University of Wisconsin-Extension
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GROUNDWATER QUALITY OF BARRON COUNTY, WISCONSIN
Preliminary Report

Alexander Zaporozec

Prepared by
Wisconsin Geological and Natural History Survey
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ABSTRACT

An abundance of groundwater of excellent quality is available from two major aquifers of Barron County, the sand-and-gravel and sandstone aquifers. This groundwater is soft to moderately hard, calcium-magnesium-bicarbonate type, containing on the average 200 milligrams per liter (mg/L) of dissolved substances. Its overall natural quality is good, generally within the limits set by federal and state drinking-water standards.

The soils and rocks of Barron County do not always provide good natural protection against groundwater pollution. Only about half of the county is covered by soils having good potential for attenuating pollutants, and a large portion of the county is underlain by highly permeable sand and gravel that has little or no potential for attenuation. Therefore, it is important to consider the attenuation capacity of the environment only as a supplemental tool in designing a groundwater protection program. The pollution control efforts should be concentrated on regulating land uses and on controlling pollution at the source.

Barron County does not have serious, large-scale pollution problems at this time. The pesticide aldicarb was detected in 12 wells in two sections of a township in the southeastern part of the county, and an aldicarb moratorium was declared around one of these wells in 1986. Nitrate is the most common identifiable pollutant. However, only about 10 percent of the 722 samples contained more than the established drinking-water limit of 10 mg/L nitrate-nitrogen. Nitrate concentrations varied between zero and 42 mg/L, and averaged 3.0 mg/L. About 55 percent of samples contained less than 3 mg/L. Most of the higher nitrate concentrations were found on the irrigated outwash plains in the southeast and in the areas of shallow bedrock in the south. Principal human-related sources of nitrate in the county are barnyards, temporary storage of manure, septic tanks, and nitrogen fertilizer applied to irrigated fields. In many cases, pollution was caused by improperly located or constructed wells. Monthly monitoring of two wells indicated an impact of fertilizer-application patterns on nitrate concentration of water in the wells.

To preserve the good quality of water, the county government should develop a strategy for protection of groundwater. Protection strategies could include educational and informational programs on groundwater occurrence and movement, drinking-water protection, and agricultural management practices; continuing research on and monitoring of potential pollution sources; and assuming certain regulatory functions allowed by the state groundwater law.

ACKNOWLEDGMENTS

Many organizations and persons assisted the study by providing data and information. Among the contributors of data were the Wisconsin Department of Natural Resources (DNR), Northwest District in Spooner and Bureau of Water Supply in Madison; the U.S. Department of Agriculture Soil Conservation Service (SCS), District Office and Agricultural Stabilization and Conservation Service office in Barron; and the U.S. Geological Survey, District Office in Madison. Appreciation is given to Gene Hausner, SCS District Conservationist, who was extremely helpful in collecting basic information on soils, agricultural practices, and pollution sources, in providing suggestions for the general scope of the study, and in reviewing parts of the report; to Don Drost, County Agricultural Agent, for providing information on agricultural activities and use of fertilizers; to Dale Hanson, County Conservationist, for collecting data on springs and collecting water samples; and to Ken Lubich, SCS Area Soil Scientist, Spooner, for review of the chapter on soils and suggestions in grouping soil series for interpretation. Many individuals and Jerome's Food, Inc., allowed access to their wells for collection of water samples for chemical analysis. Acknowledgment is given to Dale Cotter, U.S. Geological Survey, who reviewed the entire report and to Phil Kammerer, with the same agency, who reviewed the chapter on groundwater quality.

Special appreciation is due to the Barron County Board of Supervisors who, on the recommendation of the Land Conservation Committee and Planning and Zoning Committee, contributed a part of the cost of the study and hired a student for collection of water samples during the summer of 1983; and to Dale Thorsbakken, County Zoning Administrator, for enthusiastic support of the study, general guidance, and generous help, which he provided, together with his staff, in collecting water samples and in gathering basic data.

INTRODUCTION

Barron County, located in northwestern Wisconsin (fig. 1), is divided into 25 townships. Its total area is 904 mi^2 (approximately 578,000 acres), of which 29 mi^2 (3.2%) are covered by water (Wisconsin Legislative Reference Bureau, 1981). Its numerous lakes (more than 110) are an important base for rapidly growing recreational activities.

Barron County is basically rural; agriculture is the largest industry. With about 2,000 farms and annual gross income of approximately $145 million in 1984, Barron County is the richest agriculturally of any Wisconsin county this far north. Dairying (the primary agricultural industry), turkey raising, and vegetable production for commercial processing activities support a strong agribusiness sector. Recreation is a growing economic asset of the county. It has the potential to increase the income level of the county if current facilities and resources are further developed (West Central Wisconsin Regional Planning Commission, 1978).

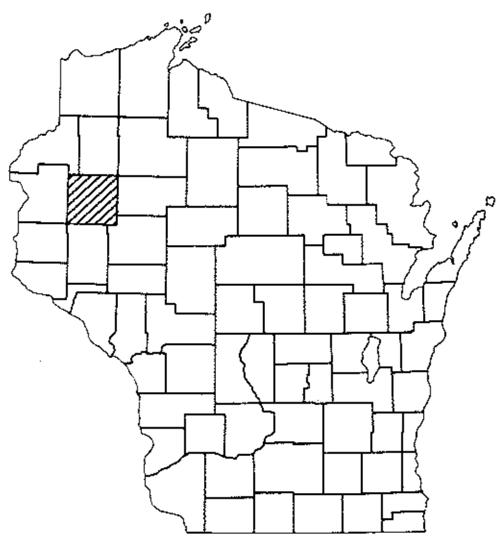


Figure 1. Location of Barron County in Wisconsin.

Groundwater is used by agriculture, industry, commerce, recreation, and the rural and urban population. More than 95 percent of water used in 1979 for municipal, rural, industrial, and agricultural purposes was supplied by groundwater (Lawrence and Ellefson, 1982). Concern over the quality of groundwater supplies prompted the Barron County government to initiate a study to define the current quality of groundwater and identify the existing and potential pollution sources and potential problem areas. The study was jointly undertaken by the Wisconsin Geological and Natural History Survey (WGNHS) and Barron County Zoning Department. Work on the project began in July 1983 and field work was completed in April 1986.

This report is published in fulfillment of the original agreement between WGNHS and Barron County. It describes in general terms the soils and geology of the county, but concentrates primarily on the existing quality of groundwater and potential water-quality problems. During the project, staff of WGNHS collected and interpreted other data, which were not part of the contract. All these findings and interpretive maps will be made available to the county and will appear in the comprehensive Barron County Atlas, which will be published later. The atlas is designed to present the soils, geology, hydrogeology, groundwater quality, and other information at a county scale and it will not be applicable for site-specific situations. Local details have been generalized to fit the mapping scale (1:100,000 and 1:250,000) and local data scarcity has required generalized interpretations. For site-specific situations, additional on-site investigations are needed.

SOILS AND THEIR ATTENUATION POTENTIAL

Soils usually comprise only the upper 3 to 5 feet of unconsolidated materials at the earth's surface. They support the growth of plants and trees, are the basis of agricultural production, and provide the foundation for houses, roads, and buildings. They also serve, if properly used, as treatment and recycling facilities for wastes from individual homes, livestock and poultry farms, and municipal and industrial sewage treatment plants. Soil characteristics (slope, depth, texture, and permeability) are among the most significant factors determining the rate and extent of groundwater recharge and the degree of natural protection against pollution.

The soils of Barron County have been grouped into six soil associations as shown on figure 2. These associations consist of the major soil series that are commonly found together in the landscape. General soil maps depicting soil associations are well suited to broad-scale or general land-use planning. More detailed soil maps are available at the Barron County Soil and Water Conservation District office for soil and land use management of greater intensity.

The six soil associations of Barron County are:

1. Amery-Cloquet Association
   Deep, well drained, gently sloping to moderately steep loamy soils underlain by loamy and sandy glacial till; on glacial moraines. Wet mineral and organic soils in depressional areas.

2. Spencer-Almena-Santiago Association
   Deep, well to somewhat poorly drained, nearly level to sloping silty soils underlain by loamy glacial till; on glacial moraines. Wet mineral and organic soils in depressional areas.

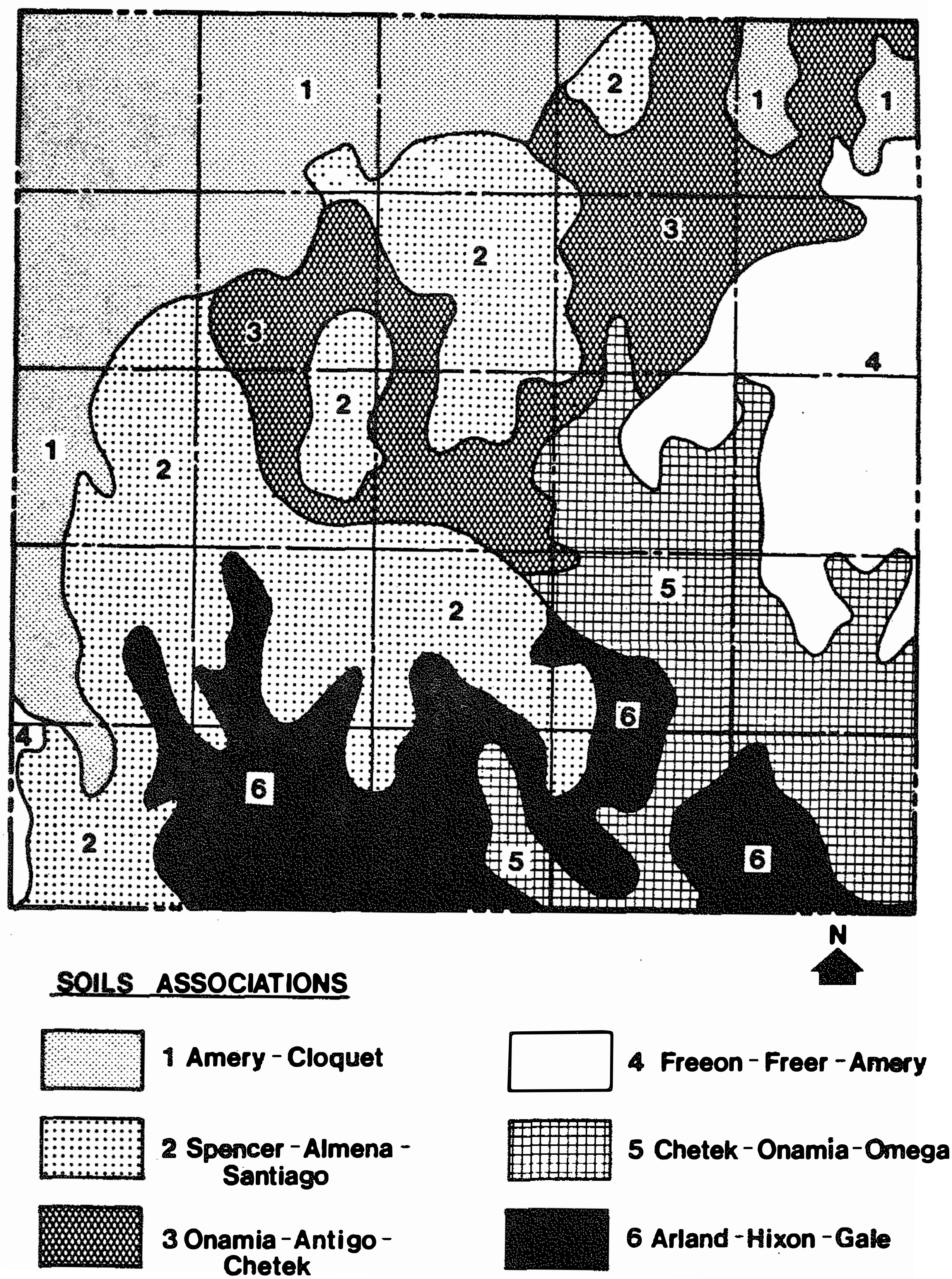


Figure 2. Barron County soil associations (from West Central Wisconsin Regional Planning Commission, 1978).

3. Onamia-Antigo-Chetek Association
   Shallow to moderately deep, well drained, nearly level to sloping loamy soils underlain by sand or sand and gravel; on stream terraces and outwash plains.

4. Freeon-Freer-Amery Association
   Deep, well to somewhat poorly drained, nearly level to rolling soils formed in moderately thick silty and loamy deposits and loamy glacial till; on glacial moraines. Wet mineral and organic soils in depressional areas.

5. Chetek-Onamia-Omega Association
   Shallow to moderately deep, well to excessively drained, nearly level to sloping loamy and sandy soils underlain by sand or sand and gravel; on stream terraces and outwash plains.

6. Arland-Hixton-Gale Association
   Moderately deep, well drained, gently sloping to steep loamy soils underlain by sandstone; on uplands.

To evaluate the potential of soils for attenuating pollutants, a different grouping of individual soil series based solely on physical and chemical characteristics is required. An evaluative system was developed to assess those soil properties that play a role in the attenuation of potential groundwater pollutants resulting from land-use activities. This process of attenuation can involve holding essential plant nutrients for uptake by agronomic crops or immobilizing metals that might be contained in municipal sewage sludge or removing bacteria contained in animal or human wastes. It is a complex process, or series of processes, all of which are not clearly understood, but it is extremely important in that it makes the soil an integral part of the natural protection of groundwater from surface-applied pollutants.

For assessing soil potential for attenuation of pollutants, seven physical and chemical characteristics were selected for each soil series and were given weighted values to a maximum of 10 (table 1). Values assigned to each characteristic were determined subjectively with 1 being the lowest and 10 the highest score possible. These values were summed, and soils with similar total point scores were assigned to one of four soil groups; each group has a different attenuation potential (table 2). Soil series were selected for evaluation because, as a lower category in the soil classification system, each series is a defined entity with unique characteristics and behavior. For evaluative purposes, only physical and chemical characteristics of the soil solum -- specifically, the A and B horizons -- were used.

Table 2 shows that the soils of the county fall about equally into categories of poor potential for attenuating pollutants (groups 1 and 2) and of good attenuation potential (groups 3 and 4). Fairly extensive areas of sandy soils having a low potential for attenuating pollutants (Omega, Chetek) are found primarily in the southeastern part of the county. Many soils in the southern third of the county are formed in a thin loess that overlies shallow sandstone (Arland). If the loess is relatively thick (more than 24 in.), these soils have good attenuation potential for surface-applied pollutants; subsoil uses are severely restricted. Much of the landscape in the northwest and northeast is covered by shallow soils that have very limited ability to attenuate pollutants. These shallow soils developed in acidic, sandy till

Table 1. Ranking system for evaluating the attenuation potential of soils in Barron County (Madison, 1985)

Physical/chemical characteristics	Classes	Weighted values
Texture of surface (A) horizon[1]	l, 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 of subsoil (B) horizon[1]	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[2]	Mollisols	8
	Alfisols	5
	Entisols; Inceptisols	3
	Histosols; Aquic suborder; and Lithic, Aquollic, and Aquic subgroups	1
pH of surface (A) horizon	≥6.6	6
	<6.6	4
Depth of soil solum (A + B horizons)	>40 in.	10
	30-40 in.	8
	20-30 in.	3
	<20 in.	1
Permeability of subsoil (B) horizon[3]	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; and excessively well drained	1

1 Soil textural classes: l = loam, sil = silt loam, scl = sandy clay loam, si = silt, c = clay, sic = sillty 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 level of the soil classification sytem; soils are assigned a lower number if they are wet or less than 20 in. 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 consistency.

Table 2. Soil series in Barron County listed by attenuation potential

	1 Least potential	2 Marginal potential	3 Good potential	4 Best potential
Sum of weighted values	0-30	31-40	41-50	51+
	Alluvial land Boone Chetek Cloquet Milaca (Amery)*-Cloquet-Peat Complex Omega Peat & muck Pitted outwash Riverwash Stoney steep land Terrace Escarpment Wallkill Warman	Adolph Almena Altoona Auburndale Barronett Burkhardt Comstock Freer Milaca (Amery)* Poskin Scott Lake	Arland Brill Chaseburg Crystal Lake Freeon Gale Hixton Spencer	Antigo Campia Onamia Otterholt Santiago
Acreage**	181,705	72,825	103,100	189,450
Percent** of total	33.2	13.3	18.8	34.6

* Modern soil series name.

**The remaining 120 acres (or 0.1%) contain gravel pits.

mixed with organic soils (Milaca [Amery], Cloquet, Muck, Peat). In some places where they occur in the vicinity of former ice-walled lakes, they are covered with up to 15 in. of loess, which improves their attenuation capacity. Throughout west-central, central, and east-central Barron County are extensive areas of deep silts (20 to 36 in.) over sand and gravel. These soils have the best potential for attenuating pollutants resulting from normal land-use activities. In some areas, the finer-textured soils (Antigo, Onamia) are thinner and they should be used more cautiously.

GEOLOGY

Surficial geology

It is generally within the uppermost 20 ft of the land surface that most ordinary human activities are concentrated. In Barron County, most of the surface and near-surface materials are glacially derived and normally have much greater lateral and vertical variation than do the underlying bedrock formations. Therefore, detailed characterization of these deposits is necessary for estimating the potential for attenuation of pollutants.

Most deposits above bedrock in Barron County are the direct or indirect result of glaciation. During the period of geologic time called Pleistocene, glaciers advanced into the county at least seven times. The oldest glacial event probably happened several hundred thousand years ago and the last one around 15,000 years ago. These advances and associated deposits were described by Johnson (1986). Glacial environments are complex, and deposits that form under and around glaciers are variable and have a wide range of characteristics. The different environments are important in determining the size of grains deposited, soil types that have formed on these deposits, and consequently, land-use suitability of the deposits. Pleistocene deposits in Barron County were mapped by Johnson (1986) during 1981 and 1982; the map will be included in the Barron County Atlas.

Glaciers leave behind unconsolidated deposits of variable thickness and character. During the erosion and transportation process glaciers mix materials of different sizes, producing sediment that is poorly sorted. This sediment, called till, is composed of an unstratified (not layered) mixture of clay, silt, sand, and gravel. Water produced by melting ice moves large amounts of material away from glaciers. Sediments deposited by meltwater streams on plains beyond the glacier consist of moderately well sorted and stratified (layered) sand and gravel. Typically in Barron County gently rolling, till-covered uplands are interspersed with broad outwash plains underlain by sand and gravel.

After the last glacial period, deposition continued by wind and by action of modern rivers. After or toward the end of the last glacial advance, loess (windblown silt) covered Pleistocene deposits. In the southern part of the county, loess was deposited directly on Cambrian sandstone. Loess is the parent material for many soils. Its thickness ranges from 0.5 to 2 ft in most of the county; the maximum depth of about 4 ft occurs in central Barron County. Because its permeability generally is low, the silt limits the rate of downward percolation of water to much of the county's aquifers. Sediment deposited on floodplains of modern rivers is similar in character to meltwater-stream deposits.

The unconsolidated deposits overlying bedrock in Barron County vary greatly in thickness even within short distances because of the uneven, erosional relief of rock surface. The deposits are thickest (more than 300 ft) in preglacial rock valleys. They are thin or absent in the south and in the Blue Hills area east of Rice Lake. Generally, unconsolidated deposits in the county thicken from the southeast to the northwest.

In many parts of southern Barron County, Cambrian sand or sandstone is less than 5 ft below the land surface. Areas where the rock is exposed at the surface are abundant; if covered, it is usually only by a thin layer of loess. In east-central Barron County, Precambrian quartzite is also very close to the surface, covered only by a few feet of till. In the southern and southeastern parts, unconsolidated deposits occur primarily in postglacial or preglacial valleys. Their thickness does not exceed 150 ft, except in the buried rock valley extending from Rice Lake south under the Rice Creek, Prairie Lake, Lake Chetek, and the Tenmile Creek, where the depth to rock is more than 200 ft. The greatest thickness of unconsolidated deposits reached by a well was more than 302 ft in a well that did not reach bedrock, located near Barronett at the northern edge of the county. The thickness of till in central Barron County is between 50 and 150 ft. In the northwest, the bedrock surface is between 150 and 250 ft below the land surface.

The surface materials in Barron County do not always offer effective, immediate protection against pollution that may result from activities below the land surface or against pollutants that penetrate the soil zone. A large part of the county is covered by highly permeable outwash deposits of sand and gravel (fig. 3), which water can move through easily. Most of the remaining surface deposits have at least moderate permeability and may not inhibit travel of pollutants. The potential for groundwater pollution is reduced in areas where the surface deposits are thick or the water table is deeper -- then pollutants have more time to attenuate.

Bedrock geology

The bedrock surface, like the land surface, is a series of valleys flanked by highlands. The rock valleys were probably preglacial watercourses that were enlarged by the action of glacier meltwater. A "Y"-shaped buried valley system cut more than 250 ft into sandstone, and the high, steep bluffs of quartzite in the Blue Hills area dominate the bedrock topography in Barron County. The hard quartzite diverted the meltwater around the quartzite bluffs and the water eroded a deep valley in the softer sandstone. The valley extends southward from Rice Lake to Cameron, and from there southeastward into Chippewa County. The valley narrows where it is restricted by the steep bluffs northeast of Cameron. A tributary rock valley extending just north from Barron to Cameron joins the main bedrock valley near Cameron. Smaller and narrower valleys dissect the bedrock surface in southern Barron County.

The youngest bedrock unit in Barron County is the Prairie du Chien dolomite of Ordovician age, which overlies Cambrian rock in the southwest and is about 500 million years old. This dolomite is only a remnant of what once may have been an extensive, thick layer deposited at the bottom of the Ordovician sea; its maximum thickness in Barron County is 80 ft. The bedrock in nearly all Barron County is sandstone of Cambrian age, which forms one of the two major aquifers. It consists of six geologic units: (in descending order) the Jordan and St. Lawrence Formations, the Tunnel City Group, and the Wonewoc, Eau Claire, and Mount Simon Formations (table 3).

Cambrian sandstone thins from about 800 ft in the southwest to zero in the Blue Hills area, where Precambrian rock outcrops. The sandstone originally covered the entire county and was much thicker, but erosion reduced it greatly

Table 3. Geologic column for Barron County

Geologic System	Geologic unit	Thickness (feet)	Character
Quaternary	Recent deposits	0-20	Alluvium (clay, silt, sand, gravel), peat, muck.
		UNCONFORMITY	
	Pleistocene deposits	0-350	Glaciolacustrine deposits; clay, silt, fine sand. Till; unstratified, unsorted mixture of clay, silt, sand, and boulders.
			Glaciofluvial deposits; chiefly well sorted sand and gravel.
		UNCONFORMITY	
Ordovician	Prairie du Chien Group	>80	Dolomite, light gray or tan; some shale.
Cambrian		20-45	Dolomite, yellow to tan, sandy.
	Jordan Formation	30-50	Sandstone, white to yellow, fine to medium grained.
		50-60	Sandstone, white, fine grained, sorted.
	St. Lawrence Formation	<10	Siltstone, light brown, and massive dolomite.
	Tunnel City Group	85-100	Sandstone, yellow, fine grained, cross-bedded; locally glauconitic.
	Wonewoc Formation	30-120	Sandstone, white, iron staining, fine to coarse-grained.
		UNCONFORMITY	
	Eau Claire Formation	100-150	Sandstone, light brown, fine grained to silty; locally fossiliferous; some shale and glauconitic beds.
	Mount Simon Formation	230-460	Sandstone, light gray, very fine to coarse grained, angular.
		UNCONFORMITY	
Lower Proterozoic	Barron Quartzite	>700	Quartzite, pink, maroon, or gray, medium grained; locally conglomeritic; underlies the eastern part of the county; local red argillite (pipestone) beds.
		UNCONFORMITY	
	Proterozoic granite	unknown	Granite to tonalite, red to gray, medium grained; may alternate with the Barron Quartzite.

or entirely removed it in some places. Cambrian and Ordovician sediments were deposited at the bottom of the sea that covered this part of Wisconsin between 550 and 450 million years ago. Rivers draining the land carried sediment that was deposited in the sea to form sandstone and shale. Animals and plants living in the sea deposited calcium carbonate and built reefs to form rock that is now dolomite -- a magnesium-rich limestone.

Igneous and metamorphic rocks of Precambrian age underlie the Cambrian in the entire county, except in the Blue Hills area, where they form the bedrock surface. The Precambrian in the western part of the county may consist of Keweenawan metasedimentary rock (sandstone). Barron Quartzite underlies the Cambrian in the eastern part of the county and may alternate with granite. Much of the Precambrian rock that once covered the county has been removed by erosion that took place between 600 and 1,000 million years before present. The eroded Precambrian rock surface generally slopes southwestward at about 15 ft per mile (Bell and Hindall, 1975). All Precambrian rock has been so extensively deformed and altered that its nature and origin is extremely difficult to interpret. The Keweenawan is probably 1,100 million years old; the Barron Quartzite was formed about 1,760 million years ago.

GROUNDWATER AVAILABILITY

Groundwater in Barron County is primarily obtained from the sand-and-gravel aquifer and the Upper Cambrian sandstone aquifer (fig. 3). Minor amounts of water can be obtained from the Ordovician Prairie du Chien dolomite and Precambrian crystalline rock.

The sand-and-gravel aquifer occurs primarily as outwash that fills preglacial rock valleys (fig. 3) in the southern two-thirds of the county and in outwash plains and buried ice-contact deposits in central Barron County and in the northwest and northeast, respectively. Thick deposits of outwash sand and gravel in the valleys of the Red Cedar and Yellow Rivers yield more than 1,000 gallons per minute (gpm) to many high-capacity wells, primarily for irrigation. Yields exceeding 2,000 gpm from these areas could be sustained for many years (Bell and Hindall, 1975). Buried sand-and-gravel deposits are beneath or included in ground and end moraines in the northwestern and northeastern part of the county (Young and Hindall, 1972). Adequate domestic wells with yields of 5 to 15 gpm can be completed in buried lenses of sand and gravel, which are often less than 5 ft thick (Young and Hindall, 1972) at depths from about 20 to 200 ft.

The sandstone aquifer underlies almost the entire county and consists of saturated formations of Ordovician and Cambrian age (fig. 3). Bedrock formations (table 3) may act as a single aquifer or, when separated by less permeable layers, as several aquifers of moderate to large yields. The Ordovician Prairie du Chien dolomite is a minor water source only in the southwestern part of the county. It forms the upland surface and usually is exposed on the valley walls. The saturated zone is thin, but adequate well yields can be obtained for domestic and stock uses. The sandstone formations of Cambrian age compose the bulk of the aquifer. They provide reliable supplies for municipal, industrial, domestic, and irrigation uses all around the county. Because sandstone is denser and 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.

Sandstone wells in most of Barron County can produce from 100 to 500 gpm, but yields of up to 1,000 gpm are not uncommon, especially in the southwest

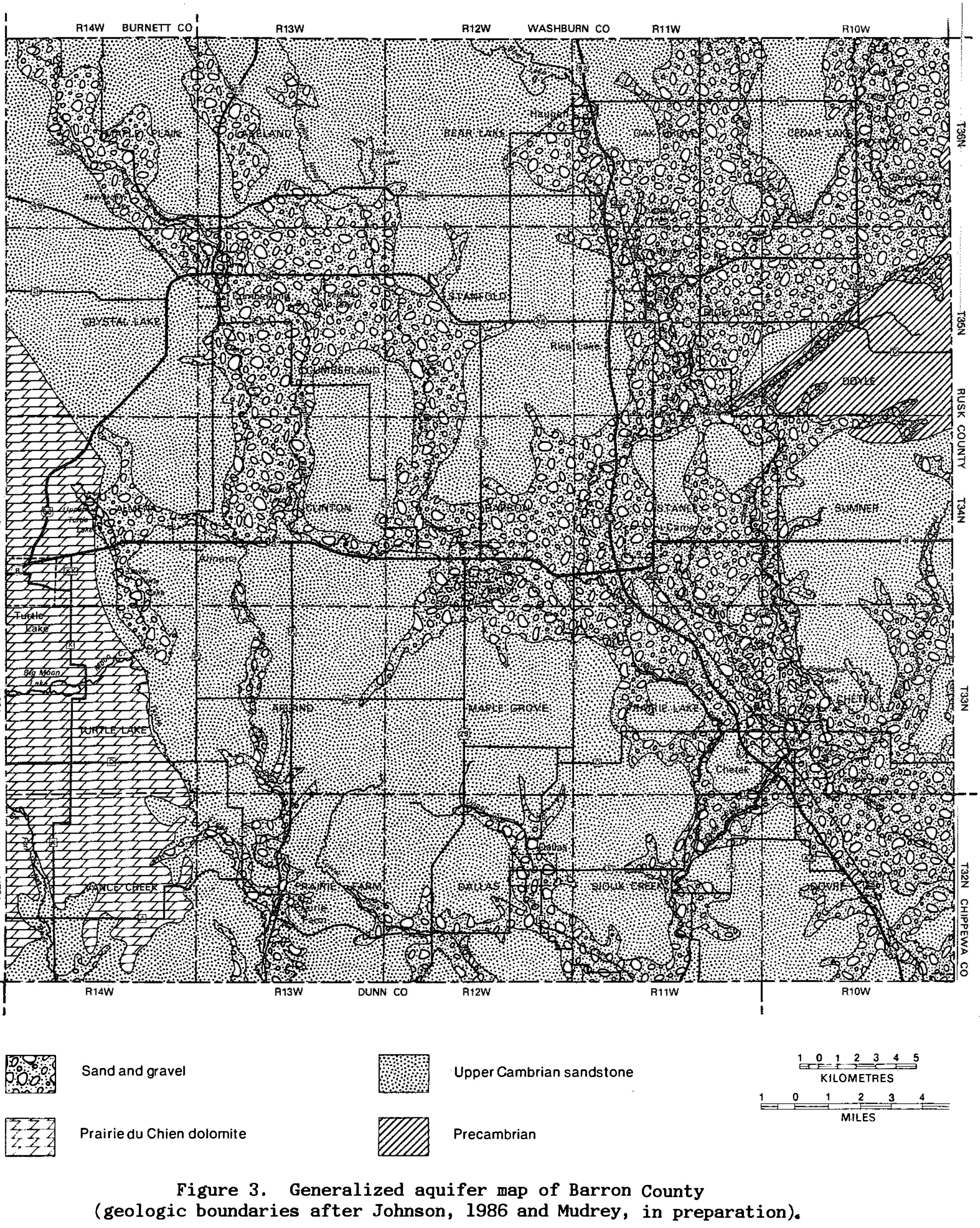


Figure 3. Generalized aquifer map of Barron County (geologic boundaries after Johnson, 1986 and Mudrey, in preparation).

(Young and Hindall, 1972). The sandstone aquifer is the sole source of water in the southwest and south, where overlying unconsolidated deposits are thin or absent. Adequate water for high-capacity irrigation wells is also available from sandstone underlying the outwash sand and gravel. Because the two aquifers generally are connected hydraulically, wells penetrating the sandstone aquifer also withdraw water indirectly from the sand-and-gravel aquifer. The sandstone aquifer is not used much in northern Barron County because the overlying Pleistocene deposits are thick and yield adequate amounts of water to domestic wells.

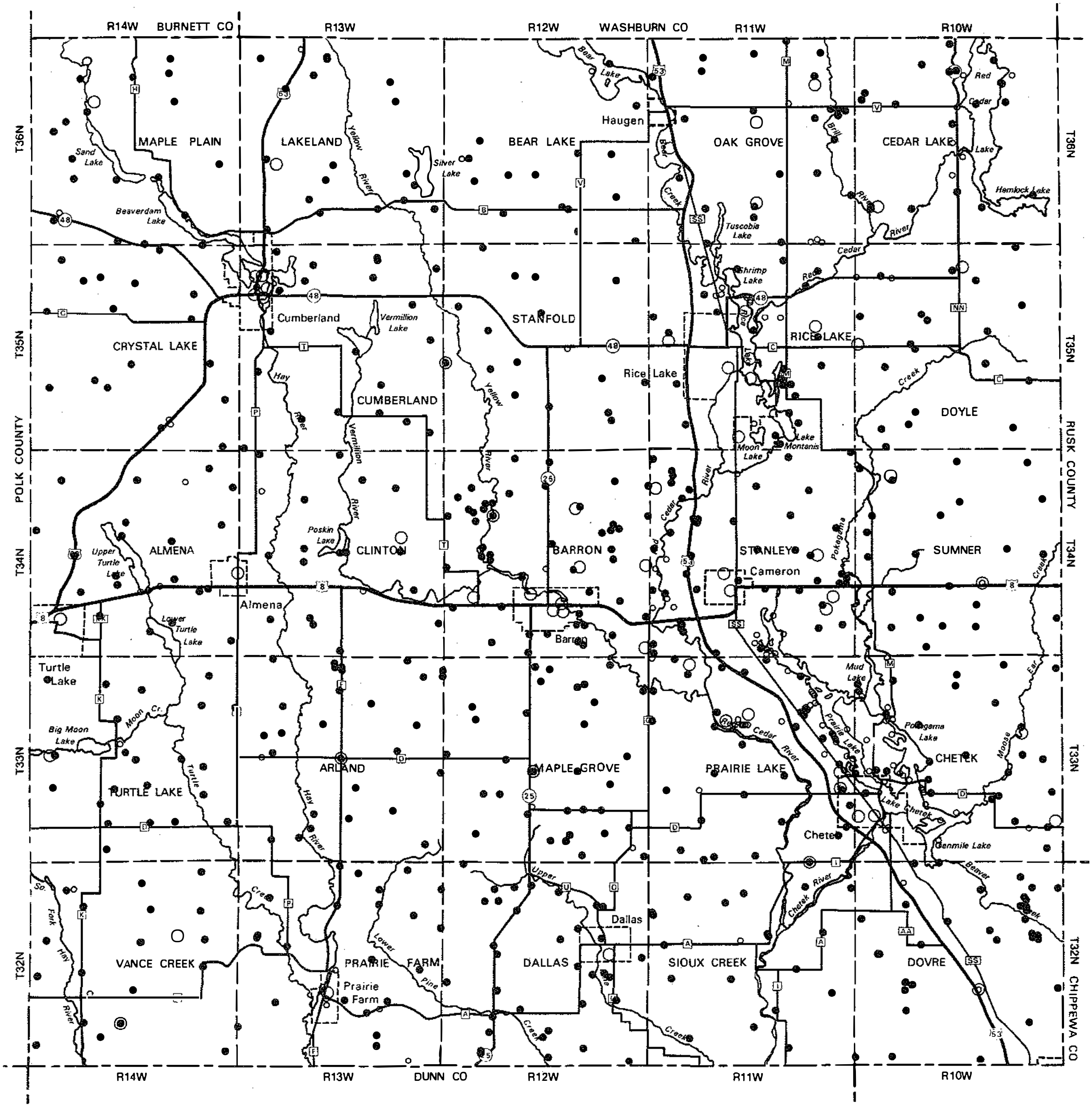
Precambrian rocks are not a major source of water in Barron County relative to other aquifers. Over most of the county they form the lower limit of groundwater movement. The Precambrian sandstone aquifer is not used because it is overlain by the thick sandstone and sand-and-gravel aquifers. The Precambrian crystalline aquifer is the sole source of water in the Blue Hills area, where the two principal aquifers are absent. The Precambrian aquifer yields small amounts of water (generally less than 10 gpm) from the weathered zone at the bedrock surface and from fractures within the rock.

Large amounts of water are being used for agricultural irrigation in Barron County. 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. Continued development of groundwater supplies for irrigation is likely because conditions are favorable for expanded vegetable production. Generally abundant supplies of groundwater are available to meet these needs. Bell and Hindall (1975) calculated that pumping 2,000 gpm from a well would result in less than 20 ft of drawdown immediately around the well and in less than 2 ft of drawdown 0.25 mi from the pumped well in much of the main bedrock valley. The 20-ft drawdown is only a small portion of the total saturated thickness of the aquifer, and indicates that a great amount of water is available from the sand-and-gravel aquifer within the valley.

GROUNDWATER QUALITY

The Wisconsin Geological and Natural History Survey (WGNHS) conducted a random sampling of private wells in Barron County from July 1983 to October 1985 to define the current quality of groundwater in the county and to identify potential problem areas. During that period, 383 samples were collected from randomly selected private wells in all of the 25 townships of the county by a student hired by the county and WGNHS personnel (fig. 4). The employees of Jerome's Food, Inc., helped in collecting water samples from wells on turkey farms. In addition, county zoning administration ordered analyses of 98 samples they collected at the request of county homeowners. All of the 481 samples were analyzed in the University of Wisconsin Soil Science Department Laboratory in Madison for all species of nitrogen and phosphorus, chloride, total solids, and specfic conductivity. Samples collected in 1984 and 1985 were also analyzed for hardness. Ninety of the 481 samples were also analyzed for calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), and chemical oxygen demand (C.O.D.). In addition, 241 nitrate analyses were gathered from the county and DNR files (fig. 4).

Sixty complete chemical analyses were available for determining basic characteristics of groundwater quality in the county (Holt and Skinner, 1973); nine additional samples were collected by WGNHS and analyzed by the U.S. Geological Survey (USGS) laboratory. The complete analysis included all major



● Wells sampled by WGNHS or county personnel

○ Wells sampled by DNR personnel

◯ Samples taken for complete analysis

1 0 1 2 3 4 5
KILOMETRES

1 0 1 2 3 4 5
MILES

Figure 4. Well-water sampling locations of Barron County, 1983-85.

cations (Na, K, Ca, Mg, Fe, Mn) and anions (Cl, SO_4, HCO_3, F, NO_3) and basic properties of water (specific conductivity, alkalinity, pH, total dissolved solids, and hardness). Data on trace and minor constituents were compiled from the results of the National Uranium Resource Evaluation (NURE) program (Arendt and others, 1978). Sixty-two well-water samples were taken for this program from August to November 1977 in the county area covered by the 1:250,000 Rice Lake quadrangle (a part of the county east of the 92° latitude). The wells selected for sampling formed a more or less regular grid, with wells approximately 5 miles apart.

Current quality of groundwater

The overall natural quality of groundwater in Barron County is good, and the water is suitable for most purposes. The composition of groundwater in the county is primarily a result of its movement through and interaction with the unconsolidated deposits and sedimentary rocks that contain large amounts of carbonate minerals. Therefore, the groundwater is predominately of the calcium-magnesium-bicarbonate type. Regional differences in the quality of water are due to the composition, solubility, and physical properties of soil and rock particles through which the water moves, and to the length of time the water is in contact with these materials. The natural composition of groundwater changes very slowly.

Total dissolved solids (TDS) in a water sample is a measure of dissolved mineral constituents derived from solution of rocks and soils. The total concentration of minerals dissolved in water is a general indication of the overall suitability of a water for various types of uses. If the water contains less than 500 milligrams per liter (mg/L) TDS, it is generally satisfactory for domestic and many industrial uses. Mineralization of groundwater in Barron County is low under natural conditions. More than 80 percent of samples collected during the study contained less than 300 mg/L TDS; most samples had between 100 and 200 mg/L TDS, which is normal for the sand-and-gravel and sandstone aquifers in this part of Wisconsin (Devaul, 1975a; b). Groundwater is more mineralized (more than 300 mg/L TDS) in the western part of the county underlain by dolomite (fig. 5). The lowest concentrations of TDS are in areas of outwash sand and gravel, where rapid movement of groundwater through the coarse-grained material results in low mineralization. The median concentration of dissolved solids in water from 566 wells sampled for analysis was 164 mg/L (table 4). The lowest concentration was 27 mg/L in a well in the town of Doyle, and the highest was 1,041 mg/L in a well in the town of Prairie Farm. Only 17 samples exceeded the limit of 500 mg/L recommended by the U.S. Environmental Protection Agency for drinking water. These higher concentrations can be considered anomalies in this area, and may indicate impairment of natural water quality. However, higher mineralization itself does not pose any health hazard, but the water may have a disagreeable taste and may be corrosive.

The number of major dissolved constituents of groundwater is quite small, and the natural variations are not as great as might be expected from the complex mineral and organic materials through which the water has passed. Six ions included in figure 6 -- calcium (Ca), magnesium (Mg), sodium (Na), bicarbonate (HCO_3), sulfate (SO_4), and chloride (Cl) -- form more than 95 percent of all the dissolved substances in water. Major chemical constituents shown in figure 6 indicate that the quality of water differs only slightly

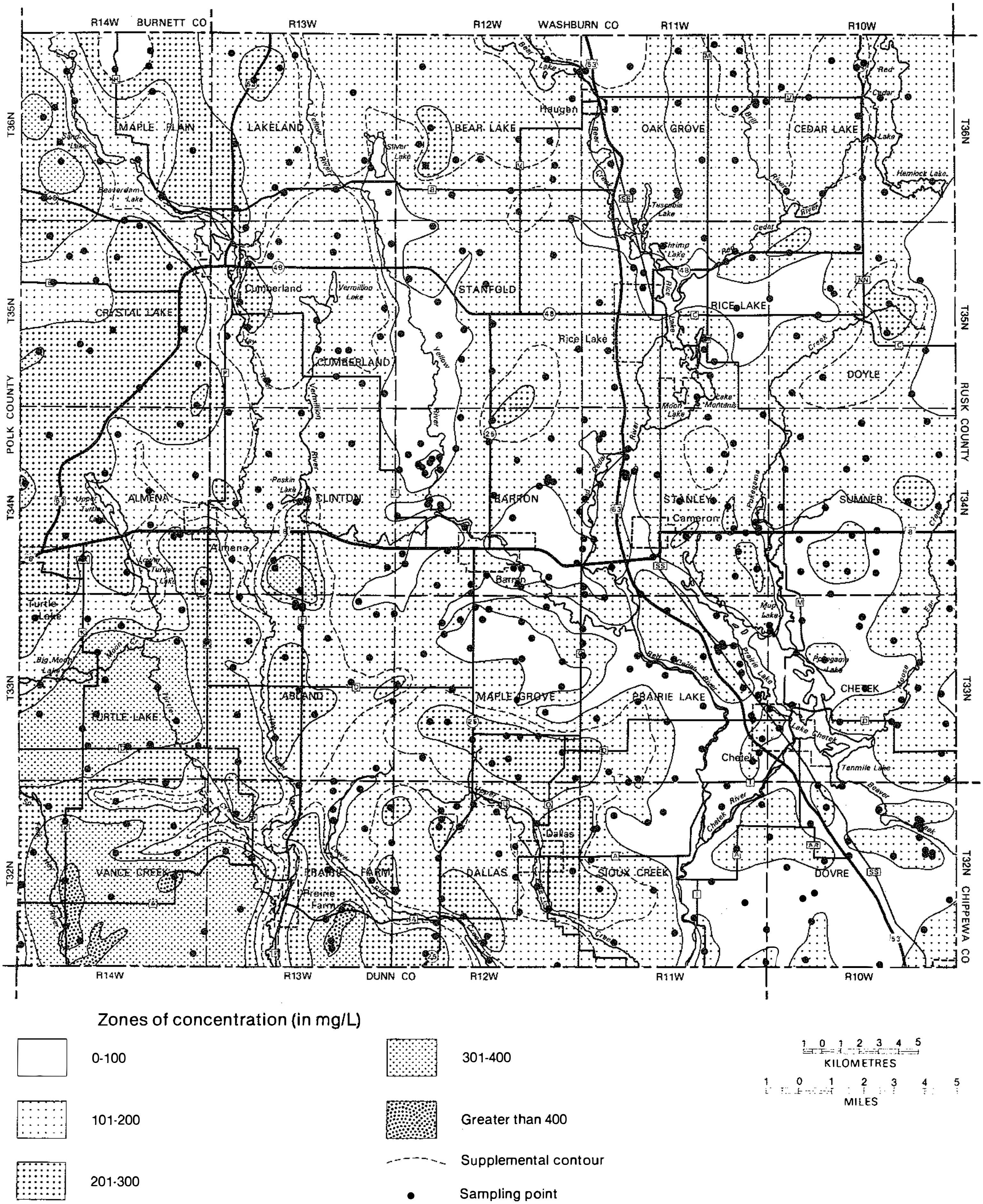


Figure 5. Generalized mineral concentration of groundwater in Barron County.

between aquifers. Water in the sandstone aquifer is generally more mineralized and harder than water in the sand-and-gravel aquifer. Common chemical constituents of groundwater in Barron County and their maximum, minimum, and average values are summarized in table 4.

Besides these common constituents, groundwater in Barron County contains a number of minor, or trace elements. The concentrations summarized in table 5 are the result of sampling done during the NURE program in 1977 (Arendt and others, 1978). Almost all the samples taken from 62 wells in the county contained only small quantities of these elements, well below the limits recommended for drinking water. Limits included in table 5 were set by the U.S. EPA and accepted by the state only for those elements that in the greater quantities may have toxic effects on humans (Wisconsin Administrative Code, 1982). More than 60 percent of samples analyzed for copper and all samples analyzed for zinc had detectable amounts of each. Only one sample exceeded the established limits -- a well in the town of Stanfold had 6.2 mg/L (6,249 g/L) of zinc in the water sample. In addition, samples taken from two wells in the town of Barron at the request of homeowners had concentrations of copper higher than the standard for drinking water: 1,800 and 4,000 mg/L, respectively. Many water distribution systems use copper pipes, galvanized well casing, or galvanized pressure tanks. Dissolution from copper pipe or galvanized casing may be a source of copper or zinc in some water samples. Concentrations of phosophate normally present in groundwater are far less than those of nitrate, and they were generally less than a few tenths of a milligram per liter in the county.

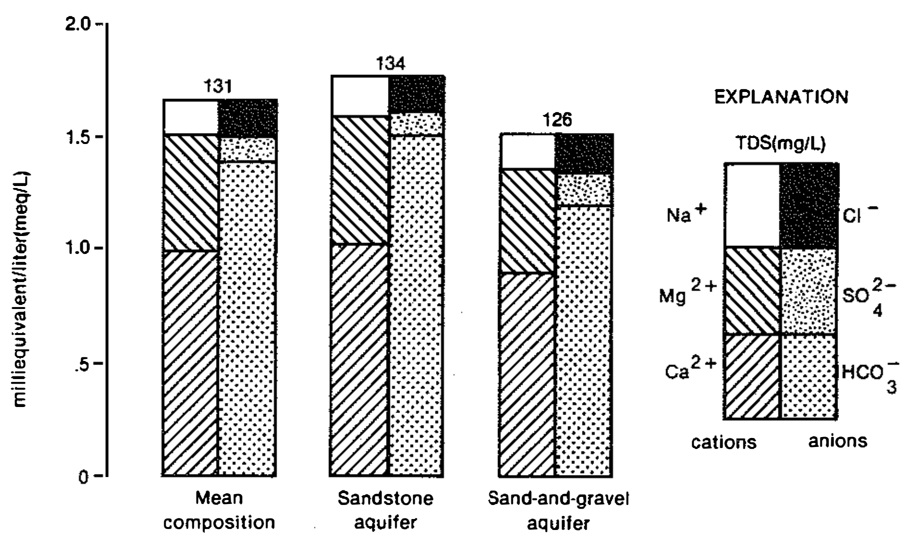


Figure 6. Mean composition of water in Barron County, by aquifer

Table 4. Summary of chemical and physical characteristics of groundwater in Barron County (all in milligrams per liter, mg/L, unless indicated otherwise)

Constituent or Property	No. of samples	Maximum	Minimum	Median	Mean	No. over limit*
Alkalinity, total, lab (as $CaCO_3$)	71	242	11	51	58	-
Bicarbonate (HCO_3^-)	54	246	13	68	85	-
Calcium (Ca^{2+})	58	57	3.5	19.5	21	-
Chloride (Cl^-)**	65	32	0	4.3	6.9	0
Fluoride (F^-)	57	0.6	0	0.1	0.1	0
Hardness (as $CaCO_3$)**	66	215	14	78	84	-
Iron and manganese, total dissolved (Fe + Mn)	65	32	0	0.1	0.8	5
Magnesium (Mg^{2+})	57	19	1.1	6.6	7.1	-
Nitrate-nitrogen (NO_3-N)**	62	80	0	6.2	10.2	19
pH, lab (no units)	64	8.3	6.0	6.9	7.0	-
Potassium (K^-)	45	3.5	0.1	0.7	0.9	-
Sodium (Na^+)	51	14	0.9	3.6	4.0	-
Specific conductance (in micromhos)	54	457	31	133	171	-
Sulfate (SO_4^{2-})	65	33	0.5	6.3	6.8	0
Total dissolved solids (TDS)**	66	270	45	119	131	0
Chloride	657	167	0.04	7.0	6.4	0
Hardness	198	468	16	84	94	-
Nitrate-nitrogen	722	42	0	2.5	4.3	73
Total dissolved solids	566	1,041	27	164	208	17

*For limits, see Wisconsin Administrative Code (1982)

**Includes only results of the complete chemical analyses. Values from the analyses of samples collected during 1983-85 are below.

Source: Holt and Skinner (1973); recent USGS analyses; analyses of samples collected in 1983-85.

Table 5. Concentrations of minor and trace constituents in groundwater in Barron County (in micrograms per liter, μg/L)

Constituent	No. of samples	Maximum	Minimum	Median	Maximum limit*
Aluminum (Al)	62	37	< 10.0	< 10.0	-
Arsenic (As)	62	2.2	< 0.5	< 0.5	5
Barium (Ba)	62	261	< 2.0	< 5.5	1,000
Beryllium (Be)	62	< 1.0	< 1.0	< 1.0	-
Boron (B)	62	270	< 5.0	< 8.0	-
Chromium (Cr)	62	8.0	< 4.0	< 4.0	50
Cobalt (Co)	62	17.0	< 2.0	< 2.0	-
Copper (Cu)	62	302	< 2.0	< 4.0	1,000
Lithium (Li)	62	4.0	< 2.0	< 2.0	-
Molybdenum (Mo)	62	9.0	< 4.0	< 4.0	-
Nickel (Ni)	62	9.0	< 4.0	< 4.0	-
Scandium (Sc)	62	< 1.0	< 1.0	< 1.0	-
Selenium (Se)	62	3.0	< 0.2	< 0.2	10
Silver (Ag)	62	< 2.0	< 2.0	< 2.0	50
Titanium (Ti)	62	< 2.0	< 2.0	< 2.0	-
Zinc (Zn)	62	6,249	5.0	60.0	5,000

*From: Wisconsin Administrative Code (1982)

Source: Arendt and others (1978)

General water-quality problems

The quality of Barron County groundwater is much better than required by drinking-water standards (Wisconsin Administrative Code, 1982). Only a few of the properties and constituents of groundwater listed in table 4 have caused or have a potential to cause water-quality problems.

Hardness. Minor water-use problems can be caused by hardness. Groundwater in Barron County is, on the average, moderately hard. The countywide median hardness for 198 samples was 84 mg/L as $CaCO_3$ (see table 4). Hardness increases across the county from the east (less than 60 mg/L) to the west (more than 180 mg/L) (fig. 7). The federal or state regulations of drinking water do not include a limit for hardness because no serious health problems are known to result from consumption of hard water. Hardness of water is caused by calcium and magnesium, two of the major dissolved constituents found in the county's groundwater. Hard water is objectionable for domestic and industrial uses because the insoluble residue collects in kettles and boilers used for heating water and a curd forms when hard water comes into contact with soap. The residue in water distribution systems causes premature deterioration of pipes and water heating equipment. Hardness problems can be reduced readily by softening. On the other hand, depending on factors such as the pH and alkalinity of the water, naturally soft water may cause corrosion in water distribution systems, and consequently, dissolution of copper pipes in the systems. This problem can be removed by the installation of a water hardener, which will increase the $CaCO_3$ content of the water and make the water harder.

Chloride. The concentration of chloride in the county's groundwater was low. In 657 samples collected, the concentration was, with few exceptions, less than 50 mg/L -- well below the recommended limit of 250 mg/L. This standard is based solely on aesthetic considerations (salty taste), and not on health considerations. The maximum chloride concentration in a well in the town of Lakeland was 167 mg/L. The next highest was 93 mg/L. In about 75 percent of samples, chloride concentration was less than 15 mg/L. Concentrations higher than this amount may indicate pollution of water by animal waste, sewage, or road salt. Also, higher chloride concentrations increase water corrosiveness and corrosive water may dissolve toxic metals from water-distribution pipes. Figure 8 shows that elevated chloride concentrations (more than 15 mg/L) mostly occur along the county highways, apparently caused by road salting in winter.

Nitrate. The concentration of nitrate in groundwater in Barron County generally was low during this study. Nitrate-nitrogen (NO_3-N) concentrations ranged from 0 to 42 mg/L and averaged 3.0 mg/L (see table 4). Concentrations of nitrate in groundwater vary widely with respect to season, depth to water, location of wells, type of soil or sediment in the unsaturated zone, and available sources of nitrate. Because of the variability, it is impossible to show zones of nitrate in the groundwater of Barron County on a map. However, a map showing all sampled wells and determined nitrate values is on file at the Barron County Zoning Office. General distribution of nitrate is illustrated in figure 9 by average nitrate concentrations by town. The lowest observed concentrations in individual wells (less than 2.0 mg/L) generally were limited to the northernmost and westernmost tiers of townships. The higher concentrations, more than 10 mg/L, can be found especially in the irrigated areas of outwash plains in the southeast and in the areas of shallow bedrock in the south.

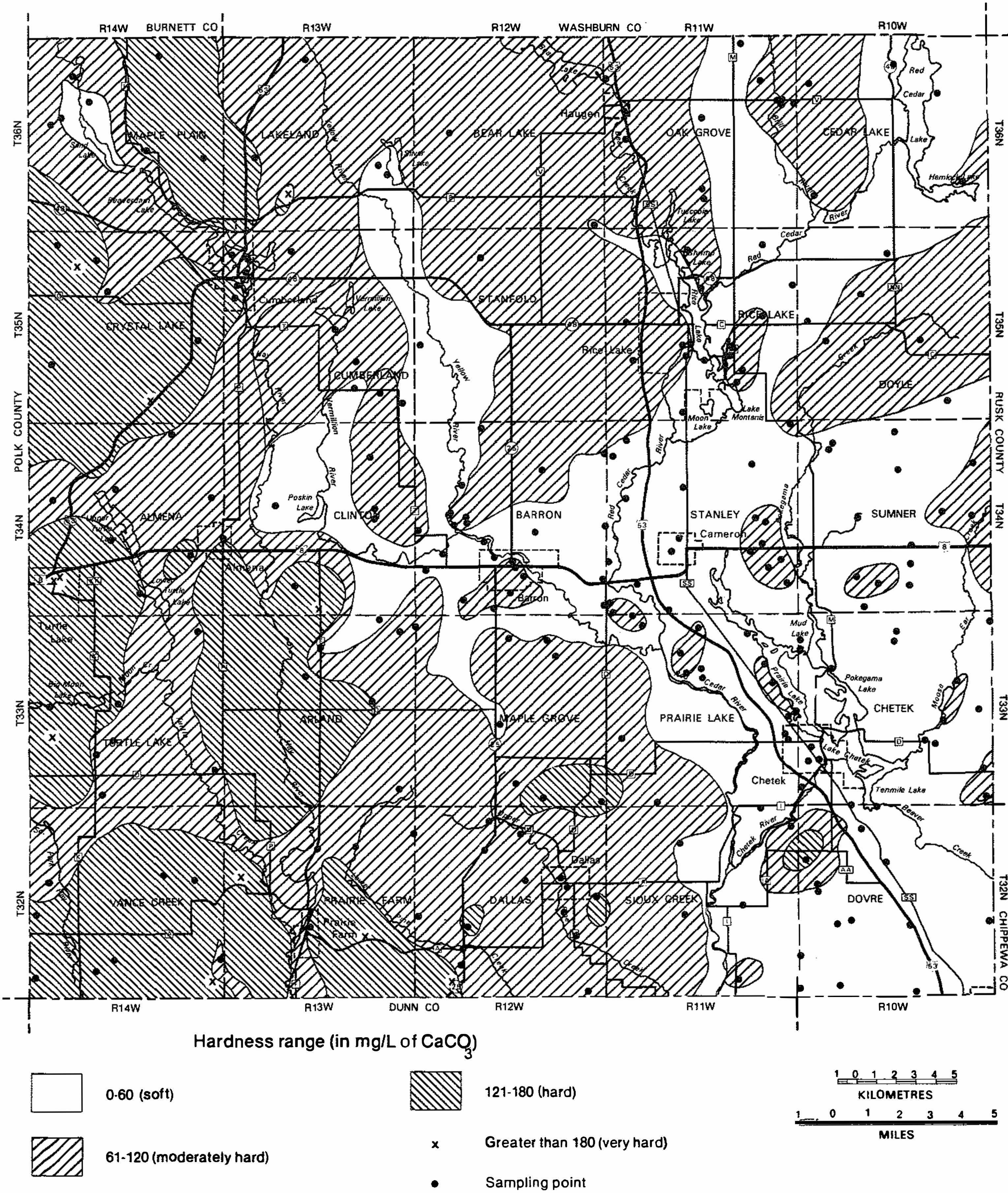


Figure 7. General distribution of hardness of groundwater in Barron County.

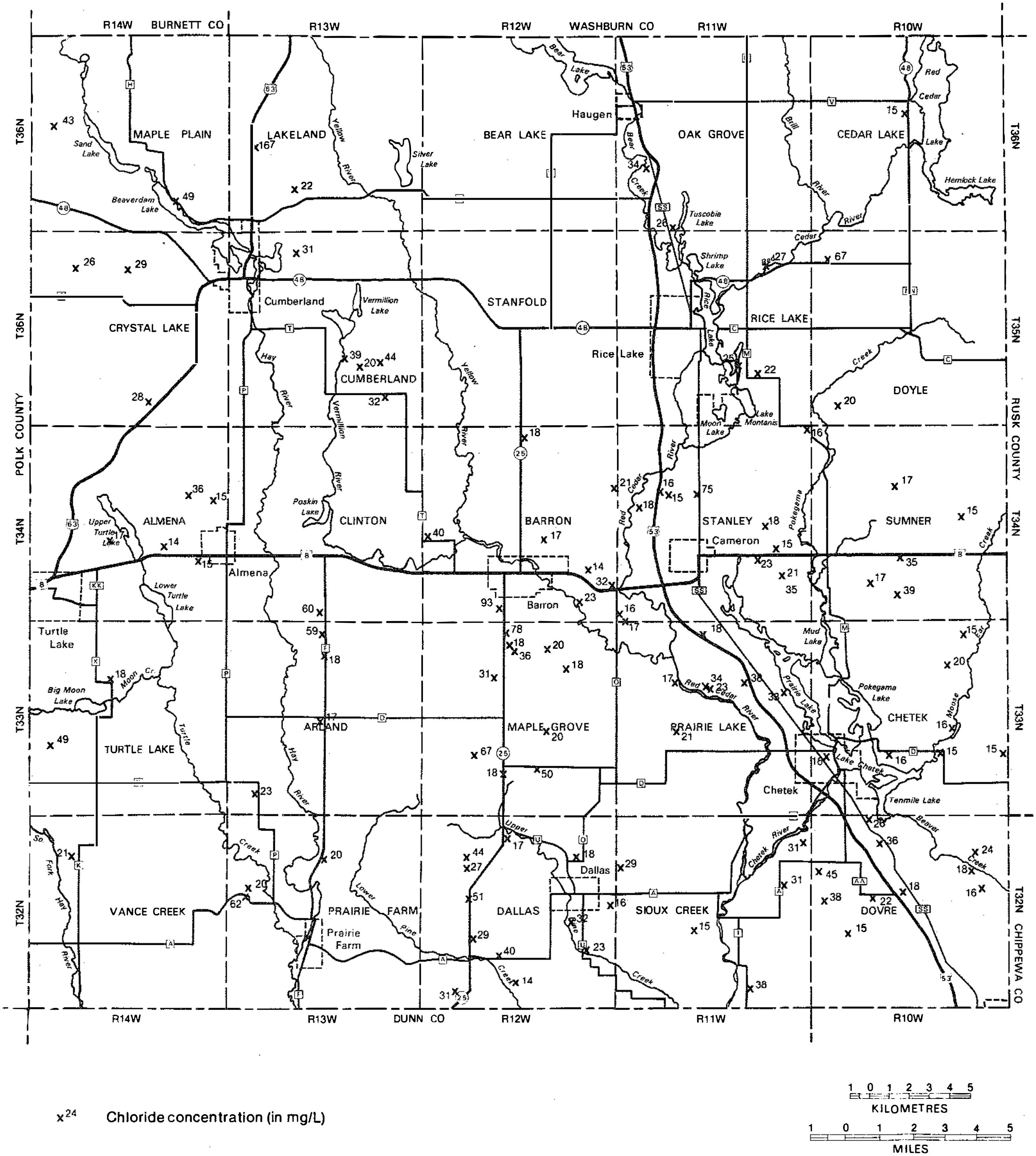


Figure 8. Chloride concentrations in Barron County greater than 15 mg/L.

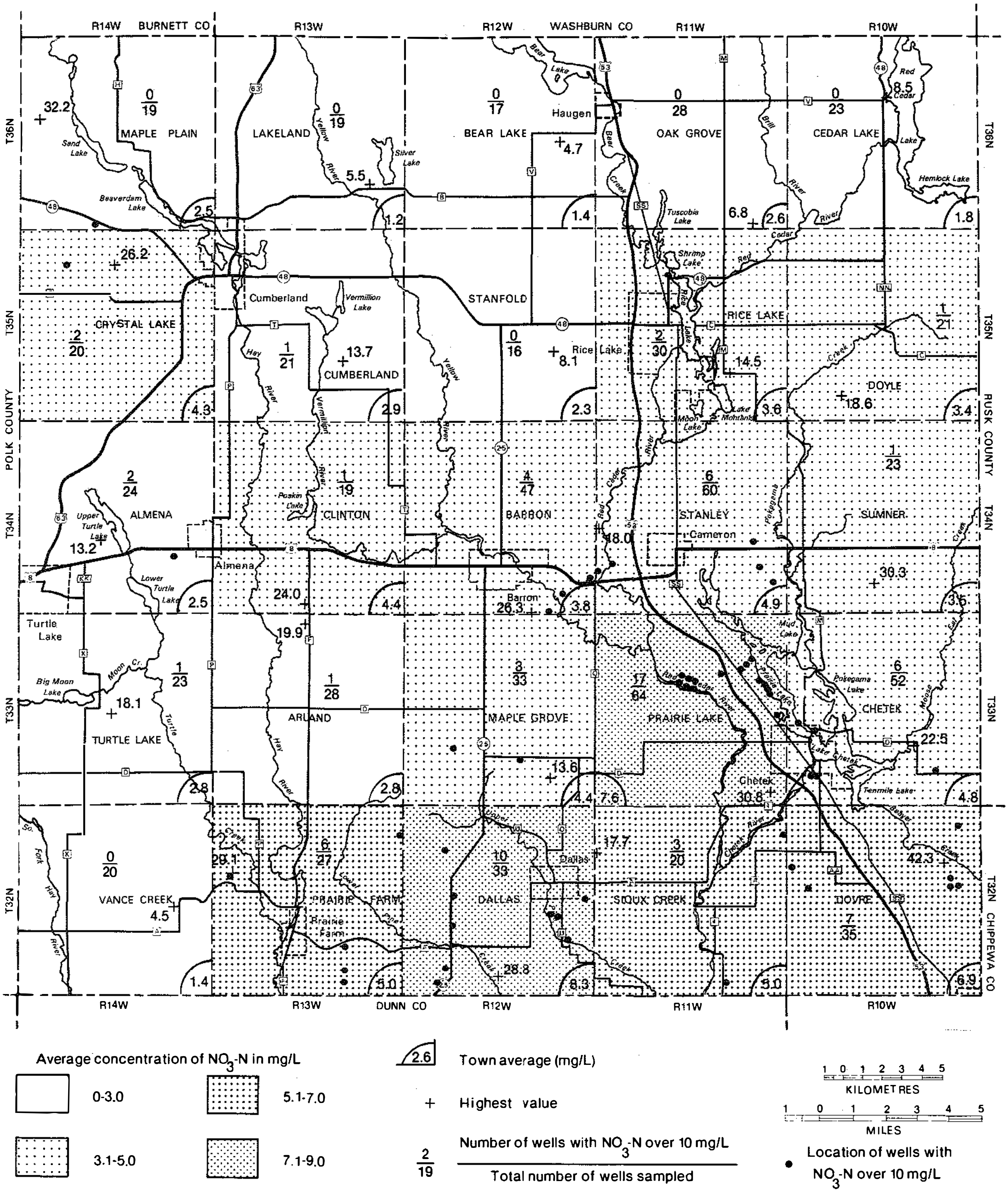


Figure 9. Nitrate distribution in Barron County, 1983-85, by town.

An unusually large amount of nitrate in well water may indicate pollution from septic tanks, privies, manure pits, or barnyards. Even though nitrate is not a problem in itself, it may serve as an indicator that the water may contain harmful bacteria, which also may be carried into the aquifer from these sources of pollution.

Under certain conditions, nitrate can be reduced to nitrite (NO_2) by denitrifying bacteria in the upper digestive tract of some infants. High concentration of nitrate can result in a serious, though easily treated, blood disorder in infants called infantile methemoglobinemia (or cyanosis). The reaction of nitrites with the hemoglobin of the blood reduces the capability of the blood to carry oxygen to the body tissues. Because the skin of affected infants takes on a blue tone, similar to that which would occur from suffocation, such infants are called blue babies. Prompt medical treatment normally results in quick recovery.

Infants under 6 months of age are most susceptible to this disease, but not all infants are affected. Many infants have drunk water with nitrate concentration higher than 10 mg/L and have not developed the disease. In Wisconsin no fatalities associated with nitrate in drinking water have been reported, and the actual occurrence of the disease is thought to be quite rare (Wisconsin Department of Natural Resources, 1980). The standard of 10 mg/L nitrate-nitrogen (NO_3-N) is based on the medical observation that no known cases of methemoglobinemia have been reported when water contained less than 10 mg/L. Older children, adults, and animals can consume water with larger concentrations with no known ill effect because their stomach juices are more acidic than those of infants and do not promote the growth of denitrifying bacteria.

To determine the nitrate concentrations in Barron County, 722 analyses were collected from various sources. Table 6 shows that about 10 percent of the samples (76 samples) exceeded the established limit for drinking water of 10 mg/L NO_3-N, and that only 20 of the 76 samples contained more than 20 mg/L. About 55 percent of the samples (391 samples) contained less than 3.0 mg/L, and of that amount 195 samples contained less than 1.0 mg/L NO_3-N.

Nitrate in groundwater is derived from a variety of natural and human sources. The principal natural sources are soil nitrogen (product of decaying vegetation, growth of certain plants, and wild-animal waste) and atmospheric deposition. Principal human-related sources include barnyards, feedlots, animal waste disposal, septic systems, and application of nitrogen fertilizers on irrigated fields. Nonpoint sources (that is, dispersed over wide areas) -- such as soil nitrogen and leaching of commercial fertilizers — are very difficult to distinguish from other sources. The level of nitrate concentration that is considered to be above natural or background levels and, thus, the result of human activities, has not been clearly defined. The U.S. Geological Survey evaluated existing nitrate data for the United States and concluded that a concentration of more than 3.0 mg/L indicates possible human inputs (Madison and Brunnett, 1985). Rural areas have greater potential for nitrate pollution than urban areas because of barnyard drainage, inadequate storage of animal waste, and use of fertilizers.

Twenty-two wells that exceeded 10 mg/L NO_3-N during the first round of random sampling in 1983 were resampled in 1984 and showed essentially the same nitrate concentrations. The continuing presence of high amounts of nitrate indicated the presence of a pollution source. Therefore, the location of these wells — together with another 11 wells that tested high in nitrate during the second round of random sampling in 1984 -- were field-checked for pollution sources in 1985. The on-site inspection showed that septic tanks, runoff from

Table 6. Barron County nitrate survey, 1983-85

Township	Nitrate-Nitrogen (NO_3-N) in mg/L: 0-0.9		1.0-2.99		3.0-9.99		10.0-19.9		20.0 & more		Wells sampled		Highest value		Township average
	No. of samples	%	No. of samples	%	No. of samples	%	No. of samples	%	No. of samples	%	Total no.	% of wells w/NO_3-N 10.0 mg/L or more	mg/L	Date	
Almena	8	33.3	7	29.2	7	29.2	2	8.3	0	0	24	8.3	13.2	7/8/83	2.49
Arlano	12	42.8	8	28.6	7	25.0	1	3.6	0	0	28	3.6	19.9	8/17/83	2.79
Barron	21	44.7	7	14.9	15	31.9	3	6.4	1	2.1	47	8.5	26.3	8/22/83	3.77
Bear Lake	10	58.8	4	23.5	3	17.6	0	0	0	0	17	0	4.7	7/21/83	1.44
Cedar Lake	11	45.8	8	33.3	5	20.8	0	0	0	0	24	0	8.5	10/8/85	1.76
Chetek	7	13.5	10	19.2	29	55.8	5	9.6	1	1.9	52	11.5	22.5	11/5/85	4.75
Clinton	4	21.0	5	26.3	9	47.4	0	0	1	5.3	19	5.3	24.0	10/21/85	4.36
Crystal Lake	8	42.1	4	21.1	5	26.3	0	0	2	10.5	19	10.5	26.2	7/18/83	4.31
Cumberland	7	33.3	6	28.6	7	33.3	1	4.8	0	0	21	4.8	13.7	9/25/84	2.86
Dallas	5	14.7	5	14.7	14	41.2	6	17.6	4	11.8	34	29.4	28.8	8/16/83	8.34
Dovre	5	14.3	13	3.7	10	28.6	4	11.4	3	8.6	35	20.0	42.3	8/18/83	6.89
Doyle	4	19.0	10	47.6	6	28.6	1	4.8	0	0	21	4.8	18.6	3/7/83	3.37
Lakeland	12	63.2	5	26.3	2	10.5	0	0	0	0	19	0	5.5	1/31/83	1.19
Maple Grove	4	12.1	13	39.4	13	39.4	3	9.1	0	0	33	9.1	13.6	2/22/83	4.42
Maple Plain	9	47.3	6	31.6	2	10.5	1	5.3	1	5.3	19	10.6	32.2	5/21/84	2.55
Oak Grove	8	28.6	9	32.1	11	39.3	0	0	0	0	28	0	6.8	6/17/85	2.61
Prairie Farm	6	22.2	7	25.9	8	29.6	4	14.8	2	7.4	27	22.2	29.1	10/3/84	4.99
Prairie Lake	4	6.3	14	22.2	28	44.4	13	20.6	4	6.3	63	26.9	30.8	8/18/83	7.59
Rice Lake	7	22.6	11	35.5	11	35.5	2	6.5	0	0	31	6.5	14.5	9/12/84	3.57
Sioux Creek	1	5.0	8	40.0	8	40.0	3	15.0	0	0	20	15.0	17.7	1/16/84	4.95
Stanfold	5	31.3	6	37.5	5	31.3	0	0	0	0	16	0	8.1	4/20/83	2.34
Stanley	11	18.6	10	16.9	32	54.2	6	10.2	0	0	59	10.2	18.0	9/15/83	4.86
Sumner	8	34.8	8	34.8	6	26.1	0	0	1	4.3	23	4.3	30.3	10/5/84	3.55
Turtle Lake	8	34.8	6	26.1	8	34.8	1	4.3	0	0	23	4.3	18.1	8/29/84	2.80
Vance Creek	10	50.0	6	30.0	4	20.0	0	0	0	0	20	0	4.5	8/3/83	1.37
TOTALS*	195	27.0	196	27.2	255	35.3	56	7.7	20	2.8	722	10.5%	42.3		

* Mean = 4.26, Median = 2.50

Data from: 1983-85 survey, county files, DNR noncommunity water supply and aldicarb monitoring programs.

barnyards and temporary manure storage, and fertilizer application, in combination with deficiencies in well construction, were the major sources of nitrate in the inspected wells.

Nitrate concentrations vary in space and time. Areal distribution of nitrate in Barron County was described previously. However, nitrate varies not only horizontally, but also vertically. In most instances, elevated nitrate concentrations can be found in water from relatively shallow wells (less than 50 ft deep). The relation between well depth (especially well-casing depth) and nitrate concentration is shown in table 7. From the 383 wells randomly selected for testing during 1983-85, only 176 (46%) had available data on well construction. Table 7 shows less nitrate at greater depth, indicating that the shallow wells are more likely to be polluted by nitrate than the deeper wells.

In an attempt to investigate long-term variations in nitrate concentrations with time, nitrate data were compiled for 232 samples taken by various agencies during 1964-82. These analyses are not directly compatible with the results of the 1983-85 sampling because the samples were not taken from the same wells and were not randomly distributed. The concentration of nitrate-nitrogen varied from 0 to 80 mg/L, and about 25 percent of the samples exceeded 10 mg/L. Eleven of 33 wells that contained higher concentrations of nitrate during 1964-72 were resampled in 1983-85. All of them except one had nitrate concentrations lower than those from the previous samplings.

A comparison of two DNR studies from 1980 and 1986 shows that the nitrate concentration has not changed significantly during the last 5 years. Noncommunity public water supply systems in Barron County (i.e., systems serving at least 25 people per day at least 60 days per year) are being periodically sampled for nitrate by the DNR. First sampling was done during 1979-80, when 125 systems were tested for nitrate (Wisconsin Department of Natural Resources, 1980). The sampling revealed that four (3.2%) noncommunity facilities out of the total 125 had average nitrate-nitrogen levels of 10 mg/L or greater. Median nitrate value was 1.1 mg/L NO_3-N. In 1985, all noncommunity facilities in the county with detectable levels of nitrate (more than 0.5 mg/L) in 1979-80 were resampled (Strous, 1986). A comparison of the results of the two sampling periods shows no statistically significant trend. In 1985, the limit (10 mg/L) was exceeded in four (2.4%) of the total 166 facilities tested; the median was 2.6 mg/L. Compared to other Wisconsin counties, Barron County ranked 20th in 1980 and 24th in 1985 in median nitrate values; and 33rd in 1980 and 19th in 1985 in the percentage of wells that exceeded 10.5 mg/L NO_3-N.

There are two basic options in dealing with the nitrate problem: 1) reduce the nitrate intake at the source and 2) develop an alternative source of water. The first option includes proper location, construction, and maintenance of water wells (strict adherence to the Wisconsin well code); protection of fertilizers stored on land surface against rainfall and runoff; control of runoff from barnyards, feedlots, and manure-storage areas; and proper application of fertilizers based on soil tests, recommended rates of application, and proper timing. The removal of nitrate from water is difficult and can be accomplished only by demineralizing of water or by distillation; boiling of water does not remove nitrate. Thus, if a reduction in nitrate concentration is desired, the second option is to use water from an unaffected source or to reconstruct or relocate the well.

Three wells in the county were sampled frequently during our study to investigate short-term, seasonal variations in nitrate concentrations (fig. 10). Wells 49 and 4, both in Prairie Lake Township next to irrigated fields,

Table 7. Well casing depth versus nitrate concentration in Barron County, 1983-85

Casing depth (ft)	No. of wells	Nitrate-Nitrogen Concentration (mg/L) 0 - 0.9		1.0 - 9.9		10.0 & more	
		No. of wells	%	No. of wells	%	No. of wells	%
0-49	57	6	10.6	34	59.6	17	29.8
50-74	44	15	34.1	27	61.4	2	4.5
75-99	27	7	25.9	19	70.4	1	3.7
100-149	22	12	54.5	9	40.9	1	4.6
150-199	20	13	65.0	6	30.0	1	5.0
200 +	6	5	83.3	1	16.7	0	0
TOTAL	176	58	33.0	96	54.5	22	12.5

were initially sampled quarterly during the DNR aldicarb monitoring. Starting in 1984, they were sampled monthly by the WGNHS for a period of 18 months. Well Br 661 in Maple Grove Township, one of the randomly selected wells, was first sampled in summer 1983 and then monthly from October 1984 to April 1986. Two springs in the town of Dovre were sampled during the same period to provide a comparison with natural fluctuations of nitrate levels. The springs fluctuated between 0.2 and 1.0 mg/L and 1.2 and 1.9 mg/L, respectively, showing a slightly increasing trend. No apparent annual cycles have been detected on monitored wells. However, all three wells showed significant decrease in nitrate levels from the peak in 1983, indicating possible impact of fertilizer-application patterns at surrounding fields. By 1985, nitrate levels dropped about 22 percent on well 49, 42 percent on well Br 661, and 66 percent on well 4. The peak on well 4 apparently followed planting of potatoes on a field across the road in 1982 and 1983. In the subsequent years, other crops that demand less nitrogen were planted and nitrate concentration in the well decreased. Similar explanation applies to trends on well 49. Less clear is the trend on well Br 661. Because of time and funding limits, no attempt was made in this study to correlate nitrate concentration with various soil types and with proximity to common sources of nitrate in wells, such as barnyards, feedlots, manure pits, and septic tanks. Continued monitoring of wells and analysis of land uses on surrounding fields will be necessary for a better understanding of seasonal variations in nitrate and their relation to crop rotation.

Pesticides. Pesticides are widely used in Barron County for insect and weed control on corn, soybeans, potatoes, and other crops. The DNR is conducting two sampling programs in Barron County. Since 1981, Union Carbide has been analyzing well-water samples taken by the DNR for aldicarb, a pesticide used primarily on potatoes (Koth, 1985). The DNR analyzes a limited number of split samples to assure accuracy. Aldicarb presents a particular threat to groundwater because of its high solubility. To date, 55 wells in five rural areas of the county have had water sampled (fig. 11). Twelve wells had detectable amounts of aldicarb, with one having more than the health advisory limit 10 parts per billion (ppb). In 1986, a two-mile-radius, aldicarb moratorium circle was established by the Wisconsin Department of Agriculture, Trade & Consumer Protection around this well in the town of Prairie Lake. In the second program, begun in June 1983, the DNR has been testing for several other pesticides and herbicides. Sampling is not randomly distributed; it is slanted toward the most susceptible areas where problems can be expected. A small amount of Atrazine, a herbicide used primarily on corn, was found in a well in the town of Prairie Lake: it apparently resulted from runoff from an unprotected storage area (David Herrick, Northwest District of the Department of Natural Resources, personal communication, 1986).

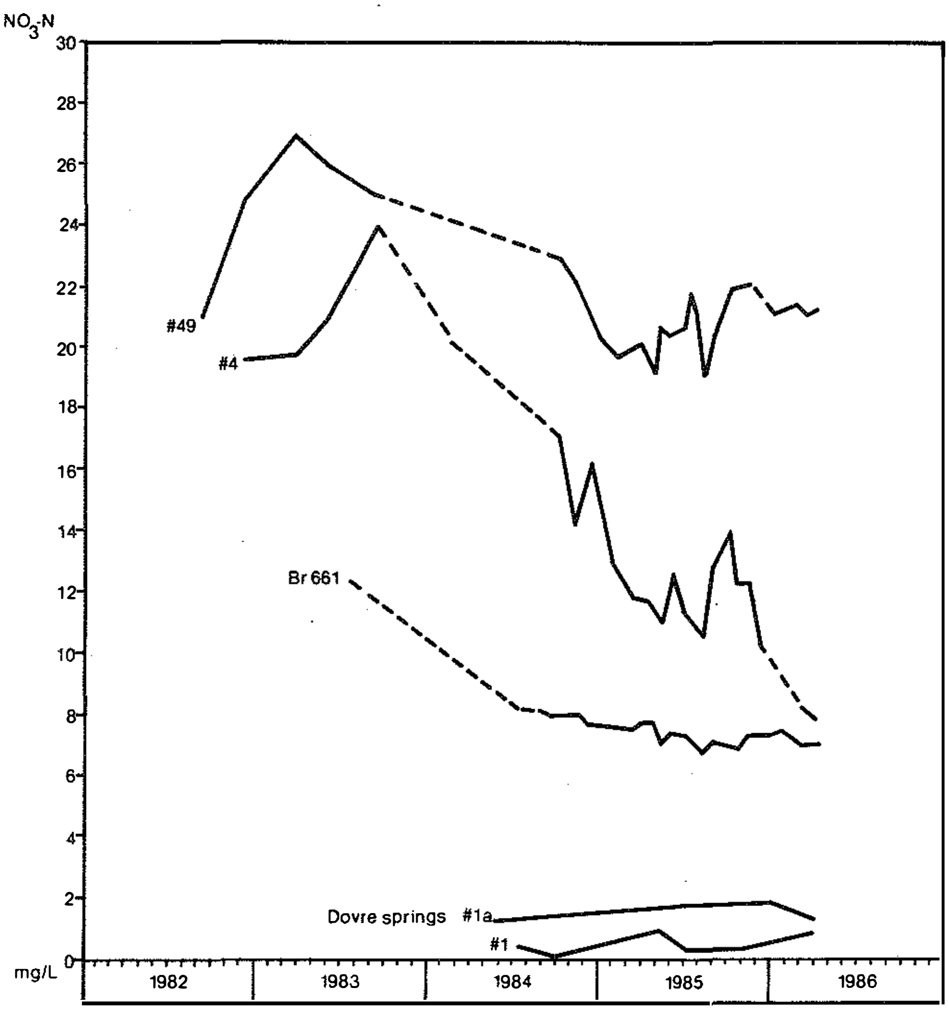


Figure 10. Seasonal variations in nitrate concentration in southern Barron County.

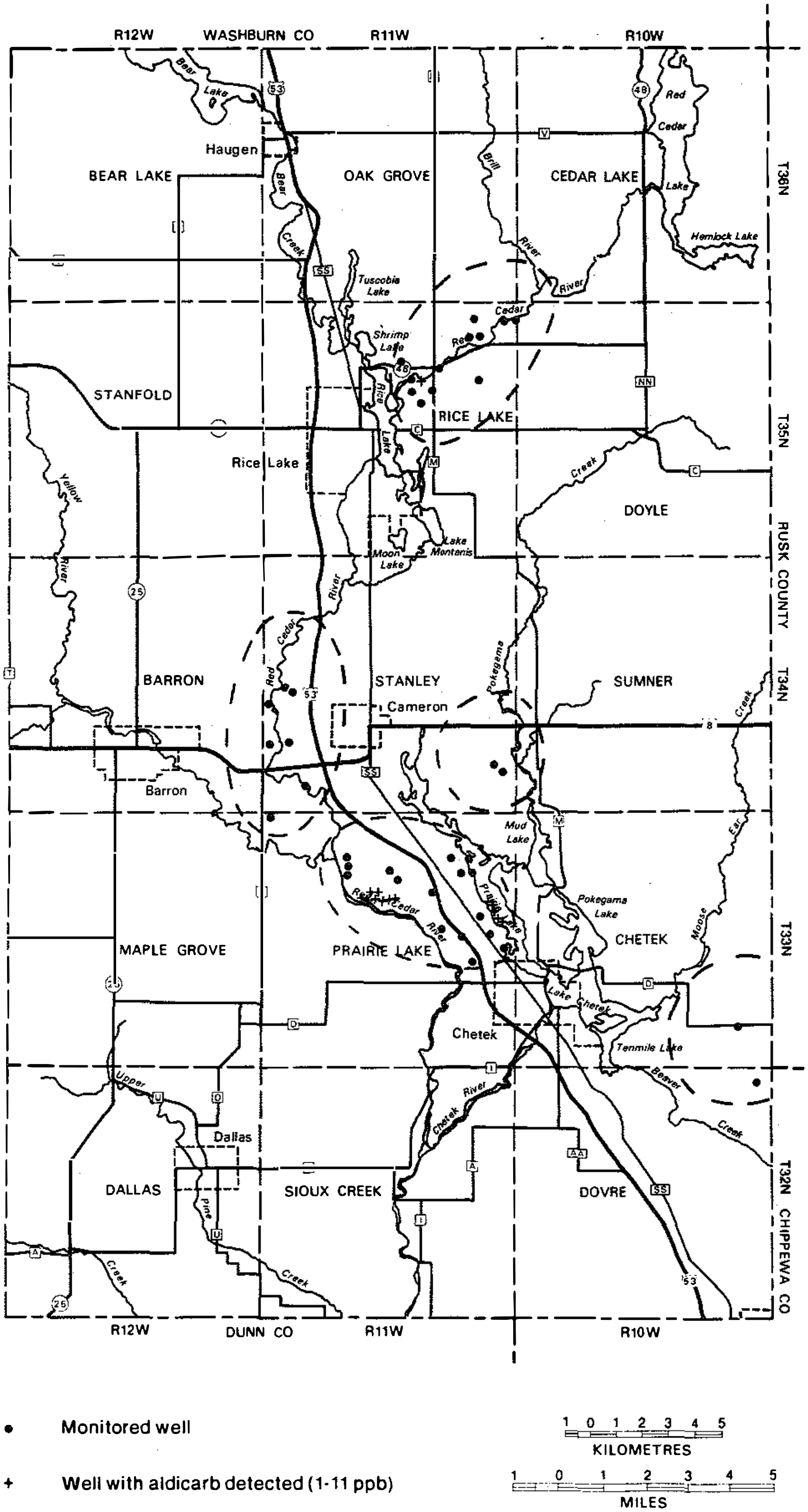


Figure 11. Aldicarb monitoring areas in Barron County, 1985. (Source: DNR aldicarb monitoring program).

SUMMARY AND RECOMMENDATIONS

The quality of groundwater in Barron County is generally good and safe for human and livestock consumption. The quality of most groundwater is much better than the quality required by the federal and state drinking-water standards. Barron County does not have serious large-scale pollution problems at this time. Some local degradation of the groundwater has been identified during the study, especially in the southeastern part of the county where pesticides have been detected in 12 wells. Nitrate is the most common identifiable pollutant in the county. Nitrate concentrations in excess of the recommended limit 10 mg/L nitrate-nitrogen have been found in 76 wells of the total 722 sampled wells (10.5 %). Excessive concentrations of nitrate are most likely to be found in wells 50 ft deep or less.

The aquifers are close to the land surface and their limited natural protection in many places makes them vulnerable to pollution. Some land uses threaten to degrade groundwater quality by providing a source for nitrate and other pollutants. Pollution can come from surface activities such as animal waste storage and spreading, fertilizer and pesticide storage and application, whey and septage spreading, road deicing, and spills of hazardous materials. Other pollution sources include densely spaced or malfunctioning septic tanks, solid waste disposal sites, and storage of chemicals on and below the ground. Water wells can be conduits for pollutants if improperly located, constructed, maintained, or abandoned. In many cases, pollution may come from a combination of several sources rather than from a single source.

The potential for groundwater pollution is increased if these activities or sources occur on lands or in materials that readily allow infiltration of water and pollutants into the groundwater. Pollutants that enter the subsurface sometimes are slowly reduced to less harmful by-products, and sometimes they are preserved and retained in the groundwater flow system for a long time. Depending upon the groundwater flow patterns and other factors, these pollutants could travel several miles and discharge, with the groundwater, into wells. Therefore, besides the identification of existing and potential pollution sources, it is necessary to determine the characteristics and thickness of soils and underlying unconsolidated deposits and solid rock, and to evaluate the general groundwater flow patterns.

To preserve the good quality of groundwater, the county government can pursue a number of avenues ranging from sponsoring continuing research to the adoption of a county groundwater protection plan. The following merely provides an example of actions, not in any priority order, that Barron County can undertake.

Educational and informational programs are an important component of any effort to protect groundwater. Such programs will aid citizens and land managers in improving their understanding of the relationship of their land use activities and groundwater quality. Programs can range from the very basic ones explaining principles of groundwater movement to programs on specific topics. For example,

* Basic information should be provided to interested individuals -- how groundwater moves, how land use activities can influence groundwater quality, what happens once groundwater is polluted, and how difficult it is to clean up polluted water.

* Drinking-water quality programs should address the importance of a safe water supply -- the water well. In cooperation with the DNR, the county can

inform the citizens about the requirements on well location relative to potential sources of pollution and on proper construction and inspection of wells.

The actual construction of a water well is extremely important to the maintenance of good groundwater quality (fig. 12). Commonly, well-pollution cases can be traced to faulty construction, mostly the water-tightness of the seal between the surface and the lower end of the casing. The sanitary protection of the well is provided by the casing surrounded by the grout seal. If the space around the casing is not properly sealed, polluted water from the surface can move downward and pollute the aquifer. Construction requirements for wells finished in various geologic environments are given in the Wisconsin Well Construction Code (Wisconsin Administrative Code, 1985).

A well should be located on the highest ground possible, and certainly higher than nearby sources of pollution. Well casing should extend above the ground, and the ground surface at the well should slope away. Minimum distances from a well to possible sources of pollution should be great enough to provide reasonable assurance that seepage of contaminated water will not reach the well. Barnyards should be down-slope from a well and 25 to 50 ft away depending on drainage conditions. The minimum separating distances required by the Wisconsin Well Construction Code (NR 112.07) should be followed.

Abandoned wells must be carefully sealed to prevent pollution of groundwater from the surface and poor quality water from moving between aquifers. A well should be checked before it is sealed to ensure that there are no obstructions that may interfere with sealing operations. The owner has the responsibility to fill and seal the well in a manner prescribed by the Wisconsin Well Construction Code (NR 112.21) and to report to the DNR that the well has been permanently abandoned. Groundwater pollution caused by abandoned wells could be practically eliminated through education of well drillers and well owners.

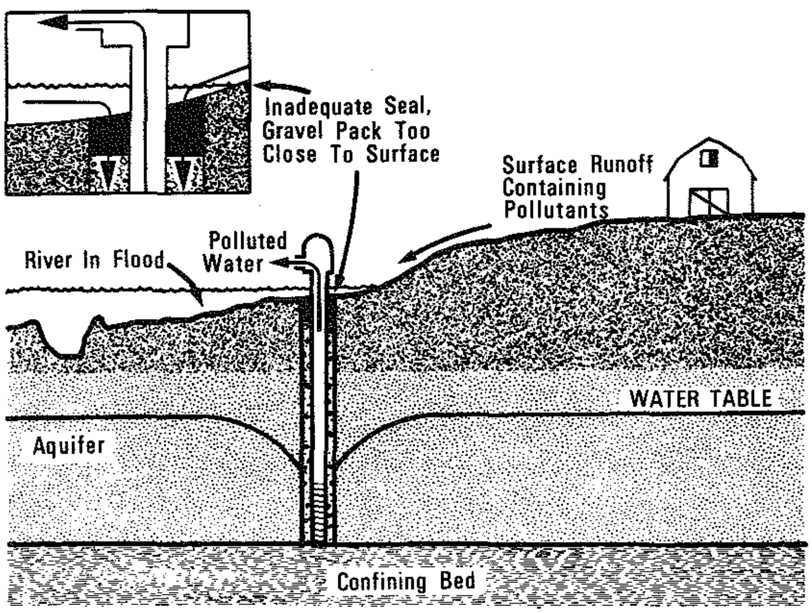


Figure 12. Groundwater pollution caused by an improperly constructed well

Citizens are concerned about water quality because they recognize they must have a safe drinking-water supply. Once citizens recognize that land-use activities in their area can affect the quality of their drinking water, they will be more likely to take action to protect groundwater. By improving public understanding that well water should be tested annually and by helping people to understand how to interpret the test results, educational programs will help individual citizens to become more aware of the importance of good housekeeping practices in protecting their own wells. Well owners should be encouraged to take samples from their wells regularly and send them for bacterial and nitrate analyses to the State Laboratory of Hygiene.

* Specific educational programs should be directed at activities that may pose a threat to groundwater. For example, the county, in cooperation with the county agricultural agent, should continue to educate landowners on the proper use of fertilizers and pesticides to ensure productivity and groundwater quality. This program can include topics such as integrated pest management, fertility management, and irrigation scheduling. In cooperation with the U.S. Soil Conservation Service, the county should encourage the proper design of manure storage facilities. A specific management plan should be developed for each animal waste storage facility to ensure proper care for the site.

Continuing research is needed to complement the results of this study, the aim of which was to provide information about current water quality and to indicate potential problem areas. Further groundwater sampling and investigations are needed to define the extent of these problem areas and potential causes of the problems. Because of the nature of groundwater pollution, continuing countywide monitoring is not recommended. The monitoring network using wells scattered over the county is likely to miss most pollution plumes, thus producing misleading results. However, it is advisable to initiate monitoring around specific potential pollution sources. Pilot studies should be initiated to define pollution potential of the major agricultural activities in the county: an irrigated field, a manure pit, a turkey range, and a dairy farm, and to determine the need for monitoring these potential pollution sources on a wider scale. The county can ask local industry and agriculture for support to finance such research projects. It is also recommended that the county resample a representative portion of wells sampled during the 1983-85 survey within 8 to 10 years to detect any changes from the current water-quality conditions.

Local regulations can play an important role in groundwater protection. Barron County is known for its public as well as private efforts to protect its groundwater resource, and the environment in general. Examples are the county's leadership in soil and water conservation programs and solid waste disposal, and the adoption of an animal waste ordinance. Similarly, the county may be involved in regulating the quality of private water supplies.

As a first step, the county can adopt a public health ordinance that would recognize groundwater pollution as a public nuisance. This ordinance can be used to control sources of pollution until protection strategy and prevention measures are developed.

The new state groundwater law (1983 Wisconsin Act 410) authorizes counties to adopt well codes and ordinances controlling land disposal of septage, and thus enables them to administer state regulations. However, county government must coordinate its regulatory activities with those of the state and other local governments. Sec. 59.067, Wisconsin Statutes, allows the

DNR to authorize counties to adopt and enforce a well construction and pump installation ordinance. Well codes must strictly conform to the DNR rules (chap. NR 112, Wisconsin Administration Code, 1985), and the DNR may revoke county authority if the code is improperly enforced or not in compliance with the administrative rules.

Inspection of location and installation of wells can logically be part of county ordinance for conformance with zoning and septic tank codes. The ordinance should also cover abandonment of unused wells, which are a potential conduit for pollution. However, such inspection and an overall administration of the well code would require additional county staff and special staff training. The additional expenditures to run this program will be counterbalanced by the fact that, because they are aware of activities in the county, county staff can enforce the well code much more effectively than state personnel.

Enlarged county staff can also establish county well-data, water-quality, and pollution-cases files. A well-data file would include well-construction data, geologic information, water-level measurements, water-quality data, nearby potential sources of pollution, and documentation of any well pollution. If recorded on the property deed, the well file can protect an unsuspecting buyer against "inheriting" a polluted well. The chemical analyses collected for this study could be a basis for a data file on county water-quality. The county should update this information by collecting new analyses of water samples taken by other agencies or by well owners. Pollution-cases files should include all occurrences of groundwater pollution, the date of occurrence, type of pollution, extent and effect of pollution, methods of inspection and investigation, and remedial actions taken.

The choice of actions undertaken by Barron County to protect its groundwater obviously depends upon local priorities and perceptions of groundwater problems. The time, effort, and funds it takes to implement these actions will be the most important elements in the decision-making.

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