas map, *Physical setting of Barron County, Wisconsin*) in 1985 was about 9.6 mgd, which is less than 4 percent of the estimated recharge. From this, it is apparent that Barron County has plentiful supplies of groundwater for years to come.

References

Bell, E.A., and Hindall, S.M., 1975, The availability of ground water for irrigation in the Rice Lake-Eau Claire area, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 31, 65 p.

Johnson, M.D., 1984, Glacial geology of Barron County, Wisconsin: University of Wisconsin, Madison, Ph.D. thesis, 369 p.

Mudrey, M.G., Jr., 1987, Bedrock geology of Barron County, Wisconsin:Wisconsin Geological and Natural History Survey Map 87-2c, 1 sheet.

Young, H.L., in press, Hydrogeology of the Cambrian-Ordovician aquifer system in the northern Midwest, United States: U.S. Geological Survey Professional Paper 1405-B.

Young, H.L., and Hindall, S.M., 1972, Water resources of Wisconsin - Chippewa River Basin: U.S. Geological Survey Hydrologic Investigations Atlas HA-386, 4 sheets.

Zaporozec, Alexander, 1982, Ground-water quality of Rock County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 41, 92 p.

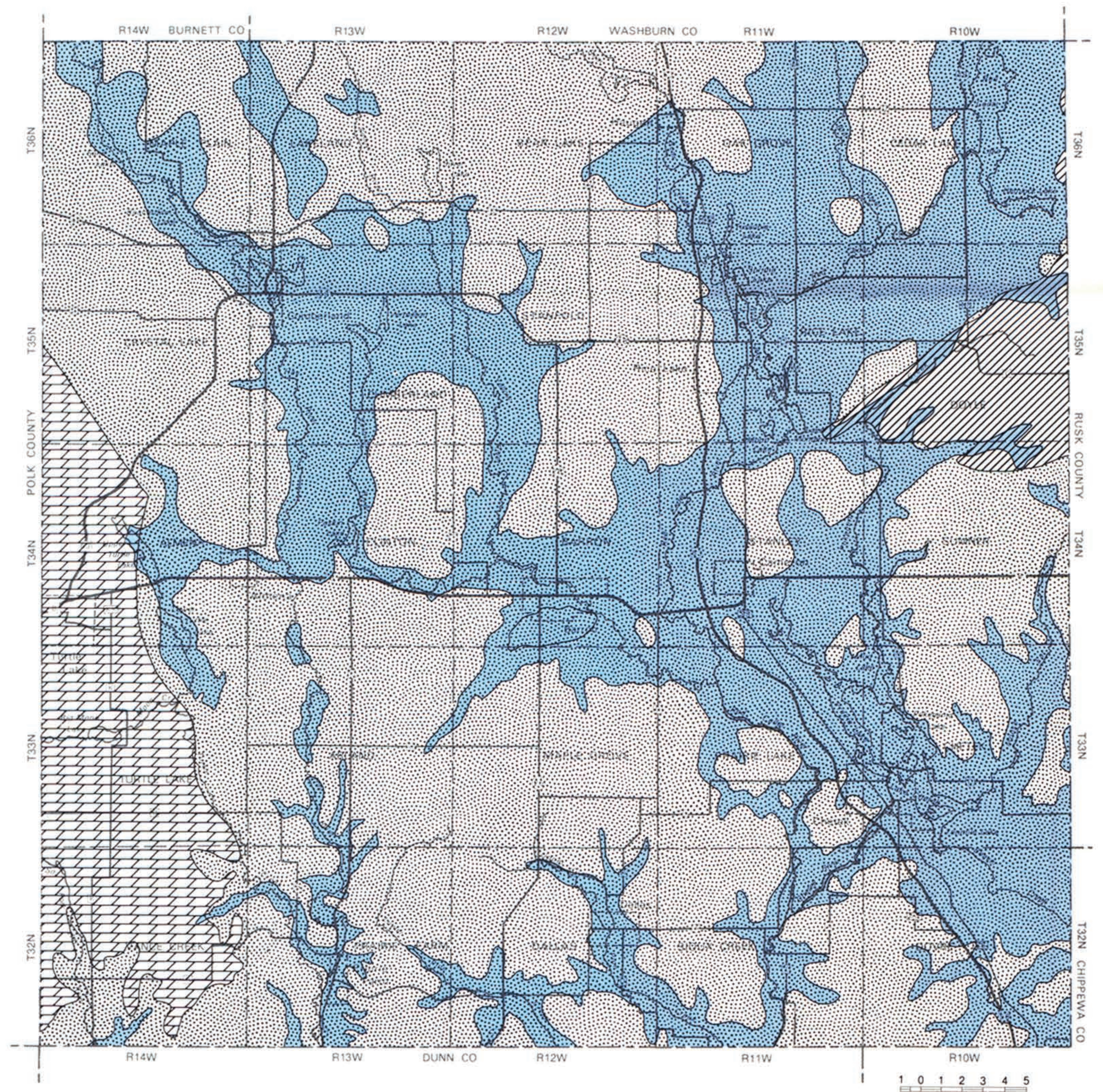


Figure 1. Generalized aquifer map of Barron County (geologic boundaries after Johnson, 1984 and Mudrey, 1987).

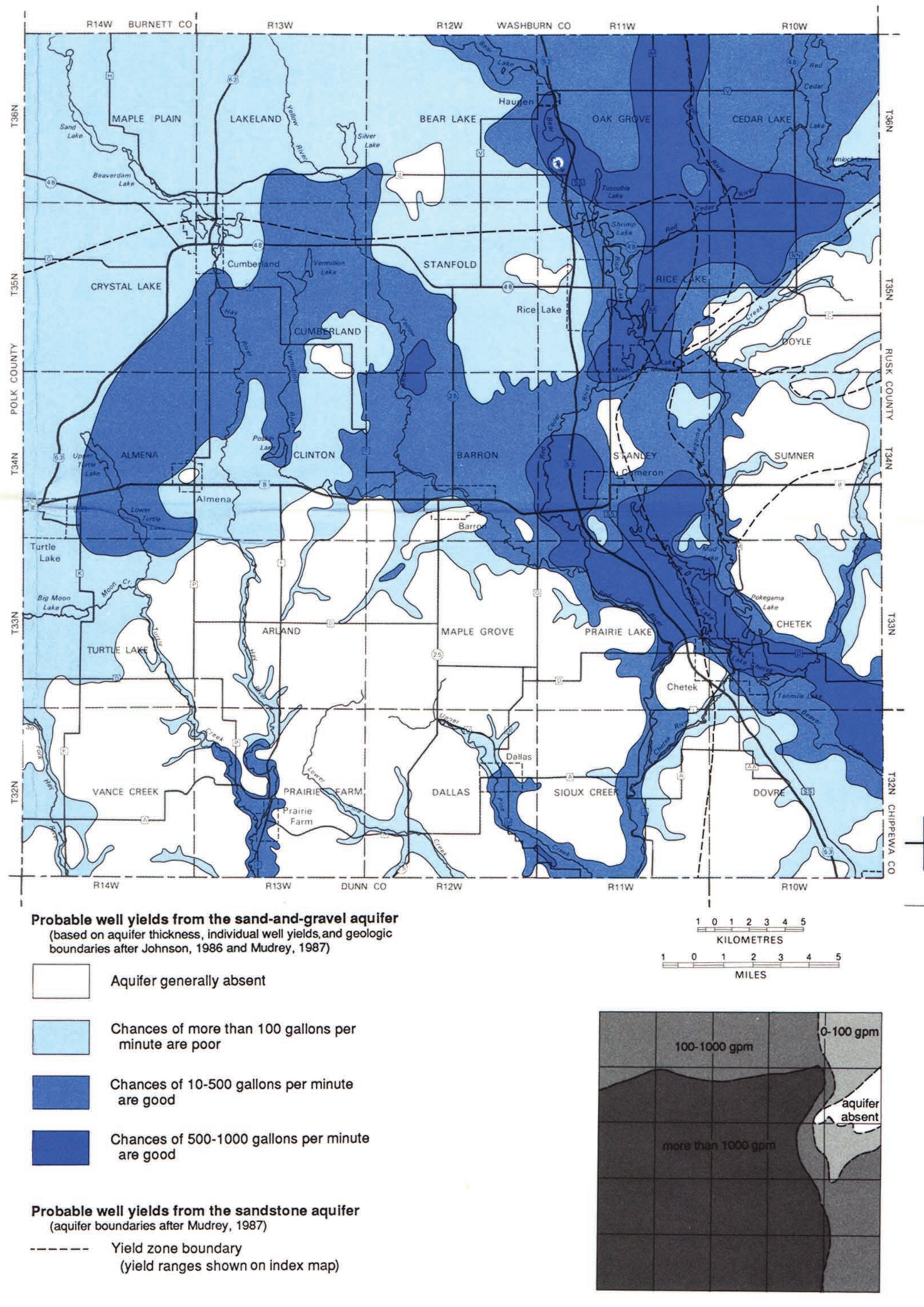
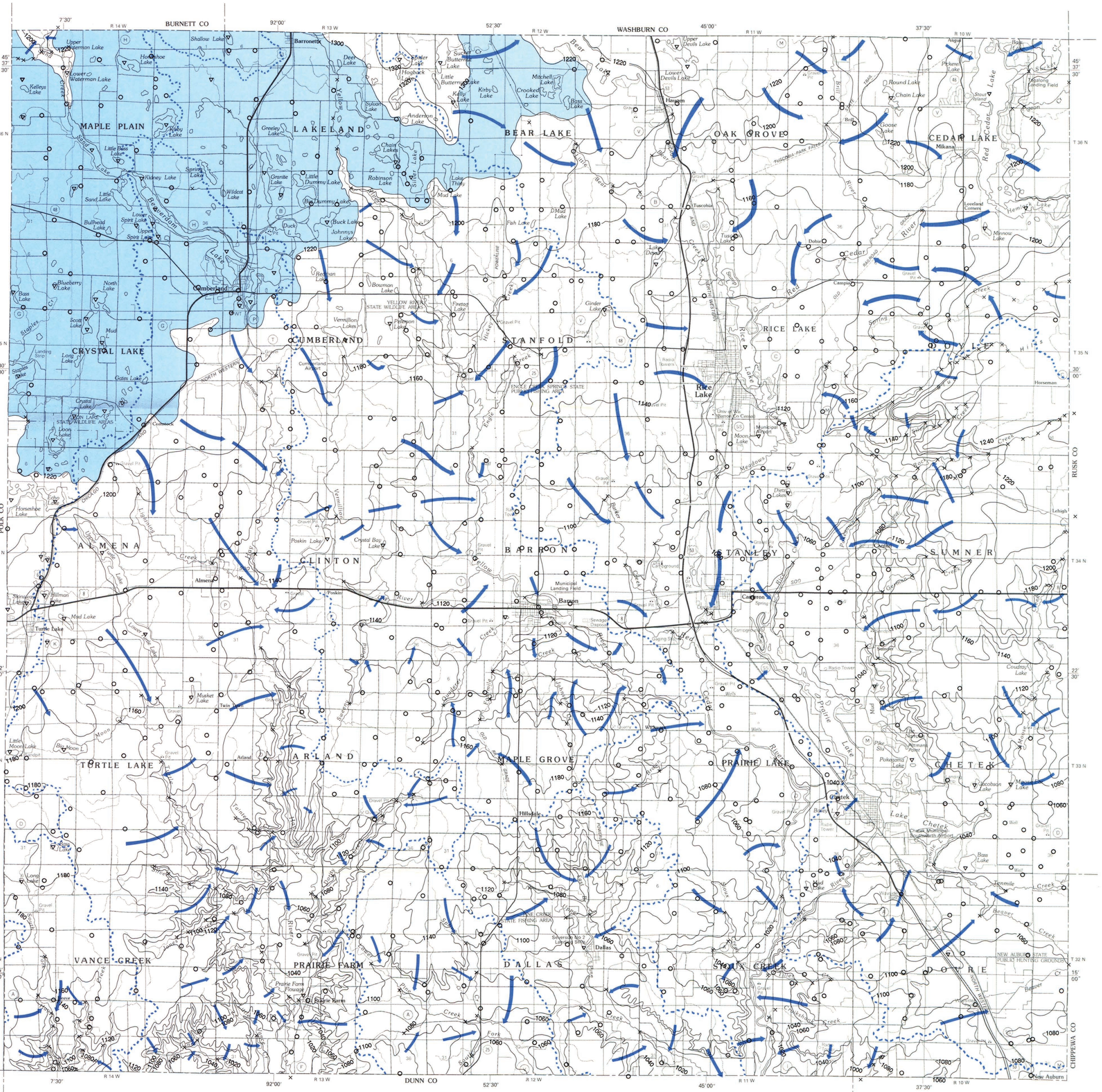


Figure 4. Potential yields of aquifers in Barron County (I.D. Lippelt, 1986)



Base map from U.S. Geological Survey 1:100,000 map--Barron County, Wis. (1979).

—1160— Water-table elevation contour (approximately located); contour interval 20 ft. Datum is mean sea level

Location of data points for water-table contours

- ○ Water well, not field checked for location or water level
- × Stream surface
- ▽ Lake level

Approximate groundwater divide; generally coincides with the surface water divide

Approximate direction of groundwater flow. (Arrows are conceptual and schematic and do not represent actual flow lines)

Area with complex hydrogeologic conditions; no contours shown

SCALE 1:100 000

KILOMETRES

MILES

Figure 3. Generalized water-table elevation of Barron County (I.D. Lippelt and A. Zaporozec, 1986)

Published by and available from
Wisconsin Geological and Natural History Survey
M.E. Ostrom, Director and State Geologist
3817 Mineral Point Road
Madison, Wisconsin 53705

Cartography by B.R. Haskins-Grahn

UWEX UNIVERSITY OF WISCONSIN—EXTENSION

Wisconsin Geological and Natural History Survey Map 87-2e

A part of the Barron County Atlas